Tarantool

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Contents

In this chapter, we show how to work with Tarantool as a DBMS – and how to connect to a Tarantool database from other programming languages.

CHAPTER 1

Creating your first Tarantool database

First thing, let's install Tarantool, start it, and create a simple database.

You can install Tarantool and work with it locally or in Docker.

1.1 Using a Docker image

For trial and test purposes, we recommend using official Tarantool images for Docker. An official image contains a particular Tarantool version and all popular external modules for Tarantool. Everything is already installed and configured in Linux. These images are the easiest way to install and use Tarantool.

Note: If you're new to Docker, we recommend going over this tutorial before proceeding with this chapter.

1.1.1 Launching a container

If you don't have Docker installed, please follow the official installation guide for your OS.

To start a fully functional Tarantool instance, run a container with minimal options:

```
$ docker run \
  --name mytarantool \
  -d -p 3301:3301 \
  -v /data/dir/on/host:/var/lib/tarantool \
  tarantool/tarantool:2
```

This command runs a new container named mytarantool. Docker starts it from an official image named tarantool/tarantool:2, with Tarantool version 2.2 and all external modules already installed.

Tarantool will be accepting incoming connections on localhost:3301. You may start using it as a key-value storage right away.

Tarantool persists data inside the container. To make your test data available after you stop the container, this command also mounts the host's directory /data/dir/on/host (you need to specify here an absolute path to an existing local directory) in the container's directory /var/lib/tarantool (by convention, Tarantool in a container uses this directory to persist data). So, all changes made in the mounted directory on the container's side are applied to the host's disk.

Tarantool's database module in the container is already configured and started. You needn't do it manually, unless you use Tarantool as an application server and run it with an application.

Note: If your container terminates soon after start, follow this page for a possible solution.

1.1.2 Attaching to Tarantool

To attach to Tarantool that runs inside the container, say:

```
$ docker exec -i -t mytarantool console
```

This command:

- Instructs Tarantool to open an interactive console port for incoming connections.
- Attaches to the Tarantool server inside the container under admin user via a standard Unix socket.

Tarantool displays a prompt:

```
tarantool.sock>
```

Now you can enter requests on the command line.

Note: On production machines, Tarantool's interactive mode is for system administration only. But we use it for most examples in this manual, because the interactive mode is convenient for learning.

1.1.3 Creating a database

While you're attached to the console, let's create a simple test database.

First, create the first space (named tester):

```
tarantool.sock> s = box.schema.space.create('tester')
```

Format the created space by specifying field names and types:

```
tarantool.sock> s:format({
             > {name = 'id', type = 'unsigned'},
             > {name = 'band_name', type = 'string'},
             > {name = 'year', type = 'unsigned'}
             > })
```

Create the first index (named primary):

```
tarantool.sock> s:create_index('primary', {
              > type = 'hash',
              > parts = {'id'}
              > })
```

This is a primary index based on the id field of each tuple.

Insert three tuples (our name for records) into the space:

```
tarantool.sock> s:insert{1, 'Roxette', 1986}
tarantool.sock> s:insert{2, 'Scorpions', 2015}
tarantool.sock> s:insert{3, 'Ace of Base', 1993}
```

To select a tuple using the primary index, say:

```
tarantool.sock> s:select{3}
```

The terminal screen now looks like this:

```
tarantool.sock> s = box.schema.space.create('tester')
---
...
tarantool.sock> s:format({
              > {name = 'id', type = 'unsigned'},
              > {name = 'band_name', type = 'string'},
              > {name = 'year', type = 'unsigned'}
              > })
---
...
tarantool.sock> s:create_index('primary', {
              > type = 'hash',
              > parts = {'id'}
              > })
---
- unique: true
  parts:
  - type: unsigned
    is_nullable: false
    fieldno: 1
  id: 0
  space_id: 512
  name: primary
  type: HASH
...
tarantool.sock> s:insert{1, 'Roxette', 1986}
---
- [1, 'Roxette', 1986]
...
tarantool.sock> s:insert{2, 'Scorpions', 2015}
---
- [2, 'Scorpions', 2015]
...
tarantool.sock> s:insert{3, 'Ace of Base', 1993}
---
- [3, 'Ace of Base', 1993]
...
tarantool.sock> s:select{3}
---
```

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```
- - [3, 'Ace of Base', 1993]
...
```

To add a secondary index based on the band_name field, say:

```
tarantool.sock> s:create_index('secondary', {
              > type = 'hash',
              > parts = {'band_name'}
              > })
```

To select tuples using the secondary index, say:

```
tarantool.sock> s.index.secondary:select{'Scorpions'}
---
- - [2, 'Scorpions', 2015]
...
```

To drop an index, say:

```
tarantool> s.index.secondary:drop()
---
...
```

1.1.4 Stopping a container

When the testing is over, stop the container politely:

```
$ docker stop mytarantool
```

This was a temporary container, and its disk/memory data were flushed when you stopped it. But since you mounted a data directory from the host in the container, Tarantool's data files were persisted to the host's disk. Now if you start a new container and mount that data directory in it, Tarantool will recover all data from disk and continue working with the persisted data.

1.2 Using a package manager

For production purposes, we recommend to install Tarantool via official package manager. You can choose one of three versions: LTS, stable, or beta. An automatic build system creates, tests and publishes packages for every push into a corresponding branch at Tarantool's GitHub repository.

To download and install the package that's appropriate for your OS, start a shell (terminal) and enter the command-line instructions provided for your OS at Tarantool's download page.

1.2.1 Starting Tarantool

To start working with Tarantool, run a terminal and say this:

```
$ tarantool
$ # by doing this, you create a new Tarantool instance
```

Tarantool starts in the interactive mode and displays a prompt:

```
tarantool>
```

Now you can enter requests on the command line.

Note: On production machines, Tarantool's interactive mode is for system administration only. But we use it for most examples in this manual, because the interactive mode is convenient for learning.

1.2.2 Creating a database

Here is how to create a simple test database after installation.

1. To let Tarantool store data in a separate place, create a new directory dedicated for tests:

   ```
   $ mkdir ~/tarantool_sandbox
   $ cd ~/tarantool_sandbox
   ```

   You can delete the directory when the tests are over.

2. Check if the default port the database instance will listen to is vacant.

   Depending on the release, during installation Tarantool may start a demonstrative global example.lua instance that listens to the 3301 port by default. The example.lua file showcases basic configuration and can be found in the /etc/tarantool/instances.enabled or /etc/tarantool/instances.available directories.

   However, we encourage you to perform the instance startup manually, so you can learn.

   Make sure the default port is vacant:

   1. To check if the demonstrative instance is running, say:

      ```
      $ lsof -i :3301
      COMMAND    PID USER   FD   TYPE DEVICE SIZE/OFF NODE NAME
      tarantool 6851 root   12u  IPv4  40827      0t0  TCP *:3301 (LISTEN)
      ```

   2. If it does, kill the corresponding process. In this example:

      ```
      $ kill 6851
      ```

3. To start Tarantool's database module and make the instance accept TCP requests on port 3301, say:

   ```
   tarantool> box.cfg{listen = 3301}
   ```

4. Create the first space (named tester):

   ```
   tarantool> s = box.schema.space.create('tester')
   ```

5. Format the created space by specifying field names and types:

   ```
   tarantool> s:format({
            > {name = 'id', type = 'unsigned'},
            > {name = 'band_name', type = 'string'},
            > {name = 'year', type = 'unsigned'}
            > })
   ```

6. Create the first index (named primary):

```
tarantool> s:create_index('primary', {
         > type = 'hash',
         > parts = {'id'}
         > })
```

This is a primary index based on the id field of each tuple.

7. Insert three tuples (our name for records) into the space:

```
tarantool> s:insert{1, 'Roxette', 1986}
tarantool> s:insert{2, 'Scorpions', 2015}
tarantool> s:insert{3, 'Ace of Base', 1993}
```

8. To select a tuple using the primary index, say:

```
tarantool> s:select{3}
```

The terminal screen now looks like this:

```
tarantool> s = box.schema.space.create('tester')
---
...
tarantool> s:format({
         > {name = 'id', type = 'unsigned'},
         > {name = 'band_name', type = 'string'},
         > {name = 'year', type = 'unsigned'}
         > })
---
...
tarantool> s:create_index('primary', {
         > type = 'hash',
         > parts = {'id'}
         > })
---
- unique: true
  parts:
  - type: unsigned
    is_nullable: false
    fieldno: 1
  id: 0
  space_id: 512
  name: primary
  type: HASH
...
tarantool> s:insert{1, 'Roxette', 1986}
---
- [1, 'Roxette', 1986]
...
tarantool> s:insert{2, 'Scorpions', 2015}
---
- [2, 'Scorpions', 2015]
...
tarantool> s:insert{3, 'Ace of Base', 1993}
---
- [3, 'Ace of Base', 1993]
...
tarantool> s:select{3}
---
```

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```
- - [3, 'Ace of Base', 1993]
...
```

9. To add a secondary index based on the band_name field, say:

```
tarantool> s:create_index('secondary', {
         > type = 'hash',
         > parts = {'band_name'}
         > })
```

10. To select tuples using the secondary index, say:

```
tarantool> s.index.secondary:select{'Scorpions'}
---
- - [2, 'Scorpions', 2015]
...
```

11. Now, to prepare for the example in the next section, try this:

```
tarantool> box.schema.user.grant('guest', 'read,write,execute', 'universe')
```

1.2.3 Connecting remotely

In the request box.cfg{listen = 3301} that we made earlier, the listen value can be any form of a URI (uniform resource identifier). In this case, it's just a local port: port 3301. You can send requests to the listen URI via:

(1) telnet,

(2) a connector,

(3) another instance of Tarantool (using the console module), or

(4) tarantoolctl utility.

Let's try (4).

Switch to another terminal. On Linux, for example, this means starting another instance of a Bash shell. You can switch to any working directory in the new terminal, not necessarily to ~/tarantool_sandbox.

Start the tarantoolctl utility:

```
$ tarantoolctl connect '3301'
```

This means "use tarantoolctl connect to connect to the Tarantool instance that's listening on localhost:3301".

Try this request:

```
localhost:3301> box.space.tester:select{2}
```

This means "send a request to that Tarantool instance, and display the result". The result in this case is one of the tuples that was inserted earlier. Your terminal screen should now look like this:

```
$ tarantoolctl connect 3301
/usr/local/bin/tarantoolctl: connected to localhost:3301
localhost:3301> box.space.tester:select{2}
---
```

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```
- - [2, 'Scorpions', 2015]
...
```

You can repeat box.space...:insert{} and box.space...:select{} indefinitely, on either Tarantool instance.

When the testing is over:

- To drop the space: s:drop()
- To stop tarantoolctl: Ctrl+C or Ctrl+D
- To stop Tarantool (an alternative): the standard Lua function os.exit()
- To stop Tarantool (from another terminal): sudo pkill -f tarantool
- To destroy the test: rm -r ~/tarantool_sandbox

CHAPTER 2

Connecting from your favorite language

Now that you have a Tarantool database, let's see how to connect to it from Python, PHP and Go.

2.1 Connecting from Python

2.1.1 Pre-requisites

Before we proceed:

1. Install the tarantool module. We recommend using python3 and pip3.
2. Start Tarantool (locally or in Docker) and make sure that you have created and populated a database as we suggested earlier:

```
box.cfg{listen = 3301}
s = box.schema.space.create('tester')
s:format({
        {name = 'id', type = 'unsigned'},
        {name = 'band_name', type = 'string'},
        {name = 'year', type = 'unsigned'}
        })
s:create_index('primary', {
        type = 'hash',
        parts = {'id'}
        })
s:create_index('secondary', {
        type = 'hash',
        parts = {'band_name'}
        })
s:insert{1, 'Roxette', 1986}
s:insert{2, 'Scorpions', 2015}
s:insert{3, 'Ace of Base', 1993}
```

Important: Please do not close the terminal window where Tarantool is running – you'll need it soon.

3. In order to connect to Tarantool as an administrator, reset the password for the admin user:

```
box.schema.user.passwd('pass')
```

2.1.2 Connecting to Tarantool

To get connected to the Tarantool server, say this:

```
>>> import tarantool
>>> connection = tarantool.connect("localhost", 3301)
```

You can also specify the user name and password, if needed:

```
>>> tarantool.connect("localhost", 3301, user=username, password=password)
```

The default user is guest.

2.1.3 Manipulating the data

A space is a container for tuples. To access a space as a named object, use connection.space:

```
>>> tester = connection.space('tester')
```

Inserting data

To insert a tuple into a space, use insert:

```
>>> tester.insert((4, 'ABBA', 1972))
[4, 'ABBA', 1972]
```

Querying data

Let's start with selecting a tuple by the primary key (in our example, this is the index named primary, based on the id field of each tuple). Use select:

```
>>> tester.select(4)
[4, 'ABBA', 1972]
```

Next, select tuples by a secondary key. For this purpose, you need to specify the number or name of the index.

First off, select tuples using the index number:

```
>>> tester.select('Scorpions', index=1)
[2, 'Scorpions', 2015]
```

(We say index=1 because index numbers in Tarantool start with 0, and we're using our second index here.)

Now make a similar query by the index name and make sure that the result is the same:

```
>>> tester.select('Scorpions', index='secondary')
[2, 'Scorpions', 2015]
```

Finally, select all the tuples in a space via a select with no arguments:

```
>>> tester.select()
```

Updating data

Update a field value using update:

```
>>> tester.update(4, [('=', 1, 'New group'), ('+', 2, 2)])
```

This updates the value of field 1 and increases the value of field 2 in the tuple with id = 4. If a tuple with this id doesn't exist, Tarantool will return an error.

Now use replace to totally replace the tuple that matches the primary key. If a tuple with this primary key doesn't exist, Tarantool will do nothing.

```
>>> tester.replace((4, 'New band', 2015))
```

You can also update the data using upsert that works similarly to update, but creates a new tuple if the old one was not found.

```
>>> tester.upsert((4, 'Another band', 2000), [('+', 2, 5)])
```

This increases by 5 the value of field 2 in the tuple with id = 4, – or inserts the tuple (4, "Another band", 2000) if a tuple with this id doesn't exist.

Deleting data

To delete a tuple, use delete(primary_key):

```
>>> tester.delete(4)
[4, 'New group', 2012]
```

To delete all tuples in a space (or to delete an entire space), use call. We'll focus on this function in more detail in the next section.

To delete all tuples in a space, call space:truncate:

```
>>> connection.call('box.space.tester:truncate', ())
```

To delete an entire space, call space:drop. This requires connecting to Tarantool as the admin user:

```
>>> connection.call('box.space.tester:drop', ())
```

2.1.4 Executing stored procedures

Switch to the terminal window where Tarantool is running.

Note: If you don't have a terminal window with remote connection to Tarantool, check out these guides:

- connecting to a local Tarantool instance
- attaching to a Tarantool instance that runs in a Docker container

Define a simple Lua function:

```
function sum(a, b)
    return a + b
end
```

Now we have a Lua function defined in Tarantool. To invoke this function from python, use call:

```
>>> connection.call('sum', (3, 2))
5
```

To send bare Lua code for execution, use eval:

```
>>> connection.eval('return 4 + 5')
9
```

2.2 Connecting from PHP

2.2.1 Pre-requisites

Before we proceed:

1. Install the tarantool/client library.
2. Start Tarantool (locally or in Docker) and make sure that you have created and populated a database as we suggested earlier:

   ```
   box.cfg{listen = 3301}
   s = box.schema.space.create('tester')
   s:format({
            {name = 'id', type = 'unsigned'},
            {name = 'band_name', type = 'string'},
            {name = 'year', type = 'unsigned'}
            })
   s:create_index('primary', {
            type = 'hash',
            parts = {'id'}
            })
   s:create_index('secondary', {
            type = 'hash',
            parts = {'band_name'}
            })
   s:insert{1, 'Roxette', 1986}
   s:insert{2, 'Scorpions', 2015}
   s:insert{3, 'Ace of Base', 1993}
   ```

   Important: Please do not close the terminal window where Tarantool is running – you'll need it soon.

3. In order to connect to Tarantool as an administrator, reset the password for the admin user:

```
box.schema.user.passwd('pass')
```

2.2.2 Connecting to Tarantool

To configure a connection to the Tarantool server, say this:

```
use Tarantool\Client\Client;

require __DIR__.'/vendor/autoload.php';
$client = Client::fromDefaults();
```

The connection itself will be established at the first request. You can also specify the user name and password, if needed:

```
$client = Client::fromOptions([
    'uri' => 'tcp://127.0.0.1:3301',
    'username' => '<username>',
    'password' => '<password>'
]);
```

The default user is guest.

2.2.3 Manipulating the data

A space is a container for tuples. To access a space as a named object, use getSpace:

```
$tester = $client->getSpace('tester');
```

Inserting data

To insert a tuple into a space, use insert:

```
$result = $tester->insert([4, 'ABBA', 1972]);
```

Querying data

Let's start with selecting a tuple by the primary key (in our example, this is the index named primary, based on the id field of each tuple). Use select:

```
use Tarantool\Client\Schema\Criteria;

$result = $tester->select(Criteria::key([4]));
printf(json_encode($result));
```

```
[[4, 'ABBA', 1972]]
```

Next, select tuples by a secondary key. For this purpose, you need to specify the number or name of the index.

First off, select tuples using the index number:

```
$result = $tester->select(Criteria::index(1)->andKey(['Scorpions']));
printf(json_encode($result));
```

```
[2, 'Scorpions', 2015]
```

(We say index(1) because index numbers in Tarantool start with 0, and we're using our second index here.)

Now make a similar query by the index name and make sure that the result is the same:

```
$result = $tester->select(Criteria::index('secondary')->andKey(['Scorpions']));
printf(json_encode($result));
```

```
[2, 'Scorpions', 2015]
```

Finally, select all the tuples in a space via a select:

```
$result = $tester->select(Criteria::allIterator());
```

Updating data

Update a field value using update:

```
use Tarantool\Client\Schema\Operations;

$result = $tester->update([4], Operations::set(1, 'New group')->andAdd(2, 2));
```

This updates the value of field 1 and increases the value of field 2 in the tuple with id = 4. If a tuple with this id doesn't exist, Tarantool will return an error.

Now use replace to totally replace the tuple that matches the primary key. If a tuple with this primary key doesn't exist, Tarantool will do nothing.

```
$result = $tester->replace([4, 'New band', 2015]);
```

You can also update the data using upsert that works similarly to update, but creates a new tuple if the old one was not found.

```
use Tarantool\Client\Schema\Operations;

$tester->upsert([4, 'Another band', 2000], Operations::add(2, 5));
```

This increases by 5 the value of field 2 in the tuple with id = 4, – or inserts the tuple (4, "Another band", 2000) if a tuple with this id doesn't exist.

Deleting data

To delete a tuple, use delete(primary_key):

```
$result = $tester->delete([4]);
```

To delete all tuples in a space (or to delete an entire space), use call. We'll focus on this function in more detail in the next section.

To delete all tuples in a space, call space:truncate:

```
$result = $client->call('box.space.tester:truncate');
```

To delete an entire space, call space:drop. This requires connecting to Tarantool as the admin user:

```
$result = $client->call('box.space.tester:drop');
```

2.2.4 Executing stored procedures

Switch to the terminal window where Tarantool is running.

Note: If you don't have a terminal window with remote connection to Tarantool, check out these guides:

- connecting to a local Tarantool instance
- attaching to a Tarantool instance that runs in a Docker container

Define a simple Lua function:

```
function sum(a, b)
    return a + b
end
```

Now we have a Lua function defined in Tarantool. To invoke this function from php, use call:

```
$result = $client->call('sum', 3, 2);
```

To send bare Lua code for execution, use eval:

```
$result = $client->evaluate('return 4 + 5');
```

2.3 Connecting from Go

2.3.1 Pre-requisites

Before we proceed:

1. Install the go-tarantool library.
2. Start Tarantool (locally or in Docker) and make sure that you have created and populated a database as we suggested earlier:

```
box.cfg{listen = 3301}
s = box.schema.space.create('tester')
s:format({
         {name = 'id', type = 'unsigned'},
         {name = 'band_name', type = 'string'},
         {name = 'year', type = 'unsigned'}
         })
s:create_index('primary', {
         type = 'hash',
         parts = {'id'}
         })
```

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```
s:create_index('secondary', {
        type = 'hash',
        parts = {'band_name'}
        })
s:insert{1, 'Roxette', 1986}
s:insert{2, 'Scorpions', 2015}
s:insert{3, 'Ace of Base', 1993}
```

Important: Please do not close the terminal window where Tarantool is running – you'll need it soon.

3. In order to connect to Tarantool as an administrator, reset the password for the admin user:

```
box.schema.user.passwd('pass')
```

2.3.2 Connecting to Tarantool

To get connected to the Tarantool server, write a simple Go program:

```
package main

import (
    "fmt"

    "github.com/tarantool/go-tarantool"
)

func main() {

    conn, err := tarantool.Connect("127.0.0.1:3301", tarantool.Opts{
            User: "admin",
            Pass: "pass",
    })

    if err != nil {
            log.Fatalf("Connection refused")
    }

    defer conn.Close()

    // Your logic for interacting with the database
}
```

The default user is guest.

2.3.3 Manipulating the data

Inserting data

To insert a tuple into a space, use Insert:

```
resp, err = conn.Insert("tester", []interface{}{4, "ABBA", 1972})
```

This inserts the tuple (4, "ABBA", 1972) into a space named tester.

The response code and data are available in the tarantool.Response structure:

```
code := resp.Code
data := resp.Data
```

Querying data

To select a tuple from a space, use Select:

```
resp, err = conn.Select("tester", "primary", 0, 1, tarantool.IterEq, []interface{}{4})
```

This selects a tuple by the primary key with offset = 0 and limit = 1 from a space named tester (in our example, this is the index named primary, based on the id field of each tuple).

Next, select tuples by a secondary key.

```
resp, err = conn.Select("tester", "secondary", 0, 1, tarantool.IterEq, []interface{}{"ABBA"})
```

Finally, it would be nice to select all the tuples in a space. But there is no one-liner for this in Go; you would need a script like this one.

For more examples, see https://github.com/tarantool/go-tarantool#usage

Updating data

Update a field value using Update:

```
resp, err = conn.Update("tester", "primary", []interface{}{4}, []interface{}{[]interface{}{"+", 2, 3}})
```

This increases by 3 the value of field 2 in the tuple with id = 4. If a tuple with this id doesn't exist, Tarantool will return an error.

Now use Replace to totally replace the tuple that matches the primary key. If a tuple with this primary key doesn't exist, Tarantool will do nothing.

```
resp, err = conn.Replace("tester", []interface{}{4, "New band", 2011})
```

You can also update the data using Upsert that works similarly to Update, but creates a new tuple if the old one was not found.

```
resp, err = conn.Upsert("tester", []interface{}{4, "Another band", 2000}, []interface{}{[]interface{}{"+", 2, 5}})
```

This increases by 5 the value of the third field in the tuple with id = 4, – or inserts the tuple (4, "Another band", 2000) if a tuple with this id doesn't exist.

Deleting data

To delete a tuple, use connection.Delete:

```
resp, err = conn.Delete("tester", "primary", []interface{}{4})
```

To delete all tuples in a space (or to delete an entire space), use Call. We'll focus on this function in more detail in the next section.

To delete all tuples in a space, call space:truncate:

```
resp, err = conn.Call("box.space.tester:truncate", []interface{}{})
```

To delete an entire space, call space:drop. This requires connecting to Tarantool as the admin user:

```
resp, err = conn.Call("box.space.tester:drop", []interface{}{})
```

2.3.4 Executing stored procedures

Switch to the terminal window where Tarantool is running.

Note: If you don't have a terminal window with remote connection to Tarantool, check out these guides:

- connecting to a local Tarantool instance
- attaching to a Tarantool instance that runs in a Docker container

Define a simple Lua function:

```
function sum(a, b)
    return a + b
end
```

Now we have a Lua function defined in Tarantool. To invoke this function from go, use Call:

```
resp, err = conn.Call("sum", []interface{}{2, 3})
```

To send bare Lua code for execution, use Eval:

```
resp, err = connection.Eval("return 4 + 5", []interface{}{})
```

CHAPTER 3

Creating your first Tarantool Cartridge application

Here we'll walk you through developing a simple cluster application.

First, set up the development environment.

Next, create an application named myapp. Say:

```
$ cartridge create --name myapp
```

This will create a Tarantool Cartridge application in the ./myapp directory, with a handful of template files and directories inside.

Go inside and make a dry run:

```
$ cd ./myapp
$ cartridge build
$ cartridge start
```

This will build the application locally, start 5 instances of Tarantool, and run the application as it is, with no business logic yet.

Why 5 instances? See the instances.yml file in your application directory. It contains the configuration of all instances that you can use in the cluster. By default, it defines configuration for 5 Tarantool instances.

```
myapp.router:
  workdir: ./tmp/db_dev/3301
  advertise_uri: localhost:3301
  http_port: 8081

myapp.s1-master:
  workdir: ./tmp/db_dev/3302
  advertise_uri: localhost:3302
  http_port: 8082

myapp.s1-replica:
  workdir: ./tmp/db_dev/3303
```

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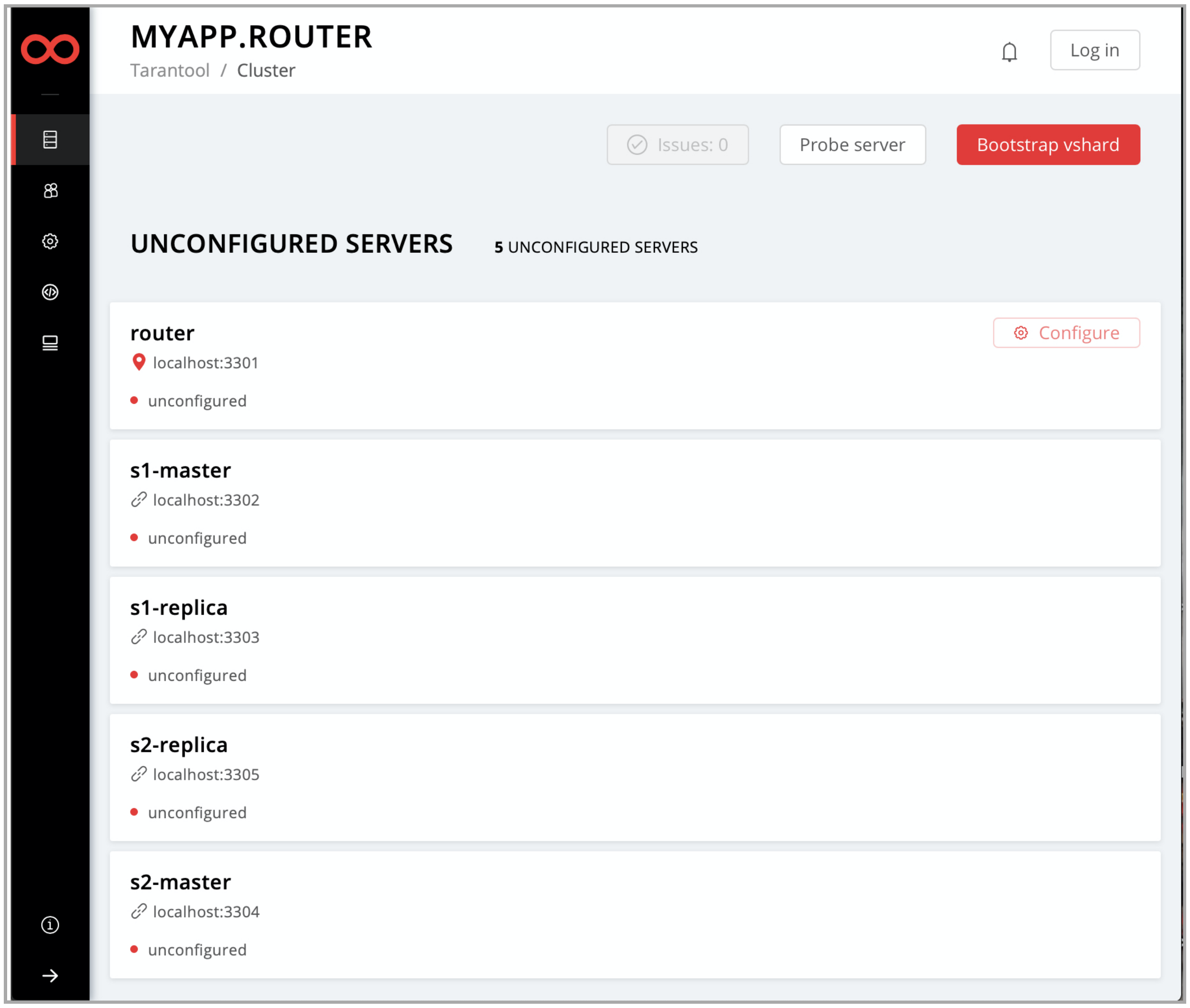
```
  advertise_uri: localhost:3303
  http_port: 8083

myapp.s2-master:
  workdir: ./tmp/db_dev/3304
  advertise_uri: localhost:3304
  http_port: 8084

myapp.s2-replica:
  workdir: ./tmp/db_dev/3305
  advertise_uri: localhost:3305
  http_port: 8085
```

You can already see these instances in the cluster management web interface at http://localhost:8081 (here 8081 is the HTTP port of the first instance specified in instances.yml).



router
localhost:3301
unconfigured

s1-master
localhost:3302
unconfigured

s1-replica
localhost:3303
unconfigured

s2-replica
localhost:3305
unconfigured

s2-master
localhost:3304
unconfigured

Okay, press Ctrl + C to stop the cluster for a while.

Now it's time to add some business logic to your application. This will be an evergreen "Hello world!"" – just to keep things simple.

Rename the template file app/roles/custom.lua to hello-world.lua.

```
$ mv app/roles/custom.lua app/roles/hello-world.lua
```

This will be your role. In Tarantool Cartridge, a role is a Lua module that implements some instance-specific functions and/or logic. Further on we'll show how to add code to a role, build it, enable and test.

There is already some code in the role's init() function.

```
local function init(opts) -- luacheck: no unused args
    -- if opts.is_master then
    -- end

    local httpd = cartridge.service_get('httpd')
    httpd:route({method = 'GET', path = '/hello'}, function()
        return {body = 'Hello world!'}
    end)

    return true
end
```

This exports an HTTP endpoint /hello. For example, http://localhost:8081/hello if you address the first instance from the instances.yml file. If you open it in a browser after enabling the role (we'll do it here a bit later), you'll see "Hello world!" on the page.

Let's add some more code there.

```
local function init(opts) -- luacheck: no unused args
    -- if opts.is_master then
    -- end

    local httpd = cartridge.service_get('httpd')
    httpd:route({method = 'GET', path = '/hello'}, function()
        return {body = 'Hello world!'}
    end)

    local log = require('log')
    log.info('Hello world!')

    return true
end
```

This writes "Hello, world!" to the console when the role gets enabled, so you'll have a chance to spot this. No rocket science.

Next, amend role_name in the "return" section of the hello-world.lua file. This text will be displayed as a label for your role in the cluster management web interface.

```
return {
    role_name = 'Hello world!',
    init = init,
    stop = stop,
    validate_config = validate_config,
    apply_config = apply_config,
}
```

The final thing to do before you can run the application is to add your role to the list of available cluster roles in the init.lua file.

```
local ok, err = cartridge.cfg({
    workdir = 'tmp/db',
    roles = {
        'cartridge.roles.vshard-storage',
        'cartridge.roles.vshard-router',
        'app.roles.hello-world'
    },
    cluster_cookie = 'myapp-cluster-cookie',
})
```

Now the cluster will be aware of your role.

Why app.roles.hello-world? By default, the role name here should match the path from the application root (./myapp) to the role file (app/roles/hello-world.lua).

Fine! Your role is ready. Re-build the application and re-start the cluster now:

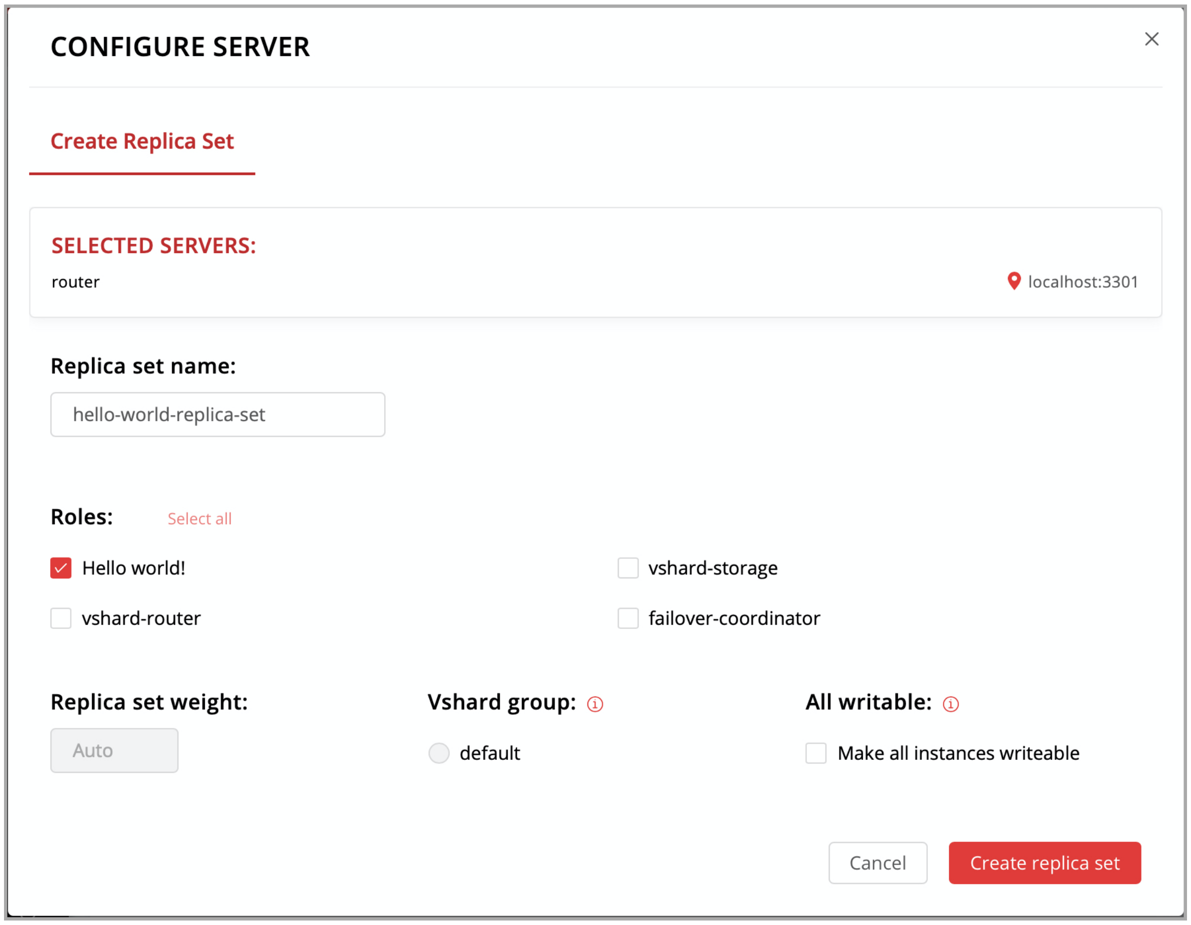
```
$ cartridge build
$ cartridge start
```

Now all instances are up, but idle, waiting for you to enable roles for them.

Instances (replicas) in a Tarantool Cartridge cluster are organized into replica sets. Roles are enabled per replica set, so all instances in a replica set have the same roles enabled.

Let's create a replica set containing just one instance and enable your role:

1. Open the cluster management web interface at http://localhost:8081.
2. Click Configure.
3. Check the role Hello world! to enable it. Notice that the role name here matches the label text that you specified in the role_name parameter in the hello-world.lua file.
4. (Optionally) Specify the replica set name, for example "hello-world-replica-set".



CONFIGURE SERVER

Create Replica Set

SELECTED SERVERS:

router localhost:3301

Replica set name:

hello-world-replica-set

Roles: Select all

[✓ Hello world!] vshard-storage

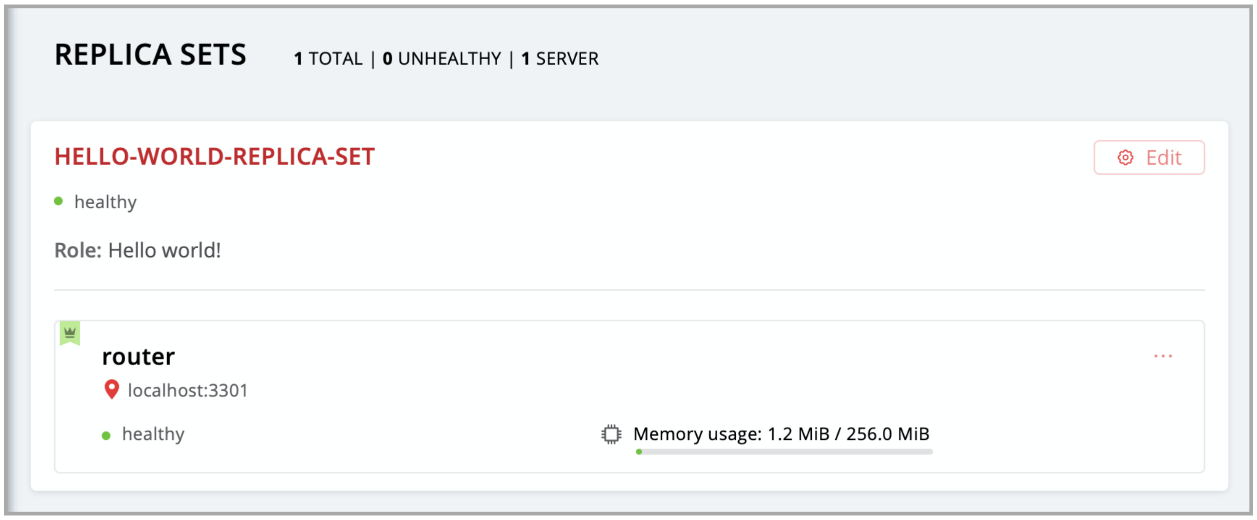
vshard-router failover-coordinator

Replica set weight: Auto

Vshard group: default

All writable: Make all instances writeable

5. Click Create replica set and see the newly-created replica set in the web interface.



REPLICA SETS 1 TOTAL | 0 UNHEALTHY | 1 SERVER

HELLO-WORLD-REPLICA-SET

healthy

Role: Hello world!

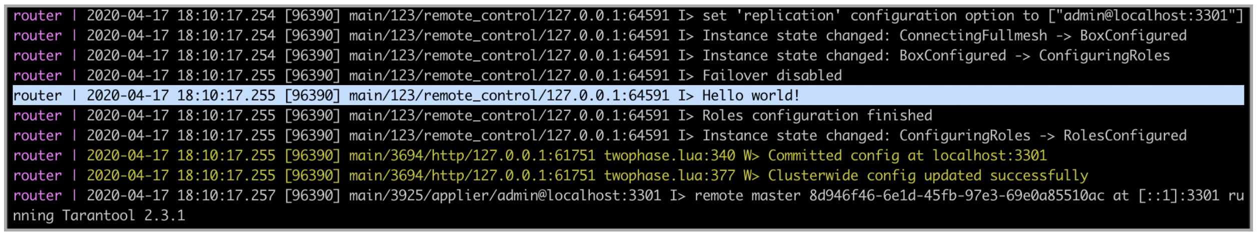
router

localhost:3301

healthy

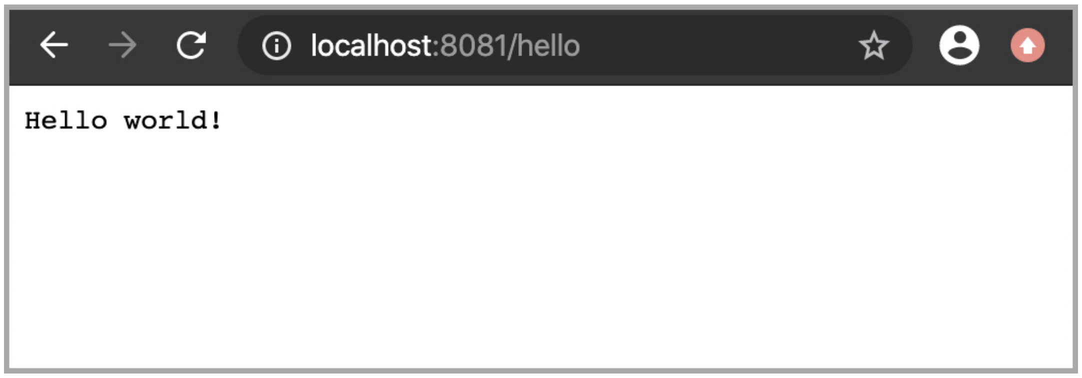
Memory usage: 1.2 MiB / 256.0 MiB

Your custom role got enabled. Find the "Hello world!" message in console, like this:



```
router | 2020-04-17 18:10:17.254 [96390] main/123/remote_control/127.0.0.1:64591 I> set 'replication' configuration option to ["admin@localhost:3301"]
router | 2020-04-17 18:10:17.254 [96390] main/123/remote_control/127.0.0.1:64591 I> Instance state changed: ConnectingFullmesh -> BoxConfigured
router | 2020-04-17 18:10:17.254 [96390] main/123/remote_control/127.0.0.1:64591 I> Instance state changed: BoxConfigured -> ConfiguringRoles
router | 2020-04-17 18:10:17.255 [96390] main/123/remote_control/127.0.0.1:64591 I> Failover disabled
router | 2020-04-17 18:10:17.255 [96390] main/123/remote_control/127.0.0.1:64591 I> Hello world!
router | 2020-04-17 18:10:17.255 [96390] main/123/remote_control/127.0.0.1:64591 I> Roles configuration finished
router | 2020-04-17 18:10:17.255 [96390] main/123/remote_control/127.0.0.1:64591 I> Instance state changed: ConfiguringRoles -> RolesConfigured
router | 2020-04-17 18:10:17.255 [96390] main/3694/http/127.0.0.1:61751 twophase.lua:340 W> Committed config at localhost:3301
router | 2020-04-17 18:10:17.255 [96390] main/3694/http/127.0.0.1:61751 twophase.lua:377 W> Clusterwide config updated successfully
router | 2020-04-17 18:10:17.257 [96390] main/3925/applier/admin@localhost:3301 I> remote master 8d946f46-6e1d-45fb-97e3-69e0a85510ac at [::1]:3301 ru
nning Tarantool 2.3.1
```

Finally, open the HTTP endpoint of this instance at http://localhost:8081/hello and see the reply to your GET request.



```
Hello world!
```

Everything is up and running! What's next?

- Follow this guide to set up the rest of the cluster and try some cool cluster management features.
- Get inspired with these examples and implement more sophisticated business logic for your role.
- Pack your application for easy distribution. Choose what you like: a DEB or RPM package, a TGZ archive, or a Docker image.

CHAPTER 4

User's Guide

4.1 Preface

Welcome to Tarantool! This is the User's Guide. We recommend reading it first, and consulting Reference materials for more detail afterwards, if needed.

4.1.1 How to read the documentation

To get started, you can install and launch Tarantool using a Docker container, a package manager, or the online Tarantool server at http://try.tarantool.org. Either way, as the first tryout, you can follow the introductory exercises from Chapter 2 "Getting started". If you want more hands-on experience, proceed to Tutorials after you are through with Chapter 2.

Chapter 3 "Database" is about using Tarantool as a NoSQL DBMS, whereas Chapter 4 "Application server" is about using Tarantool as an application server.

Chapter 5 "Server administration" and Chapter 6 "Replication" are primarily for administrators.

Chapter 7 "Connectors" is strictly for users who are connecting from a different language such as C or Perl or Python — other users will find no immediate need for this chapter.

Chapter 8 "FAQ" gives answers to some frequently asked questions about Tarantool.

For experienced users, there are also Reference materials, a Contributor's Guide and an extensive set of comments in the source code.

4.1.2 Getting in touch with the Tarantool community

Please report bugs or make feature requests at http://github.com/tarantool/tarantool/issues.

You can contact developers directly in telegram or in a Tarantool discussion group (English or Russian).

4.1.3 Conventions used in this manual

Square brackets [and] enclose optional syntax.

Two dots in a row .. mean the preceding tokens may be repeated.

A vertical bar | means the preceding and following tokens are mutually exclusive alternatives.

4.2 Database

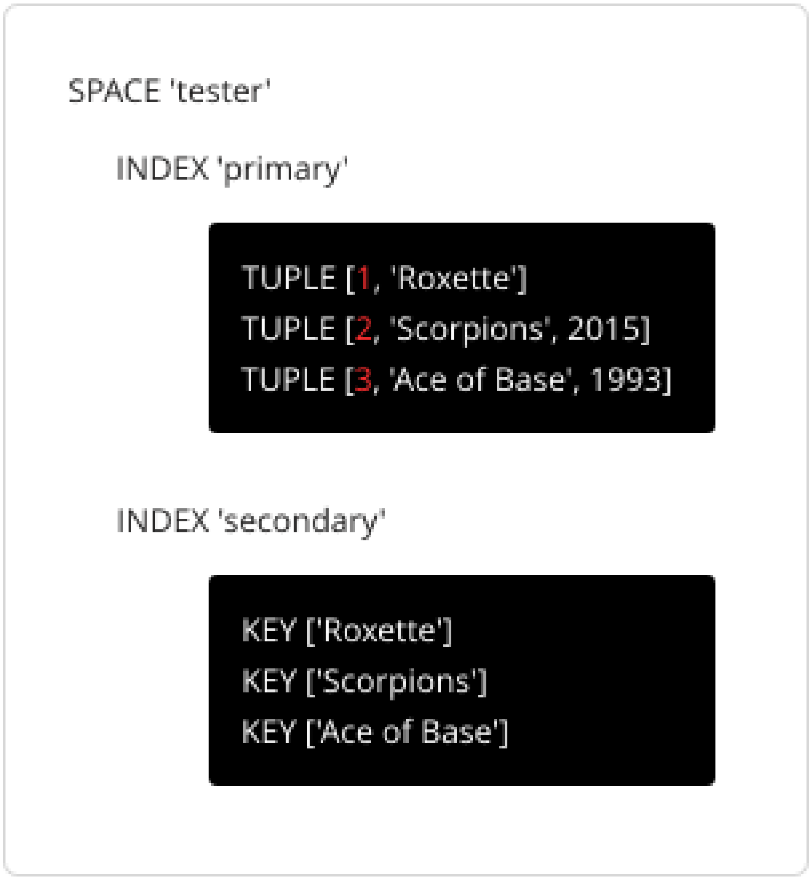
In this chapter, we introduce the basic concepts of working with Tarantool as a database manager.

This chapter contains the following sections:

4.2.1 Data model

This section describes how Tarantool stores values and what operations with data it supports.

If you tried to create a database as suggested in our "Getting started" exercises, then your test database now looks like this:



Spaces

A space – 'tester' in our example – is a container.

When Tarantool is being used to store data, there is always at least one space. Each space has a unique name specified by the user. Besides, each space has a unique numeric identifier which can be specified by the user, but usually is assigned automatically by Tarantool. Finally, a space always has an engine: memtx (default) – in-memory engine, fast but limited in size, or vinyl – on-disk engine for huge data sets.

A space is a container for tuples. To be functional, it needs to have a primary index. It can also have secondary indexes.

Tuples

A tuple plays the same role as a "row" or a "record", and the components of a tuple (which we call "fields") play the same role as a "row column" or "record field", except that:

- fields can be composite structures, such as arrays or maps, and
- fields don't need to have names.

Any given tuple may have any number of fields, and the fields may be of different types. The identifier of a field is the field's number, base 1 (in Lua and other 1-based languages) or base 0 (in PHP or C/C++). For example, 1 or 0 can be used in some contexts to refer to the first field of a tuple.

The number of tuples in a space is unlimited.

Tuples in Tarantool are stored as MsgPack arrays.

When Tarantool returns a tuple value in the console, by default it uses YAML format, for example: [3, 'Ace of Base', 1993].

Indexes

An index is a group of key values and pointers.

As with spaces, you should specify the index name, and let Tarantool come up with a unique numeric identifier ("index id").

An index always has a type. The default index type is 'TREE'. TREE indexes are provided by all Tarantool engines, can index unique and non-unique values, support partial key searches, comparisons and ordered results. Additionally, memtx engine supports HASH, RTREE and BITSET indexes.

An index may be multi-part, that is, you can declare that an index key value is composed of two or more fields in the tuple, in any order. For example, for an ordinary TREE index, the maximum number of parts is 255.

An index may be unique, that is, you can declare that it would be illegal to have the same key value twice.

The first index defined on a space is called the primary key index, and it must be unique. All other indexes are called secondary indexes, and they may be non-unique.

An index definition may include identifiers of tuple fields and their expected types. See allowed indexed field types here.

Note: A recommended design pattern for a data model is to base primary keys on the first fields of a tuple, because this speeds up tuple comparison.

In our example, we first defined the primary index (named 'primary') based on field #1 of each tuple:

```
tarantool> i = s:create_index('primary', {type = 'hash', parts = {{field = 1, type = 'unsigned'}}}
```

The effect is that, for all tuples in space 'tester', field #1 must exist and must contain an unsigned integer. The index type is 'hash', so values in field #1 must be unique, because keys in HASH indexes are unique.

After that, we defined a secondary index (named 'secondary') based on field #2 of each tuple:

```
tarantool> i = s:create_index('secondary', {type = 'tree', parts = {field = 2, type = 'string'}})
```

The effect is that, for all tuples in space 'tester', field #2 must exist and must contain a string. The index type is 'tree', so values in field #2 must not be unique, because keys in TREE indexes may be non-unique.

Note: Space definitions and index definitions are stored permanently in Tarantool's system spaces _space and _index (for details, see reference on box.space submodule).

You can add, drop, or alter the definitions at runtime, with some restrictions. See syntax details in reference on box module.

Read more about index operations here.

Data types

Tarantool is both a database and an application server. Hence a developer often deals with two type sets: the programming language types (e.g. Lua) and the types of the Tarantool storage format (MsgPack).

Lua vs MsgPack

Scalar / compound	MsgPack type	Lua type	Example value
scalar	nil	"nil"	msgpack.NULL
scalar	boolean	"boolean"	true
scalar	string	"string"	'A B C'
scalar	integer	"number"	12345
scalar	double	"number"	1.2345
scalar	double	"cdata"	1.2345
scalar	bin	"cdata"	[!!binary 3t7e]
scalar	decimal	"cdata"	1.2
scalar	ext	(converted to exact number)	1.2
compound	map	"table" (with string keys)	{'a': 5, 'b': 6}
compound	array	"table" (with integer keys)	[1, 2, 3, 4, 5]
compound	array	tuple ("cdata")	[12345, 'A B C']

In Lua, a nil type has only one possible value, also called nil (displayed as null on Tarantool's command line, since the output is in the YAML format). Nils may be compared to values of any types with == (is-equal) or ~= (is-not-equal), but other operations will not work. Nils may not be used in Lua tables; the workaround is to use msgpack.NULL

A boolean is either true or false.

A string is a variable-length sequence of bytes, usually represented with alphanumeric characters inside single quotes. In both Lua and MsgPack, strings are treated as binary data, with no attempts to determine a string's character set or to perform any string conversion – unless there is an optional collation. So, usually, string sorting and comparison are done byte-by-byte, without any special collation rules applied. (Example: numbers are ordered by their point on the number line, so 2345 is greater than 500; meanwhile, strings are ordered by the encoding of the first byte, then the encoding of the second byte, and so on, so '2345' is less than '500'.)

In Lua, a number is double-precision floating-point, but Tarantool 'number' may have both integer and floating-point values. Tarantool will try to store a Lua number as floating-point if the value contains a decimal point or is very large (greater than 100 trillion = 1e14), otherwise Tarantool will store it as an integer. To ensure that even very large numbers are stored as integers, use the tonumber64 function, or the LL (Long Long) suffix, or the ULL (Unsigned Long Long) suffix. Here are examples of numbers using regular notation, exponential notation, the ULL suffix and the tonumber64 function: -55, -2.7e+20, 100000000000000ULL, tonumber64('18446744073709551615').

The double field type exists mainly so that there will be an equivalent to Tarantool/SQL's DOUBLE data type. In MsgPack the storage type is MP_DOUBLE and the size of the encoded value is always 9 bytes. In Lua, 'double' fields can only contain non-integer numeric values and cdata values with double floating-point numbers. To avoid using the wrong kind of values inadvertently, use ffi.cast() when searching or changing 'double' fields. For example, instead of space_object:insert { value } say ffi = require('ffi') ... space_object:insert ({ffi.cast('double', value)}). Example:

```
s = box.schema.space.create('s', {format = {{'d', 'double'}}})
s:create_index('ii')
s:insert({1.1})
ffi = require('ffi')
s:insert({ffi.cast('double', 1)})
s:insert({ffi.cast('double', tonumber('123'))})
s:select(1.1)
s:select({ffi.cast('double', 1)})
```

Arithmetic with cdata 'double' will not work reliably, so for Lua it is better to use the 'number' type. This warning does not apply for Tarantool/SQL because Tarantool/SQL does implicit casting.

An ext (extension) value is an addition by Tarantool, not part of the formal MsgPack definition, for storage of decimal values. Values with the decimal type are not floating-point values although they may contain decimal points. They are exact with up to 38 digits of precision.

A bin (binary) value is not directly supported by Lua but there is a Tarantool type VARBINARY which is encoded as MessagePack binary. For an (advanced) example showing how to insert VARBINARY into a database, see the Cookbook Recipe for ffi_varbinary_insert.

Lua tables with string keys are stored as MsgPack maps; Lua tables with integer keys starting with 1 – as MsgPack arrays. Nils may not be used in Lua tables; the workaround is to use msgpack.NULL

A tuple is a light reference to a MsgPack array stored in the database. It is a special type (cdata) to avoid conversion to a Lua table on retrieval. A few functions may return tables with multiple tuples. For more tuple examples, see box.tuple.

Note: Tarantool uses the MsgPack format for database storage, which is variable-length. So, for example, the smallest number requires only one byte, but the largest number requires nine bytes.

Examples of insert requests with different data types:

```
tarantool> box.space.K:insert{1,nil,true,'A B C',12345,1.2345}
---
- [1, null, true, 'A B C', 12345, 1.2345]
...
tarantool> box.space.K:insert{2,{['a']=5,['b']=6}}
---
- [2, {'a': 5, 'b': 6}]
```

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```
...
tarantool> box.space.K:insert{3,{1,2,3,4,5}}
---
- [3, [1, 2, 3, 4, 5]]
...
```

Indexed field types

Indexes restrict values which Tarantool's MsgPack may contain. This is why, for example, 'unsigned' is a separate indexed field type, compared to 'integer' data type in MsgPack: they both store 'integer' values, but an 'unsigned' index contains only non-negative integer values and an 'integer' index contains all integer values.

Here is how Tarantool indexed field types correspond to MsgPack data types.

Indexed field type	MsgPack data type (and possible values)	Index type	Examples
unsigned (may also be called 'uint' or 'num', but 'num' is deprecated)	integer (integer between 0 and 18446744073709551615, i.e. about 18 quintillion)	TREE, BITSET or HASH	123456
integer (may also be called 'int')	integer (integer between -9223372036854775808 and 18446744073709551615)	TREE or HASH	-2^63
number	integer (integer between -9223372036854775808 and 18446744073709551615) double (single-precision floating point number or double-precision floating point number)	TREE or HASH	1.234 -44 1.447e+44
double	double	TREE or HASH	1.234
string (may also be called 'str')	string (any set of octets, up to the maximum length)	TREE, BITSET or HASH	'A B C' '\65 \66 \67'
varbinary	bin (any set of octets, up to the maximum length)	TREE or HASH	'\65 \66 \67'
boolean	bool (true or false)	TREE or HASH	true
decimal	ext (extension)	TREE or HASH	1.2

array	array (list of numbers representing points in a geometric figure)	RTREE	{10, 11}
			{3, 5, 9, 10}

scalar	null bool (true or false) integer (integer between -9223372036854775808 and 18446744073709551615) double (single-precision floating point number or double-precision floating point number) decimal (value returned by a function in the decimal module) string (any set of octets) varbinary (any set of octets) Note: When there is a mix of types, the key order is: null, then booleans, then numbers, then strings, then varbinary.	TREE or HASH	msgpack.NULL true -1 1.234 '' 'py'

Collations

By default, when Tarantool compares strings, it uses what we call a "binary" collation. The only consideration here is the numeric value of each byte in the string. Therefore, if the string is encoded with ASCII or UTF-8, then `'A'` < `'B'` < `'a'`, because the encoding of 'A' (what used to be called the "ASCII value") is 65, the encoding of 'B' is 66, and the encoding of 'a' is 98. Binary collation is best if you prefer fast deterministic simple maintenance and searching with Tarantool indexes.

But if you want the ordering that you see in phone books and dictionaries, then you need Tarantool's optional collations, such as unicode and unicode_ci, which allow for `'a'` < `'A'` < `'B'` and `'a'` = `'A'` < `'B'` respectively.

The unicode and unicode_ci optional collations use the ordering according to the Default Unicode Collation

Element Table (DUCET) and the rules described in Unicode® Technical Standard #10 Unicode Collation Algorithm (UTS #10 UCA). The only difference between the two collations is about weights:

- unicode collation observes L1 and L2 and L3 weights (strength = 'tertiary'),
- unicode_ci collation observes only L1 weights (strength = 'primary'), so for example 'a' = 'A' = 'á' = 'Á'.

As an example, take some Russian words:

```
'ЕЛЕ'
'елейный'
'ёлка'
'еловый'
'елозить'
'Ёлочка'
'ёлочный'
'ЕЛь'
'ель'
```

. . . and show the difference in ordering and selecting by index:

- with unicode collation:

```
tarantool> box.space.T:create_index('I', {parts = {{field = 1, type = 'str', collation='unicode'}}})
...
tarantool> box.space.T.index.I:select()
---
- - ['ЕЛЕ']
  - ['елейный']
  - ['ёлка']
  - ['еловый']
  - ['елозить']
  - ['Ёлочка']
  - ['ёлочный']
  - ['ель']
  - ['ЕЛь']
...
tarantool> box.space.T.index.I:select{'ЁлКа'}
---
- []
...
```

- with unicode_ci collation:

```
tarantool> box.space.T:create_index('I', {parts = {{field = 1, type ='str', collation='unicode_ci'}}})
...
tarantool> box.space.S.index.I:select()
---
- - ['ЕЛЕ']
  - ['елейный']
  - ['ёлка']
  - ['еловый']
  - ['елозить']
  - ['Ёлочка']
  - ['ёлочный']
  - ['ЕЛь']
...
tarantool> box.space.S.index.I:select{'ЁлКа'}
```

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```
---
- - ['ёлка']
...
```

In all, collation involves much more than these simple examples of upper case / lower case and accented / unaccented equivalence in alphabets. We also consider variations of the same character, non-alphabetic writing systems, and special rules that apply for combinations of characters.

For English: use "unicode" and "unicode_ci". For Russian: use "unicode" and "unicode_ci" (although a few Russians might prefer the Kyrgyz collation which says Cyrillic letters 'Е' and 'Ё' are the same with level-1 weights). For Dutch, German (dictionary), French, Indonesian, Irish, Italian, Lingala, Malay, Portuguese, Southern Soho, Xhosa, or Zulu: "unicode" and "unicode_ci" will do.

The tailored optional collations: For other languages, Tarantool supplies tailored collations for every modern language that has more than a million native speakers, and for specialized situations such as the difference between dictionary order and telephone book order. To see a complete list say box.space._collation:select(). The tailored collation names have the form unicode_[language code]_[strength] where language code is a standard 2-character or 3-character language abbreviation, and strength is s1 for "primary strength" (level-1 weights), s2 for "secondary", s3 for "tertiary". Tarantool uses the same language codes as the ones in the "list of tailorable locales" on man pages of Ubuntu and Fedora. Charts explaining the precise differences from DUCET order are in the Common Language Data Repository.

Sequences

A sequence is a generator of ordered integer values.

As with spaces and indexes, you should specify the sequence name, and let Tarantool come up with a unique numeric identifier ("sequence id").

As well, you can specify several options when creating a new sequence. The options determine what value will be generated whenever the sequence is used.

Options for box.schema.sequence.create()

Option name	Type and meaning	Default	Examples
start	Integer. The value to generate the first time a sequence is used	1	start=0
min	Integer. Values smaller than this cannot be generated	1	min=-1000
max	Integer. Values larger than this cannot be generated	9223372036854775807	max=0
cycle	Boolean. Whether to start again when values cannot be generated	false	cycle=true
cache	Integer. The number of values to store in a cache	0	cache=0
step	Integer. What to add to the previous generated value, when generating a new value	1	step=-1
if_not_exists	Boolean. If this is true and a sequence with this name exists already, ignore other options and use the existing values	false	if_not_exists=true

Once a sequence exists, it can be altered, dropped, reset, forced to generate the next value, or associated with an index.

For an initial example, we generate a sequence named 'S'.

```
tarantool> box.schema.sequence.create('S',{min=5, start=5})
---
- step: 1
  id: 5
  min: 5
  cache: 0
  uid: 1
  max: 9223372036854775807
  cycle: false
  name: S
  start: 5
...
```

The result shows that the new sequence has all default values, except for the two that were specified, min and start.

Then we get the next value, with the next() function.

```
tarantool> box.sequence.S:next()
---
- 5
...
```

The result is the same as the start value. If we called next() again, we would get 6 (because the previous value plus the step value is 6), and so on.

Then we create a new table, and say that its primary key may be generated from the sequence.

```
tarantool> s=box.schema.space.create('T');s:create_index('I',{sequence='S'})
---
...
```

Then we insert a tuple, without specifying a value for the primary key.

```
tarantool> box.space.T:insert{nil,'other stuff'}
---
- [6, 'other stuff']
...
```

The result is a new tuple where the first field has a value of 6. This arrangement, where the system automatically generates the values for a primary key, is sometimes called "auto-incrementing" or "identity".

For syntax and implementation details, see the reference for box.schema.sequence.

Persistence

In Tarantool, updates to the database are recorded in the so-called write ahead log (WAL) files. This ensures data persistence. When a power outage occurs or the Tarantool instance is killed incidentally, the in-memory database is lost. In this situation, WAL files are used to restore the data. Namely, Tarantool reads the WAL files and redoes the requests (this is called the "recovery process"). You can change the timing of the WAL writer, or turn it off, by setting wal_mode.

Tarantool also maintains a set of snapshot files. These files contain an on-disk copy of the entire data set for a given moment. Instead of reading every WAL file since the databases were created, the recovery process can load the latest snapshot file and then read only those WAL files that were produced after the snapshot file was made. After checkpointing, old WAL files can be removed to free up space.

To force immediate creation of a snapshot file, you can use Tarantool's box.snapshot() request. To enable automatic creation of snapshot files, you can use Tarantool's checkpoint daemon. The checkpoint daemon sets intervals for forced checkpoints. It makes sure that the states of both memtx and vinyl storage engines are synchronized and saved to disk, and automatically removes old WAL files.

Snapshot files can be created even if there is no WAL file.

Note: The memtx engine makes only regular checkpoints with the interval set in checkpoint daemon configuration.

The vinyl engine runs checkpointing in the background at all times.

See the Internals section for more details about the WAL writer and the recovery process.

Operations

Data operations

The basic data operations supported in Tarantool are:

- five data-manipulation operations (INSERT, UPDATE, UPSERT, DELETE, REPLACE), and
- one data-retrieval operation (SELECT).

All of them are implemented as functions in box.space submodule.

Examples:

- INSERT: Add a new tuple to space 'tester'.

  The first field, field[1], will be 999 (MsgPack type is integer).

  The second field, field[2], will be 'Taranto' (MsgPack type is string).

```
tarantool> box.space.tester:insert{999, 'Taranto'}
```

- UPDATE: Update the tuple, changing field field[2].

  The clause "{999}", which has the value to look up in the index of the tuple's primary-key field, is mandatory, because update() requests must always have a clause that specifies a unique key, which in this case is field[1].

  The clause "{{'=', 2, 'Tarantino'}}" specifies that assignment will happen to field[2] with the new value.

```
tarantool> box.space.tester:update({999}, {{'=', 2, 'Tarantino'}})
```

- UPSERT: Upsert the tuple, changing field field[2] again.

  The syntax of upsert() is similar to the syntax of update(). However, the execution logic of these two requests is different. UPSERT is either UPDATE or INSERT, depending on the database's state. Also, UPSERT execution is postponed until after transaction commit, so, unlike update(), upsert() doesn't return data back.

```
tarantool> box.space.tester:upsert({999, 'Taranted'}, {{'=', 2, 'Tarantism'}})
```

- REPLACE: Replace the tuple, adding a new field.

  This is also possible with the update() request, but the update() request is usually more complicated.

  ```
  tarantool> box.space.tester:replace{999, 'Tarantella', 'Tarantula'}
  ```

- SELECT: Retrieve the tuple.

  The clause "{999}" is still mandatory, although it does not have to mention the primary key.

  ```
  tarantool> box.space.tester:select{999}
  ```

- DELETE: Delete the tuple.

  In this example, we identify the primary-key field.

  ```
  tarantool> box.space.tester:delete{999}
  ```

Summarizing the examples:

- Functions insert and replace accept a tuple (where a primary key comes as part of the tuple).
- Function upsert accepts a tuple (where a primary key comes as part of the tuple), and also the update operations to execute.
- Function delete accepts a full key of any unique index (primary or secondary).
- Function update accepts a full key of any unique index (primary or secondary), and also the operations to execute.
- Function select accepts any key: primary/secondary, unique/non-unique, full/partial.

See reference on box.space for more details on using data operations.

Note: Besides Lua, you can use Perl, PHP, Python or other programming language connectors. The client server protocol is open and documented. See this annotated BNF.

Index operations

Index operations are automatic: if a data-manipulation request changes a tuple, then it also changes the index keys defined for the tuple.

The simple index-creation operation that we've illustrated before is:

box.space.space-name:create_index('index-name')

This creates a unique TREE index on the first field of all tuples (often called "Field#1"), which is assumed to be numeric.

The simple SELECT request that we've illustrated before is:

box.space.space-name:select(value)

This looks for a single tuple via the first index. Since the first index is always unique, the maximum number of returned tuples will be: one. You can call select() without arguments, causing all tuples to be returned.

Let's continue working with the space 'tester' created in the "Getting started" exercises but first modify it:

```
tarantool> box.space.tester:format({
         > {name = 'id', type = 'unsigned'},
         > {name = 'band_name', type = 'string'},
         > {name = 'year', type = 'unsigned'},
         > {name = 'rate', type = 'unsigned', is_nullable=true}})
---
...
```

Add the rate to the tuple #1 and #2:

```
tarantool> box.space.tester:update(1, {{'=', 4, 5}})
---
- [1, 'Roxette', 1986, 5]
...
tarantool> box.space.tester:update(2, {{'=', 4, 4}})
---
- [2, 'Scorpions', 2015, 4]
...
```

And insert another tuple:

```
tarantool> box.space.tester:insert({4, 'Roxette', 2016, 3})
---
- [4, 'Roxette', 2016, 3]
...
```

The existing SELECT variations:

1. The search can use comparisons other than equality.

```
tarantool> box.space.tester:select(1, {iterator = 'GT'})
---
- - [2, 'Scorpions', 2015, 4]
  - [3, 'Ace of Base', 1993]
  - [4, 'Roxette', 2016, 3]
...
```

The comparison operators are LT, LE, EQ, REQ, GE, GT (for "less than", "less than or equal", "equal", "reversed equal", "greater than or equal", "greater than" respectively). Comparisons make sense if and only if the index type is 'TREE'.

This type of search may return more than one tuple; if so, the tuples will be in descending order by key when the comparison operator is LT or LE or REQ, otherwise in ascending order.

2. The search can use a secondary index.

For a primary-key search, it is optional to specify an index name. For a secondary-key search, it is mandatory.

```
tarantool> box.space.tester:create_index('secondary', {parts = {{field=3, type='unsigned'}}})
---
- unique: true
  parts:
  - type: unsigned
    is_nullable: false
    fieldno: 3
  id: 2
  space_id: 512
  type: TREE
```

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```
  name: secondary
...
tarantool> box.space.tester.index.secondary:select({1993})
---
- - [3, 'Ace of Base', 1993]
...
```

3. The search may be for some key parts starting with the prefix of the key. Notice that partial key searches are available only in TREE indexes.

```
-- Create an index with three parts
tarantool> box.space.tester:create_index('tertiary', {parts = {{field = 2, type = 'string'}, {field=3, type=
↪'unsigned'}, {field=4, type='unsigned'}}})
---
- unique: true
  parts:
  - type: string
    is_nullable: false
    fieldno: 2
  - type: unsigned
    is_nullable: false
    fieldno: 3
  - type: unsigned
    is_nullable: true
    fieldno: 4
  id: 6
  space_id: 513
  type: TREE
  name: tertiary
...
-- Make a partial search
tarantool> box.space.tester.index.tertiary:select({'Scorpions', 2015})
---
- - [2, 'Scorpions', 2015, 4]
...
```

4. The search may be for all fields, using a table for the value:

```
tarantool> box.space.tester.index.tertiary:select({'Roxette', 2016, 3})
---
- - [4, 'Roxette', 2016, 3]
...
```

or the search can be for one field, using a table or a scalar:

```
tarantool> box.space.tester.index.tertiary:select({'Roxette'})
---
- - [1, 'Roxette', 1986, 5]
  - [4, 'Roxette', 2016, 3]
...
```

Working with BITSET and RTREE

BITSET example:

```
tarantool> box.schema.space.create('bitset_example')
tarantool> box.space.bitset_example:create_index('primary')
tarantool> box.space.bitset_example:create_index('bitset',{unique=false,type='BITSET', parts={2,'unsigned
↪'}})
tarantool> box.space.bitset_example:insert{1,1}
tarantool> box.space.bitset_example:insert{2,4}
tarantool> box.space.bitset_example:insert{3,7}
tarantool> box.space.bitset_example:insert{4,3}
tarantool> box.space.bitset_example.index.bitset:select(2, {iterator='BITS_ANY_SET'})
```

The result will be:

```
---
- - [3, 7]
  - [4, 3]
...
```

because (7 AND 2) is not equal to 0, and (3 AND 2) is not equal to 0.

RTREE example:

```
tarantool> box.schema.space.create('rtree_example')
tarantool> box.space.rtree_example:create_index('primary')
tarantool> box.space.rtree_example:create_index('rtree',{unique=false,type='RTREE', parts={2,'ARRAY'}}
↪)
tarantool> box.space.rtree_example:insert{1, {3, 5, 9, 10}}
tarantool> box.space.rtree_example:insert{2, {10, 11}}
tarantool> box.space.rtree_example.index.rtree:select({4, 7, 5, 9}, {iterator = 'GT'})
```

The result will be:

```
---
- - [1, [3, 5, 9, 10]]
...
```

because a rectangle whose corners are at coordinates 4,7,5,9 is entirely within a rectangle whose corners are at coordinates 3,5,9,10.

Additionally, there exist index iterator operations. They can only be used with code in Lua and C/C++. Index iterators are for traversing indexes one key at a time, taking advantage of features that are specific to an index type, for example evaluating Boolean expressions when traversing BITSET indexes, or going in descending order when traversing TREE indexes.

See also other index operations like alter() (modify index) and drop() (delete index) in reference for box.index submodule.

Complexity factors

In reference for box.space and box.index submodules, there are notes about which complexity factors might affect the resource usage of each function.

Complexity factor	Effect
Index size	The number of index keys is the same as the number of tuples in the data set. For a TREE index, if there are more keys, then the lookup time will be greater, although of course the effect is not linear. For a HASH index, if there are more keys, then there is more RAM used, but the number of low-level steps tends to remain constant.
Index type	Typically, a HASH index is faster than a TREE index if the number of tuples in the space is greater than one.
Number of indexes accessed	Ordinarily, only one index is accessed to retrieve one tuple. But to update the tuple, there must be N accesses if the space has N different indexes. Note re storage engine: Vinyl optimizes away such accesses if secondary index fields are unchanged by the update. So, this complexity factor applies only to memtx, since it always makes a full-tuple copy on every update.
Number of tuples accessed	A few requests, for example SELECT, can retrieve multiple tuples. This factor is usually less important than the others.
WAL settings	The important setting for the write-ahead log is wal_mode. If the setting causes no writing or delayed writing, this factor is unimportant. If the setting causes every data-change request to wait for writing to finish on a slow device, this factor is more important than all the others.

4.2.2 Transactions

Transactions in Tarantool occur in fibers on a single thread. That is why Tarantool has a guarantee of execution atomicity. That requires emphasis.

Threads, fibers and yields

How does Tarantool process a basic operation? As an example, let's take this query:

```
tarantool> box.space.tester:update({3}, {{'=', 2, 'size'}, {'=', 3, 0}})
```

This is equivalent to the following SQL statement for a table that stores primary keys in field[1]:

```
UPDATE tester SET "field[2]" = 'size', "field[3]" = 0 WHERE "field[1]" = 3
```

Assuming this query is received by Tarantool via network, it will be processed with three operating system threads:

1. The network thread on the server side receives the query, parses the statement, checks if it's correct, and then transforms it into a special structure–a message containing an executable statement and its options.

2. The network thread ships this message to the instance's transaction processor thread using a lock-free message bus. Lua programs execute directly in the transaction processor thread, and do not require parsing and preparation.

   The instance's transaction processor thread uses the primary-key index on field[1] to find the location of the tuple. It determines that the tuple can be updated (not much can go wrong when you're merely changing an unindexed field value).

3. The transaction processor thread sends a message to the write-ahead logging (WAL) thread to commit the transaction. When done, the WAL thread replies with a COMMIT or ROLLBACK result to the transaction processor which gives it back to the network thread, and the network thread returns the result to the client.

Notice that there is only one transaction processor thread in Tarantool. Some people are used to the idea that there can be multiple threads operating on the database, with (say) thread #1 reading row #x, while thread #2 writes row #y. With Tarantool, no such thing ever happens. Only the transaction processor thread can access the database, and there is only one transaction processor thread for each Tarantool instance.

Like any other Tarantool thread, the transaction processor thread can handle many fibers. A fiber is a set of computer instructions that may contain "yield" signals. The transaction processor thread will execute all computer instructions until a yield, then switch to execute the instructions of a different fiber. Thus (say) the thread reads row #x for the sake of fiber #1, then writes row #y for the sake of fiber #2.

Yields must happen, otherwise the transaction processor thread would stick permanently on the same fiber. There are two types of yields:

- implicit yields: every data-change operation or network-access causes an implicit yield, and every statement that goes through the Tarantool client causes an implicit yield.
- explicit yields: in a Lua function, you can (and should) add "yield" statements to prevent hogging. This is called cooperative multitasking.

Cooperative multitasking

Cooperative multitasking means: unless a running fiber deliberately yields control, it is not preempted by some other fiber. But a running fiber will deliberately yield when it encounters a "yield point": a transaction commit, an operating system call, or an explicit "yield" request. Any system call which can block will be performed asynchronously, and any running fiber which must wait for a system call will be preempted, so that another ready-to-run fiber takes its place and becomes the new running fiber.

This model makes all programmatic locks unnecessary: cooperative multitasking ensures that there will be no concurrency around a resource, no race conditions, and no memory consistency issues. The way to achieve this is quite simple: in critical sections, don't use yields, explicit or implicit, and no one can interfere into the code execution.

When requests are small, for example simple UPDATE or INSERT or DELETE or SELECT, fiber scheduling is fair: it takes only a little time to process the request, schedule a disk write, and yield to a fiber serving the next client.

However, a function might perform complex computations or might be written in such a way that yields do not occur for a long time. This can lead to unfair scheduling, when a single client throttles the rest of the system, or to apparent stalls in request processing. Avoiding this situation is the responsibility of the function's author.

Transactions

In the absence of transactions, any function that contains yield points may see changes in the database state caused by fibers that preempt. Multi-statement transactions exist to provide isolation: each transaction sees a consistent database state and commits all its changes atomically. At commit time, a yield happens and all transaction changes are written to the write ahead log in a single batch. Or, if needed, transaction changes can be rolled back – completely or to a specific savepoint.

In Tarantool, transaction isolation level is serializable with the clause "if no failure during writing to WAL". In case of such a failure that can happen, for example, if the disk space is over, the transaction isolation level becomes read uncommitted.

In vynil, to implement isolation Tarantool uses a simple optimistic scheduler: the first transaction to commit wins. If a concurrent active transaction has read a value modified by a committed transaction, it is aborted.

The cooperative scheduler ensures that, in absence of yields, a multi-statement transaction is not preempted and hence is never aborted. Therefore, understanding yields is essential to writing abort-free code.

Sometimes while testing the transaction mechanism in Tarantool you can notice that yielding after box.begin() but before any read/write operation does not cause an abort as it should according to the description. This happens because actually box.begin() does not start a transaction. It is a mark telling Tarantool to start a transaction after some database request that follows.

In memtx, if an instruction that implies yields, explicit or implicit, is executed during a transaction, the transaction is fully rolled back. In vynil, we use more complex transactional manager that allows yields.

Note: You can't mix storage engines in a transaction today.

Implicit yields

The only explicit yield requests in Tarantool are fiber.sleep() and fiber.yield(), but many other requests "imply" yields because Tarantool is designed to avoid blocking.

Database requests imply yields if and only if there is disk I/O. For memtx, since all data is in memory, there is no disk I/O during a read request. For vinyl, since some data may not be in memory, there may be disk I/O for a read (to fetch data from disk) or for a write (because a stall may occur while waiting for memory to be free). For both memtx and vinyl, since data-change requests must be recorded in the WAL, there is normally a commit. A commit happens automatically after every request in default "autocommit" mode, or a commit happens at the end of a transaction in "transaction" mode, when a user deliberately commits by calling box.commit(). Therefore for both memtx and vinyl, because there can be disk I/O, some database operations may imply yields.

Many functions in modules fio, net_box, console and socket (the "os" and "network" requests) yield.

That is why executing separate commands such as select(), insert(), update() in the console inside a transaction will cause an abort. This is due to implicit yield happening after each chunk of code is executed in the console.

Example #1

- Engine = memtx The sequence select() insert() has one yield, at the end of insertion, caused by implicit commit; select() has nothing to write to the WAL and so does not yield.
- Engine = vinyl The sequence select() insert() has one to three yields, since select() may yield if the data is not in cache, insert() may yield waiting for available memory, and there is an implicit yield at commit.
- The sequence begin() insert() insert() commit() yields only at commit if the engine is memtx, and can yield up to 3 times if the engine is vinyl.

Example #2

Assume that in the memtx space 'tester' there are tuples in which the third field represents a positive dollar amount. Let's start a transaction, withdraw from tuple#1, deposit in tuple#2, and end the transaction, making its effects permanent.

```
tarantool> function txn_example(from, to, amount_of_money)
         >   box.begin()
         >   box.space.tester:update(from, {{'-', 3, amount_of_money}})
         >   box.space.tester:update(to,   {{'+', 3, amount_of_money}})
         >   box.commit()
         >   return "ok"
         > end
---
...
```

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```
tarantool> txn_example({999}, {1000}, 1.00)
---
- "ok"
...
```

If wal_mode = 'none', then implicit yielding at commit time does not take place, because there are no writes to the WAL.

If a task is interactive – sending requests to the server and receiving responses – then it involves network I/O, and therefore there is an implicit yield, even if the request that is sent to the server is not itself an implicit yield request. Therefore, the following sequence

```
conn.space.test:select{1}
conn.space.test:select{2}
conn.space.test:select{3}
```

causes yields three times sequentially when sending requests to the network and awaiting the results. On the server side, the same requests are executed in common order possibly mixing with other requests from the network and local fibers. Something similar happens when using clients that operate via telnet, via one of the connectors, or via the MySQL and PostgreSQL rocks, or via the interactive mode when using Tarantool as a client.

After a fiber has yielded and then has regained control, it immediately issues testcancel.

4.2.3 Access control

Understanding security details is primarily an issue for administrators. However, ordinary users should at least skim this section to get an idea of how Tarantool makes it possible for administrators to prevent unauthorized access to the database and to certain functions.

Briefly:

- There is a method to guarantee with password checks that users really are who they say they are ("authentication").
- There is a _user system space, where usernames and password-hashes are stored.
- There are functions for saying that certain users are allowed to do certain things ("privileges").
- There is a _priv system space, where privileges are stored. Whenever a user tries to do an operation, there is a check whether the user has the privilege to do the operation ("access control").

Details follow.

Users

There is a current user for any program working with Tarantool, local or remote. If a remote connection is using a binary port, the current user, by default, is 'guest'. If the connection is using an admin-console port, the current user is 'admin'. When executing a Lua initialization script, the current user is also 'admin'.

The current user name can be found with box.session.user().

The current user can be changed:

- For a binary port connection – with the AUTH protocol command, supported by most clients;
- For an admin-console connection and in a Lua initialization script – with box.session.su;

- For a binary-port connection invoking a stored function with the CALL command – if the SETUID property is enabled for the function, Tarantool temporarily replaces the current user with the function's creator, with all the creator's privileges, during function execution.

Passwords

Each user (except 'guest') may have a password. The password is any alphanumeric string.

Tarantool passwords are stored in the _user system space with a cryptographic hash function so that, if the password is 'x', the stored hash-password is a long string like 'lL3OvhkIPOKh+Vn9Avlkx69M/Ck='. When a client connects to a Tarantool instance, the instance sends a random salt value which the client must mix with the hashed-password before sending to the instance. Thus the original value 'x' is never stored anywhere except in the user's head, and the hashed value is never passed down a network wire except when mixed with a random salt.

Note: For more details of the password hashing algorithm (e.g. for the purpose of writing a new client application), read the scramble.h header file.

This system prevents malicious onlookers from finding passwords by snooping in the log files or snooping on the wire. It is the same system that MySQL introduced several years ago, which has proved adequate for medium-security installations. Nevertheless, administrators should warn users that no system is foolproof against determined long-term attacks, so passwords should be guarded and changed occasionally. Administrators should also advise users to choose long unobvious passwords, but it is ultimately up to the users to choose or change their own passwords.

There are two functions for managing passwords in Tarantool: box.schema.user.passwd() for changing a user's password and box.schema.user.password() for getting a hash of a user's password.

Owners and privileges

Tarantool has one database. It may be called "box.schema" or "universe". The database contains database objects, including spaces, indexes, users, roles, sequences, and functions.

The owner of a database object is the user who created it. The owner of the database itself, and the owner of objects that are created initially (the system spaces and the default users) is 'admin'.

Owners automatically have privileges for what they create. They can share these privileges with other users or with roles, using box.schema.user.grant requests. The following privileges can be granted:

- 'read', e.g. allow select from a space
- 'write', e.g. allow update on a space
- 'execute', e.g. allow call of a function, or (less commonly) allow use of a role
- 'create', e.g. allow box.schema.space.create (access to certain system spaces is also necessary)
- 'alter', e.g. allow box.space.x.index.y:alter (access to certain system spaces is also necessary)
- 'drop', e.g. allow box.sequence.x:drop (access to certain system spaces is also necessary)
- 'usage', e.g. whether any action is allowable regardless of other privileges (sometimes revoking 'usage' is a convenient way to block a user temporarily without dropping the user)
- 'session', e.g. whether the user can 'connect'.

To create objects, users need the 'create' privilege and at least 'read' and 'write' privileges on the system space with a similar name (for example, on the _space if the user needs to create spaces).

To access objects, users need an appropriate privilege on the object (for example, the 'execute' privilege on function F if the users need to execute function F). See below some examples for granting specific privileges that a grantor – that is, 'admin' or the object creator – can make.

To drop an object, users must be 'admin' or have the 'super' role. Some objects may also be dropped by their creators. As the owner of the entire database, 'admin' can drop any object including other users.

To grant privileges to a user, the object owner says grant(). To revoke privileges from a user, the object owner says revoke(). In either case, there are up to five parameters:

```
(user-name, privilege, object-type [, object-name [, options]])
```

- user-name is the user (or role) that will receive or lose the privilege;
- privilege is any of 'read', 'write', 'execute', 'create', 'alter', 'drop', 'usage', or 'session' (or a comma-separated list);
- object-type is any of 'space', 'index', 'sequence', 'function', 'user', 'role', or 'universe';
- object-name is what the privilege is for (omitted if object-type is 'universe') (may be omitted or nil if the intent is to grant for all objects of the same type);
- options is a list inside braces for example {if_not_exists=true|false} (usually omitted because the default is acceptable).

  Every update of user privileges is reflected immediately in the existing sessions and objects, e.g. functions.

Example for granting many privileges at once

In this example user 'admin' grants many privileges on many objects to user 'U', with a single request.

```
box.schema.user.grant('U','read,write,execute,create,drop','universe')
```

Examples for granting privileges for specific operations

In these examples an administrator grants precisely the minimal privileges necessary for particular operations, to user 'U'.

```
-- So that 'U' can create spaces:
  box.schema.user.grant('U','create','space')
  box.schema.user.grant('U','write', 'space', '_schema')
  box.schema.user.grant('U','write', 'space', '_space')
-- So that 'U' can  create indexes on space T
  box.schema.user.grant('U','create,read','space','T')
  box.schema.user.grant('U','read,write','space','_space_sequence')
  box.schema.user.grant('U','write', 'space', '_index')
-- So that 'U' can  alter indexes on space T (assuming 'U' did not create the index)
  box.schema.user.grant('U','alter','space','T')
  box.schema.user.grant('U','read','space','_space')
  box.schema.user.grant('U','read','space','_index')
  box.schema.user.grant('U','read','space','_space_sequence')
  box.schema.user.grant('U','write','space','_index')
-- So that 'U' can alter indexes on space T (assuming 'U' created the index)
  box.schema.user.grant('U','read','space','_space_sequence')
  box.schema.user.grant('U','read,write','space','_index')
-- So that 'U' can create users:
  box.schema.user.grant('U','create','user')
```

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```
  box.schema.user.grant('U', 'read,write', 'space', '_user')
  box.schema.user.grant('U', 'write', 'space', '_priv')
-- So that 'U' can create roles:
  box.schema.user.grant('U','create','role')
  box.schema.user.grant('U', 'read,write', 'space', '_user')
  box.schema.user.grant('U', 'write', 'space', '_priv')
-- So that 'U' can create sequence generators:
  box.schema.user.grant('U','create','sequence')
  box.schema.user.grant('U', 'read,write', 'space', '_sequence')
-- So that 'U' can create functions:
  box.schema.user.grant('U','create','function')
  box.schema.user.grant('U','read,write','space','_func')
-- So that 'U' can create any object of any type
  box.schema.user.grant('guest','read,write,create','universe')
-- So that 'U' can grant access on objects that 'U' created
  box.schema.user.grant('U','write','space','_priv')
-- So that 'U' can select or get from a space named 'T'
  box.schema.user.grant('U','read','space','T')
-- So that 'U' can update or insert or delete or truncate a space named 'T'
  box.schema.user.grant('U','write','space','T')
-- So that 'U' can execute a function named 'F'
  box.schema.user.grant('U','execute','function','F')
-- So that 'U' can use the "S:next()" function with a sequence named S
  box.schema.user.grant('U','read,write','sequence','S')
-- So that 'U' can use the "S:set()" or "S:reset() function with a sequence named S
  box.schema.user.grant('U','write','sequence','S')
-- So that 'U' can drop a sequence (assuming 'U' did not create it)
  box.schema.user.grant('U','drop','sequence')
  box.schema.user.grant('U','write','space','_sequence_data')
  box.schema.user.grant('U','write','space','_sequence')
-- So that 'U' can drop a function (assuming 'U' did not create it)
  box.schema.user.grant('U','drop','function')
  box.schema.user.grant('U','write','space','_func')
-- So that 'U' can drop a space that has some associated objects
  box.schema.user.grant('U','create,drop','space')
  box.schema.user.grant('U','write','space','_schema')
  box.schema.user.grant('U','write','space','_space')
  box.schema.user.grant('U','write','space','_space_sequence')
  box.schema.user.grant('U','read','space','_trigger')
  box.schema.user.grant('U','read','space','_fk_constraint')
  box.schema.user.grant('U','read','space','_ck_constraint')
  box.schema.user.grant('U','read','space','_func_index')
-- So that 'U' can drop any space (ignore if the privilege exists already)
  box.schema.user.grant('U','drop','space',nil,{if_not_exists=true})
```

Example for creating users and objects then granting privileges

Here we create a Lua function that will be executed under the user id of its creator, even if called by another user.

First, we create two spaces ('u' and 'i') and grant a no-password user ('internal') full access to them. Then we define a function ('read_and_modify') and the no-password user becomes this function's creator. Finally, we grant another user ('public_user') access to execute Lua functions created by the no-password user.

```
box.schema.space.create('u')
box.schema.space.create('i')
box.space.u:create_index('pk')
```

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```
box.space.i:create_index('pk')

box.schema.user.create('internal')

box.schema.user.grant('internal', 'read,write', 'space', 'u')
box.schema.user.grant('internal', 'read,write', 'space', 'i')
box.schema.user.grant('internal', 'create', 'universe')
box.schema.user.grant('internal', 'read,write', 'space', '_func')

function read_and_modify(key)
  local u = box.space.u
  local i = box.space.i
  local fiber = require('fiber')
  local t = u:get{key}
  if t ~= nil then
    u:put{key, box.session.uid()}
    i:put{key, fiber.time()}
  end
end

box.session.su('internal')
box.schema.func.create('read_and_modify', {setuid= true})
box.session.su('admin')
box.schema.user.create('public_user', {password = 'secret'})
box.schema.user.grant('public_user', 'execute', 'function', 'read_and_modify')
```

Roles

A role is a container for privileges which can be granted to regular users. Instead of granting or revoking individual privileges, you can put all the privileges in a role and then grant or revoke the role.

Role information is stored in the _user space, but the third field in the tuple – the type field – is 'role' rather than 'user'.

An important feature in role management is that roles can be nested. For example, role R1 can be granted a privilege "role R2", so users with the role R1 will subsequently get all privileges from both roles R1 and R2. In other words, a user gets all the privileges that are granted to a user's roles, directly or indirectly.

There are actually two ways to grant or revoke a role: box.schema.user.grant-or-revoke(user-name-or-role-name,'execute', 'role',role-name...) or box.schema.user.grant-or-revoke(user-name-or-role-name,role-name...). The second way is preferable.

The 'usage' and 'session' privileges cannot be granted to roles.

Example

```
-- This example will work for a user with many privileges, such as 'admin'
-- or a user with the pre-defined 'super' role
-- Create space T with a primary index
box.schema.space.create('T')
box.space.T:create_index('primary', {})
-- Create user U1 so that later we can change the current user to U1
box.schema.user.create('U1')
-- Create two roles, R1 and R2
box.schema.role.create('R1')
box.schema.role.create('R2')
```

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```
-- Grant role R2 to role R1 and role R1 to user U1 (order doesn't matter)
-- There are two ways to grant a role; here we use the shorter way
box.schema.role.grant('R1', 'R2')
box.schema.user.grant('U1', 'R1')
-- Grant read/write privileges for space T to role R2
-- (but not to role R1 and not to user U1)
box.schema.role.grant('R2', 'read,write', 'space', 'T')
-- Change the current user to user U1
box.session.su('U1')
-- An insertion to space T will now succeed because, due to nested roles,
-- user U1 has write privilege on space T
box.space.T:insert{1}
```

For more detail see box.schema.user.grant() and box.schema.role.grant() in the built-in modules reference.

Sessions and security

A session is the state of a connection to Tarantool. It contains:

- an integer id identifying the connection,
- the current user associated with the connection,
- text description of the connected peer, and
- session local state, such as Lua variables and functions.

In Tarantool, a single session can execute multiple concurrent transactions. Each transaction is identified by a unique integer id, which can be queried at start of the transaction using box.session.sync().

Note: To track all connects and disconnects, you can use connection and authentication triggers.

4.2.4 Triggers

Triggers, also known as callbacks, are functions which the server executes when certain events happen.

There are six types of triggers in Tarantool:

- box.session.on_connect() or box.session.on_disconnect(),
- box.session.on_auth(),
- space_object:on_replace() or space_object:before_replace(),
- box.on_commit() or box.on_rollback(),
- net.box.on_connect() or net.box.on_disconnect(),
- net.box.on_schema_reload(),
- box.ctl.on_schema_init() or box.ctl.on_shutdown(),
- swim_object:on_member_event().

All triggers have the following characteristics:

- Triggers associate a function with an event. The request to "define a trigger" implies passing the trigger's function to one of the "on_event()" functions:

  - box.session.on_connect() or box.session.on_disconnect(),
  - box.session.on_auth(),
  - net.box.on_connect() or net.box.on_disconnect(),
  - net.box.on_schema_reload(),
  - space_object:on_replace() or space_object:before_replace(),
  - box.on_commit() or box.on_rollback(),
  - box.ctl.on_schema_init() or box.ctl.on_shutdown(),
  - swim_object:on_member_event().
- Triggers are defined only by the 'admin' user.
- Triggers are stored in the Tarantool instance's memory, not in the database. Therefore triggers disappear when the instance is shut down. To make them permanent, put function definitions and trigger settings into Tarantool's initialization script.
- Triggers have low overhead. If a trigger is not defined, then the overhead is minimal: merely a pointer dereference and check. If a trigger is defined, then its overhead is equivalent to the overhead of calling a function.
- There can be multiple triggers for one event. In this case, triggers are executed in the reverse order that they were defined in. (Exception: member triggers are executed in the order that they appear in the member list.)
- Triggers must work within the event context. However, effects are undefined if a function contains requests which normally could not occur immediately after the event, but only before the return from the event. For example, putting os.exit() or box.rollback() in a trigger function would be bringing in requests outside the event context.
- Triggers are replaceable. The request to "redefine a trigger" implies passing a new trigger function and an old trigger function to one of the "on_event()" functions.
- The "on_event()" functions all have parameters which are function pointers, and they all return function pointers. Remember that a Lua function definition such as "function f() x = x + 1 end" is the same as "f = function () x = x + 1 end" – in both cases f gets a function pointer. And "trigger = box.session.on_connect(f)" is the same as "trigger = box.session.on_connect(function () x = x + 1 end)" – in both cases trigger gets the function pointer which was passed.
- You can call any "on_event()" function with no arguments to get a list of its triggers. For example, use box.session.on_connect() to return a table of all connect-trigger functions.
- Triggers can be useful in solving problems with replication. See details in

Resolving replication conflicts

Example

Here we log connect and disconnect events into Tarantool server log.

```
log = require('log')

function on_connect_impl()
  log.info("connected "..box.session.peer()..", sid "..box.session.id())
end

function on_disconnect_impl()
  log.info("disconnected, sid "..box.session.id())
```

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```
end

function on_auth_impl(user)
  log.info("authenticated sid "..box.session.id().." as "..user)
end"

function on_connect() pcall(on_connect_impl) end
function on_disconnect() pcall(on_disconnect_impl) end
function on_auth(user) pcall(on_auth_impl, user) end

box.session.on_connect(on_connect)
box.session.on_disconnect(on_disconnect)
box.session.on_auth(on_auth)
```

4.2.5 Limitations

Number of parts in an index

For TREE or HASH indexes, the maximum is 255 (box.schema.INDEX_PART_MAX). For RTREE indexes, the maximum is 1 but the field is an ARRAY of up to 20 dimensions. For BITSET indexes, the maximum is 1.

Number of indexes in a space

128 (box.schema.INDEX_MAX).

Number of fields in a tuple

The theoretical maximum is 2,147,483,647 (box.schema.FIELD_MAX). The practical maximum is whatever is specified by the space's field_count member, or the maximal tuple length.

Number of bytes in a tuple

The maximal number of bytes in a tuple is roughly equal to memtx_max_tuple_size or vinyl_max_tuple_size (with a metadata overhead of about 20 bytes per tuple, which is added on top of useful bytes). By default, the value of either memtx_max_tuple_size or vinyl_max_tuple_size is 1,048,576. To increase it, specify a larger value when starting the Tarantool instance. For example, box.cfg{memtx_max_tuple_size=2*1048576}.

Number of bytes in an index key

If a field in a tuple can contain a million bytes, then the index key can contain a million bytes, so the maximum is determined by factors such as Number of bytes in a tuple, not by the index support.

Number of spaces

The theoretical maximum is 2147483647 (box.schema.SPACE_MAX) but the practical maximum is around 65,000.

Number of connections

The practical limit is the number of file descriptors that one can set with the operating system.

Space size

The total maximum size for all spaces is in effect set by memtx_memory, which in turn is limited by the total available memory.

Update operations count

The maximum number of operations per tuple that can be in a single update is 4000 (BOX_UPDATE_OP_CNT_MAX).

Number of users and roles

32 (BOX_USER_MAX).

Length of an index name or space name or user name

65000 (box.schema.NAME_MAX).

Number of replicas in a replica set

32 (vclock.VCLOCK_MAX).

4.2.6 Storage engines

A storage engine is a set of very-low-level routines which actually store and retrieve tuple values. Tarantool offers a choice of two storage engines:

- memtx (the in-memory storage engine) is the default and was the first to arrive.
- vinyl (the on-disk storage engine) is a working key-value engine and will especially appeal to users who like to see data go directly to disk, so that recovery time might be shorter and database size might be larger.

  On the other hand, vinyl lacks some functions and options that are available with memtx. Where that is the case, the relevant description in this manual contains a note beginning with the words "Note re storage engine".

Further in this section we discuss the details of storing data using the vinyl storage engine.

To specify that the engine should be vinyl, add the clause `engine = 'vinyl'` when creating a space, for example:

```
space = box.schema.space.create('name', {engine='vinyl'})
```

Differences between memtx and vinyl storage engines

The primary difference between memtx and vinyl is that memtx is an "in-memory" engine while vinyl is an "on-disk" engine. An in-memory storage engine is generally faster (each query is usually run under 1 ms), and the memtx engine is justifiably the default for Tarantool, but on-disk engine such as vinyl is preferable when the database is larger than the available memory and adding more memory is not a realistic option.

Option	memtx	vinyl
Supported index type	TREE, HASH, RTREE or BITSET	TREE
Temporary spaces	Supported	Not supported
random() function	Supported	Not supported
alter() function	Supported	Supported starting from the 1.10.2 release (the primary index cannot be modified)
len() function	Returns the number of tuples in the space	Returns the maximum approximate number of tuples in the space
count() function	Takes a constant amount of time	Takes a variable amount of time depending on a state of a DB
delete() function	Returns the deleted tuple, if any	Always returns nil
yield	Does not yield on the select requests unless the transaction is commited to WAL	Yields on the select requests or on its equivalents: get() or pairs()

Storing data with vinyl

Tarantool is a transactional and persistent DBMS that maintains 100% of its data in RAM. The greatest advantages of in-memory databases are their speed and ease of use: they demonstrate consistently high performance, but you never need to tune them.

A few years ago we decided to extend the product by implementing a classical storage engine similar to those used by regular DBMSes: it uses RAM for caching, while the bulk of its data is stored on disk. We decided to make it possible to set a storage engine independently for each table in the database, which is the same way that MySQL approaches it, but we also wanted to support transactions from the very beginning.

The first question we needed to answer was whether to create our own storage engine or use an existing library. The open-source community offered a few viable solutions. The RocksDB library was the fastest growing open-source library and is currently one of the most prominent out there. There were also several lesser-known libraries to consider, such as WiredTiger, ForestDB, NestDB, and LMDB.

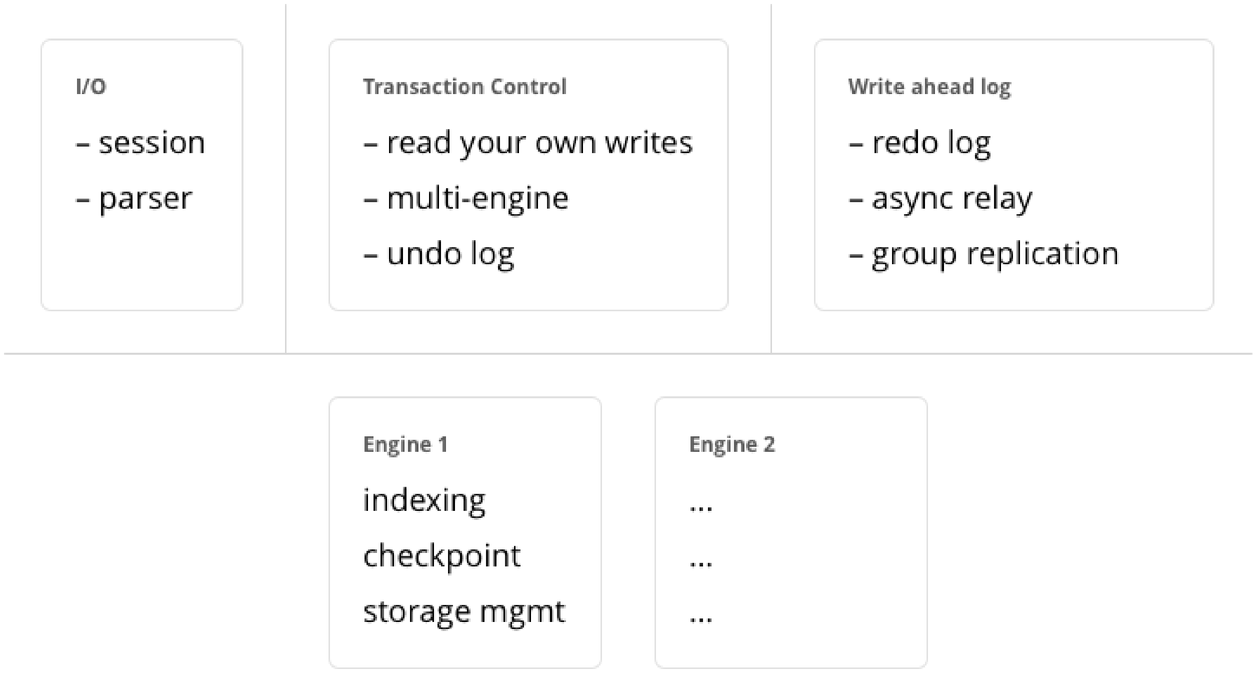
Nevertheless, after studying the source code of existing libraries and considering the pros and cons, we opted for our own storage engine. One reason is that the existing third-party libraries expected requests to come from multiple operating system threads and thus contained complex synchronization primitives for controlling parallel data access. If we had decided to embed one of these in Tarantool, we would have made our users bear the overhead of a multithreaded application without getting anything in return. The thing is, Tarantool has an actor-based architecture. The way it processes transactions in a dedicated thread allows it to do away with the unnecessary locks, interprocess communication, and other overhead that accounts for up to 80% of processor time in multithreaded DBMSes.

The Tarantool process consists of a fixed number of "actor" threads

If you design a database engine with cooperative multitasking in mind right from the start, it not only significantly speeds up the development process, but also allows the implementation of certain optimization tricks that would be too complex for multithreaded engines. In short, using a third-party solution wouldn't have yielded the best result.

Algorithm

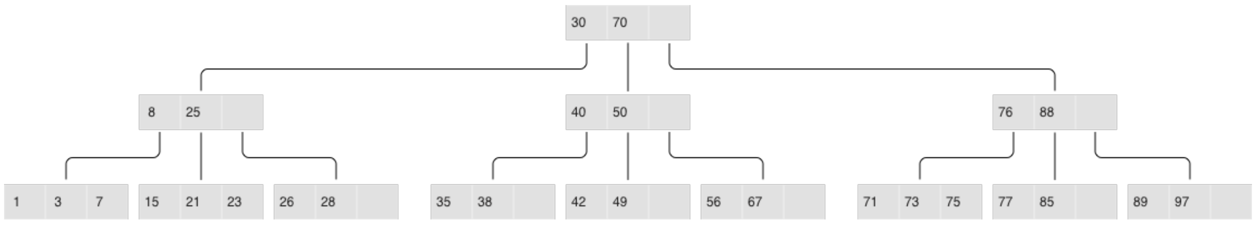
Once the idea of using an existing library was off the table, we needed to pick an architecture to build upon. There are two competing approaches to on-disk data storage: the older one relies on B-trees and



their variations; the newer one advocates the use of log-structured merge-trees, or “LSM” trees. MySQL, PostgreSQL, and Oracle use B-trees, while Cassandra, MongoDB, and CockroachDB have adopted LSM trees.

B-trees are considered better suited for reads and LSM trees—for writes. However, with SSDs becoming more widespread and the fact that SSDs have read throughput that’s several times greater than write throughput, the advantages of LSM trees in most scenarios was more obvious to us.

Before dissecting LSM trees in Tarantool, let’s take a look at how they work. To do that, we’ll begin by analyzing a regular B-tree and the issues it faces. A B-tree is a balanced tree made up of blocks, which contain sorted lists of key- value pairs. (Topics such as filling and balancing a B-tree or splitting and merging blocks are outside of the scope of this article and can easily be found on Wikipedia). As a result, we get a container sorted by key, where the smallest element is stored in the leftmost node and the largest one in the rightmost node. Let’s have a look at how insertions and searches in a B-tree happen.



Classical B-tree

If you need to find an element or check its membership, the search starts at the root, as usual. If the key is found in the root block, the search stops; otherwise, the search visits the rightmost block holding the largest element that’s not larger than the key being searched (recall that elements at each level are sorted). If the first level yields no results, the search proceeds to the next level. Finally, the search ends up in one of the leaves and probably locates the needed key. Blocks are stored and read into RAM one by one, meaning the algorithm reads $logB(N)$ blocks in a single search, where N is the number of elements in the B-tree. In the simplest case, writes are done similarly: the algorithm finds the block that holds the necessary element and updates (inserts) its value.

To better understand the data structure, let's consider a practical example: say we have a B-tree with 100,000,000 nodes, a block size of 4096 bytes, and an element size of 100 bytes. Thus each block will hold up to 40 elements (all overhead considered), and the B-tree will consist of around 2,570,000 blocks and 5 levels: the first four will have a size of 256 Mb, while the last one will grow up to 10 Gb. Obviously, any modern computer will be able to store all of the levels except the last one in filesystem cache, so read requests will require just a single I/O operation.

But if we change our perspective —B-trees don't look so good anymore. Suppose we need to update a single element. Since working with B-trees involves reading and writing whole blocks, we would have to read in one whole block, change our 100 bytes out of 4096, and then write the whole updated block to disk. In other words,we were forced to write 40 times more data than we actually modified!

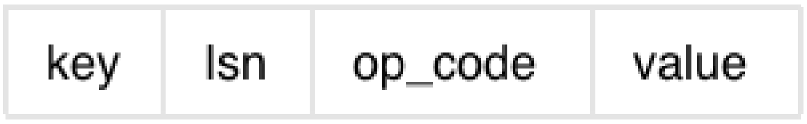
If you take into account the fact that an SSD block has a size of 64 Kb+ and not every modification changes a whole element, the extra disk workload can be greater still.

Authors of specialized literature and blogs dedicated to on-disk data storage have coined two terms for these phenomena: extra reads are referred to as "read amplification" and writes as "write amplification".

The amplification factor (multiplication coefficient) is calculated as the ratio of the size of actual read (or written) data to the size of data needed (or actually changed). In our B-tree example, the amplification factor would be around 40 for both reads and writes.

The huge number of extra I/O operations associated with updating data is one of the main issues addressed by LSM trees. Let's see how they work.

The key difference between LSM trees and regular B-trees is that LSM trees don't just store data (keys and values), but also data operations: insertions and deletions.

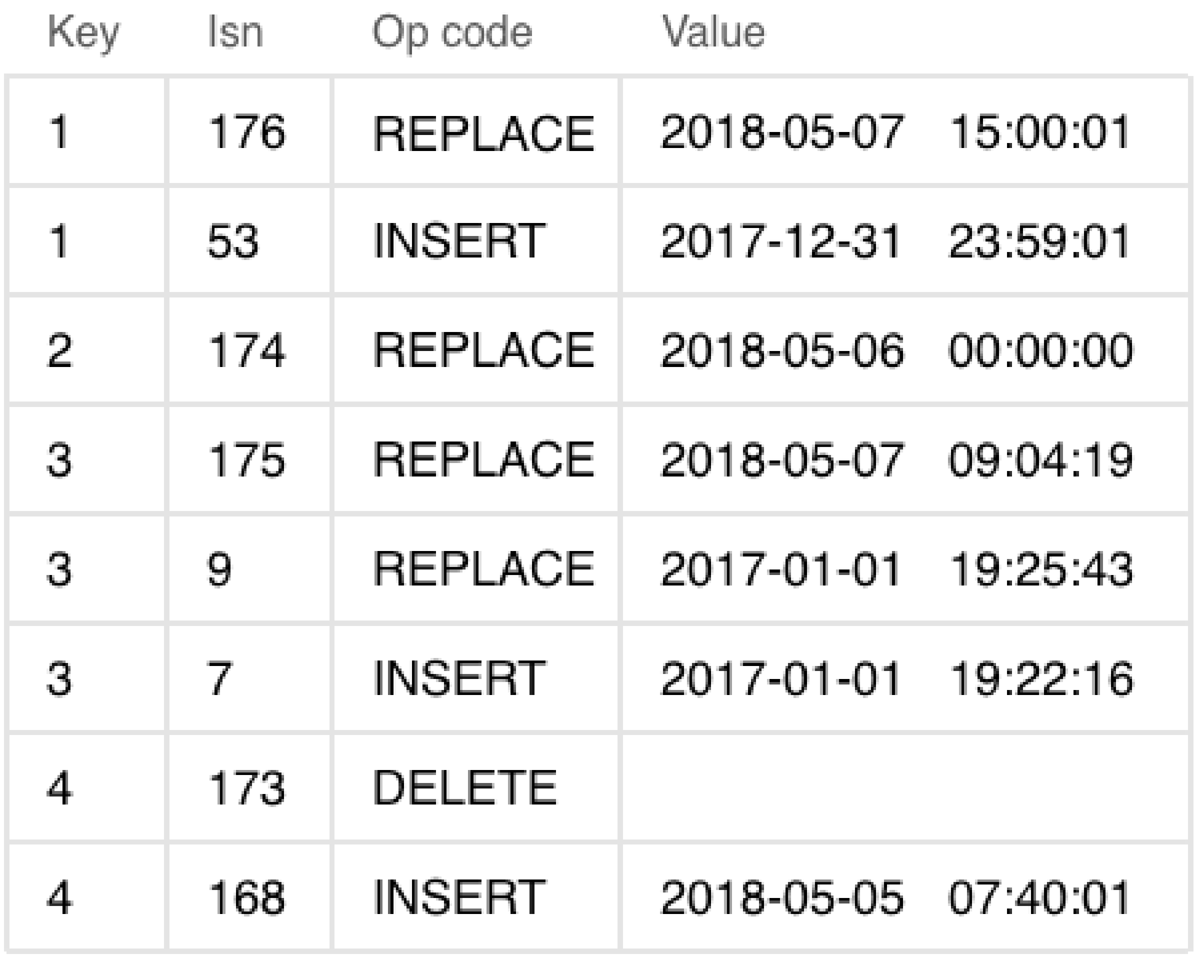


key	lsn	op_code	value

LSM tree:

- Stores statements, not values:
  - REPLACE
  - DELETE
  - UPSERT
- Every statement is marked by LSN Append-only files, garbage is collected after a checkpoint
- Transactional log of all filesystem changes: vylog

For example, an element corresponding to an insertion operation has, apart from a key and a value, an extra byte with an operation code ("REPLACE" in the image above). An element representing the deletion operation contains a key (since storing a value is unnecessary) and the corresponding operation code—"DELETE". Also, each LSM tree element has a log sequence number (LSN), which is the value of a monotonically increasing sequence that uniquely identifies each operation. The whole tree is first ordered by key in ascending order, and then, within a single key scope, by LSN in descending order.



Key	lsn	Op code	Value
1	176	REPLACE	2018-05-07 15:00:01
1	53	INSERT	2017-12-31 23:59:01
2	174	REPLACE	2018-05-06 00:00:00
3	175	REPLACE	2018-05-07 09:04:19
3	9	REPLACE	2017-01-01 19:25:43
3	7	INSERT	2017-01-01 19:22:16
4	173	DELETE	
4	168	INSERT	2018-05-05 07:40:01

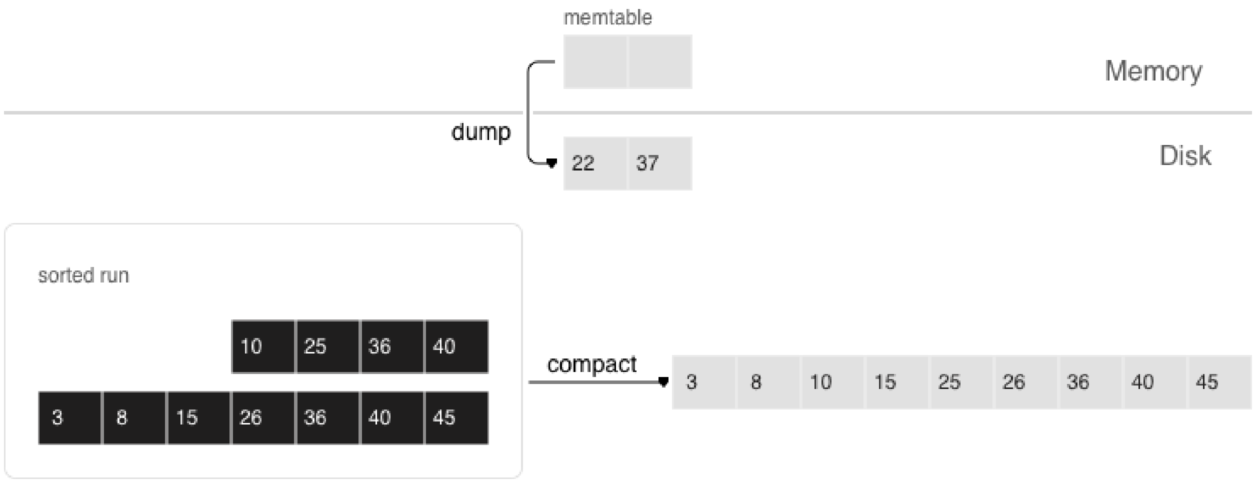
A single level of an LSM tree

Filling an LSM tree

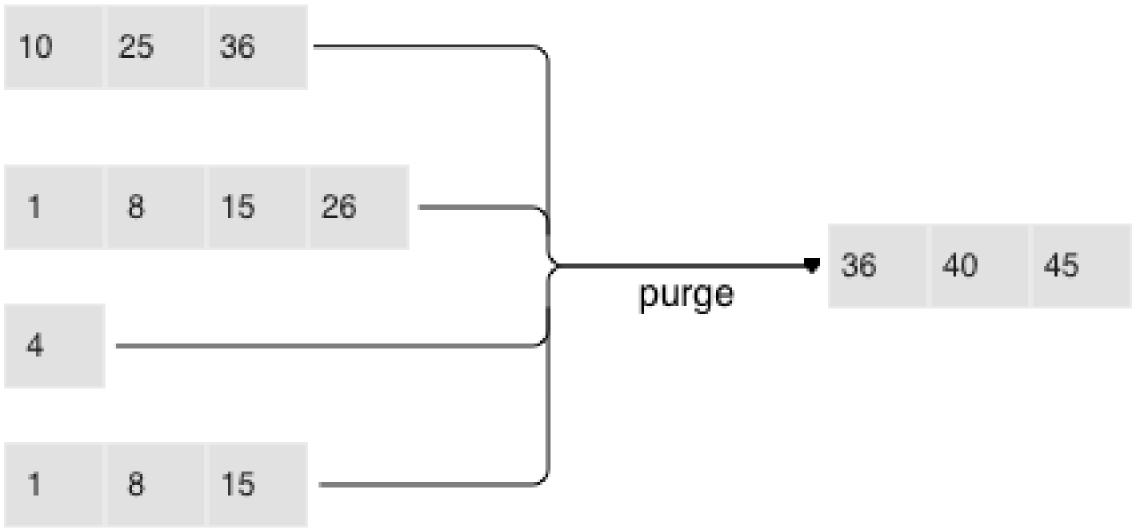
Unlike a B-tree, which is stored completely on disk and can be partly cached in RAM, when using an LSM tree, memory is explicitly separated from disk right from the start. The issue of volatile memory and data persistence is beyond the scope of the storage algorithm and can be solved in various ways—for example, by logging changes.

The part of an LSM tree that's stored in RAM is called L0 (level zero). The size of RAM is limited, so L0 is allocated a fixed amount of memory. For example, in Tarantool, the L0 size is controlled by the vinyl_memory parameter. Initially, when an LSM tree is empty, operations are written to L0. Recall that all elements are ordered by key in ascending order, and then within a single key scope, by LSN in descending order, so when a new value associated with a given key gets inserted, it's easy to locate the older value and delete it. L0 can be structured as any container capable of storing a sorted sequence of elements. For example, in Tarantool, L0 is implemented as a B+*-tree. Lookups and insertions are standard operations for the data structure underlying L0, so I won't dwell on those.

Sooner or later the number of elements in an LSM tree exceeds the L0 size and that's when L0 gets written to a file on disk (called a "run") and then cleared for storing new elements. This operation is called a "dump".

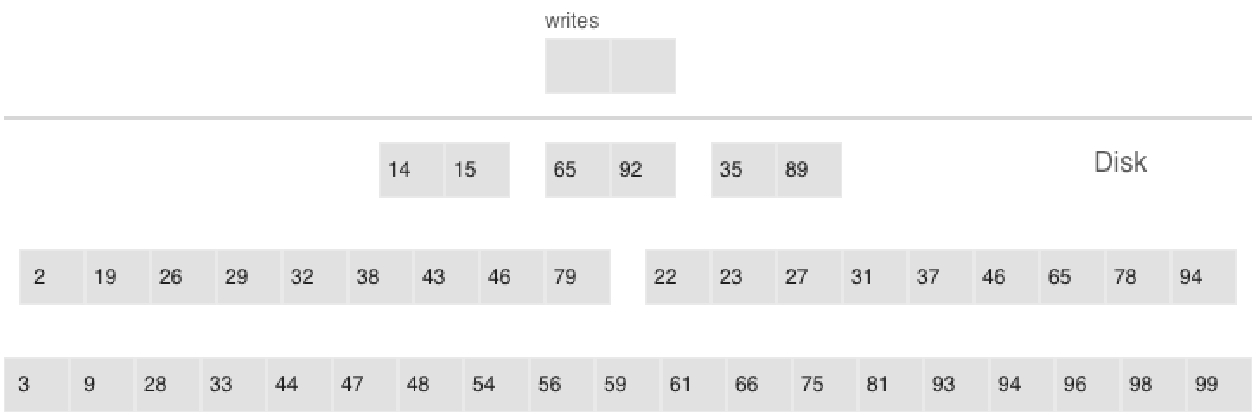


Dumps on disk form a sequence ordered by LSN: LSN ranges in different runs don't overlap, and the leftmost runs (at the head of the sequence) hold newer operations. Think of these runs as a pyramid, with the newest ones closer to the top. As runs keep getting dumped, the pyramid grows higher. Note that newer runs may contain deletions or replacements for existing keys. To remove older data, it's necessary to perform garbage collection (this process is sometimes called "merge" or "compaction") by combining several older runs into a new one. If two versions of the same key are encountered during a compaction, only the newer one is retained; however, if a key insertion is followed by a deletion, then both operations can be discarded.



The key choices determining an LSM tree's efficiency are which runs to compact and when to compact them. Suppose an LSM tree stores a monotonically increasing sequence of keys (1, 2, 3, . . . ,) with no deletions. In this case, compacting runs would be useless: all of the elements are sorted, the tree doesn't have any garbage, and the location of any key can unequivocally be determined. On the other hand, if an LSM tree contains many deletions, doing a compaction would free up some disk space. However, even if there are no deletions, but key ranges in different runs overlap a lot, compacting such runs could speed up lookups as there would be fewer runs to scan. In this case, it might make sense to compact runs after each dump. But keep in mind that a compaction causes all data stored on disk to be overwritten, so with few reads it's recommended to perform it less often.

To ensure it's optimally configurable for any of the scenarios above, an LSM tree organizes all runs into a pyramid: the newer the data operations, the higher up the pyramid they are located. During a compaction, the algorithm picks two or more neighboring runs of approximately equal size, if possible.



- Multi-level compaction can span any number of levels
- A level can contain multiple runs

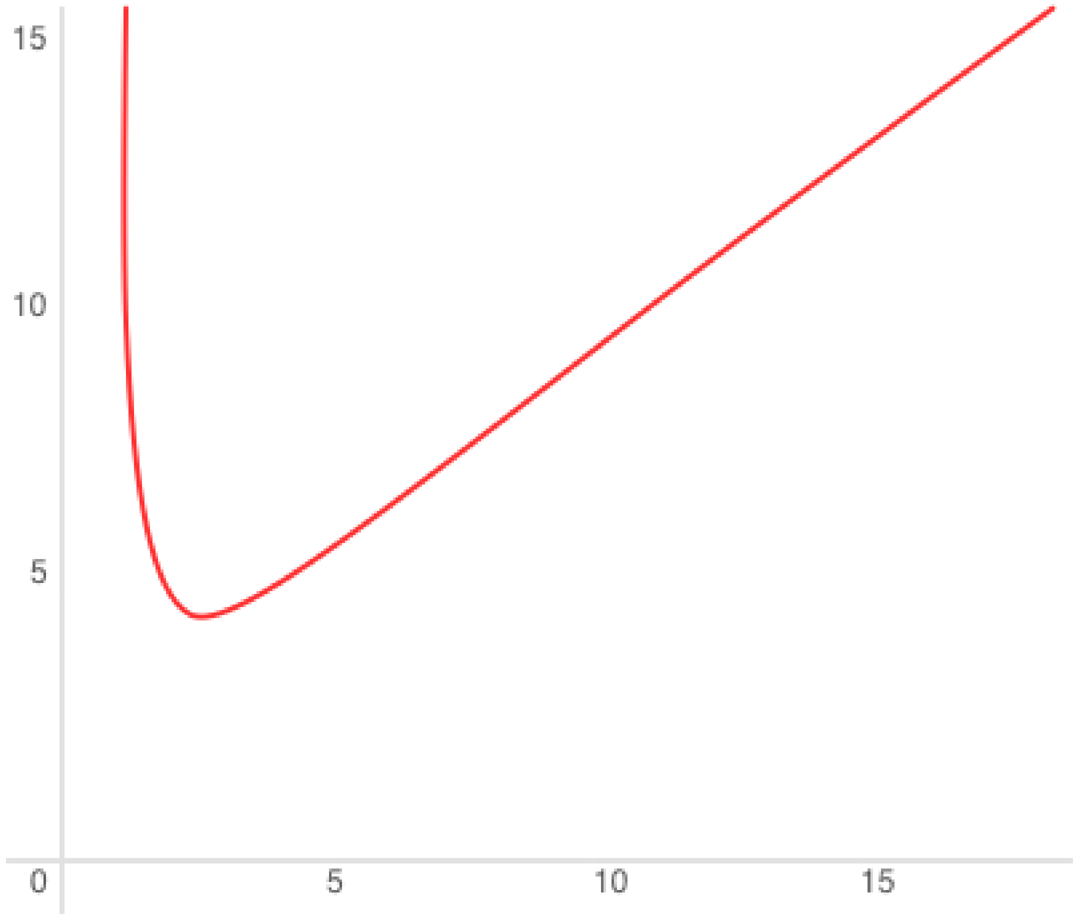
All of the neighboring runs of approximately equal size constitute an LSM tree level on disk. The ratio of run sizes at different levels determines the pyramid's proportions, which allows optimizing the tree for write-intensive or read-intensive scenarios.

Suppose the L0 size is 100 Mb, the ratio of run sizes at each level (the vinyl_run_size_ratio parameter) is 5, and there can be no more than 2 runs per level (the vinyl_run_count_per_level parameter). After the first 3 dumps, the disk will contain 3 runs of 100 Mb each—which constitute L1 (level one). Since 3 > 2, the runs will be compacted into a single 300 Mb run, with the older ones being deleted. After 2 more dumps, there will be another compaction, this time of 2 runs of 100 Mb each and the 300 Mb run, which will produce one 500 Mb run. It will be moved to L2 (recall that the run size ratio is 5), leaving L1 empty. The next 10 dumps will result in L2 having 3 runs of 500 Mb each, which will be compacted into a single 1500 Mb run. Over the course of 10 more dumps, the following will happen: 3 runs of 100 Mb each will be compacted twice, as will two 100 Mb runs and one 300 Mb run, which will yield 2 new 500 Mb runs in L2. Since L2 now has 3 runs, they will also be compacted: two 500 Mb runs and one 1500 Mb run will produce a 2500 Mb run that will be moved to L3, given its size.

This can go on infinitely, but if an LSM tree contains lots of deletions, the resulting compacted run can be moved not only down, but also up the pyramid due to its size being smaller than the sizes of the original runs that were compacted. In other words, it's enough to logically track which level a certain run belongs to, based on the run size and the smallest and greatest LSN among all of its operations.

Controlling the form of an LSM tree

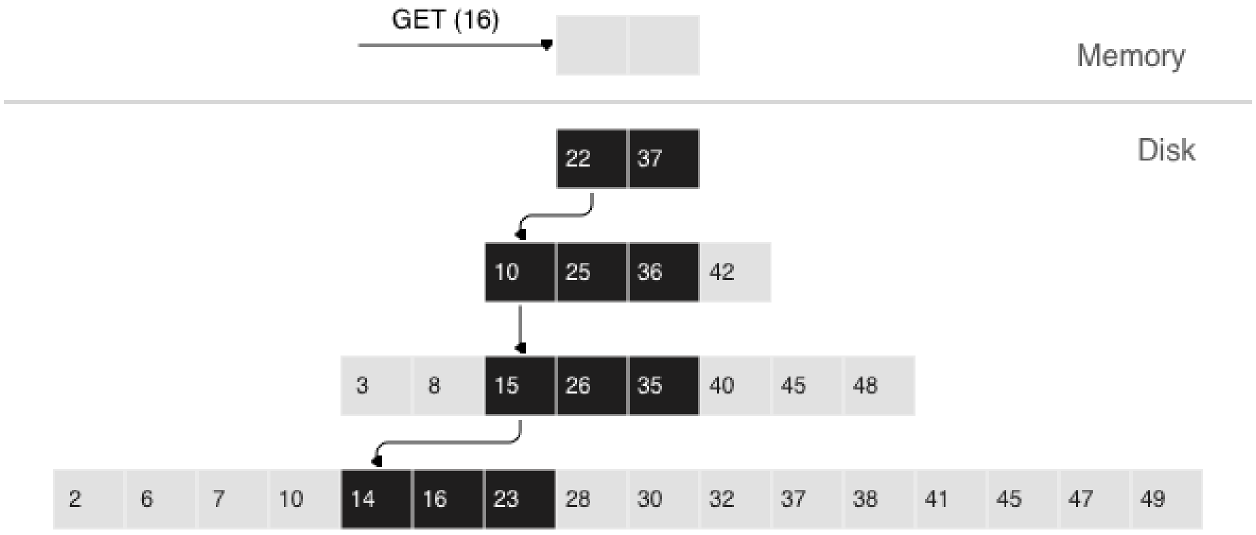
If it's necessary to reduce the number of runs for lookups, then the run size ratio can be increased, thus bringing the number of levels down. If, on the other hand, you need to minimize the compaction-related overhead, then the run size ratio can be decreased: the pyramid will grow higher, and even though runs will be compacted more often, they will be smaller, which will reduce the total amount of work done. In general, write amplification in an LSM tree is described by this formula: $log_x(\frac{N}{L0})x$ or, alternatively, $x\frac{ln(\frac{N}{C0})}{ln(x)}$, where N is the total size of all tree elements, L0 is the level zero size, and x is the level size ratio (the level_size_ratio parameter). At $\frac{N}{C0} = 40$ (the disk-to- memory ratio), the plot would look something like this:



As for read amplification, it's proportional to the number of levels. The lookup cost at each level is no greater than that for a B-tree. Getting back to the example of a tree with 100,000,000 elements: given 256 Mb of RAM and the default values of vinyl_run_size_ratio and vinyl_run_count_per_level, write amplification would come out to about 13, while read amplification could be as high as 150. Let's try to figure out why this happens.

Search

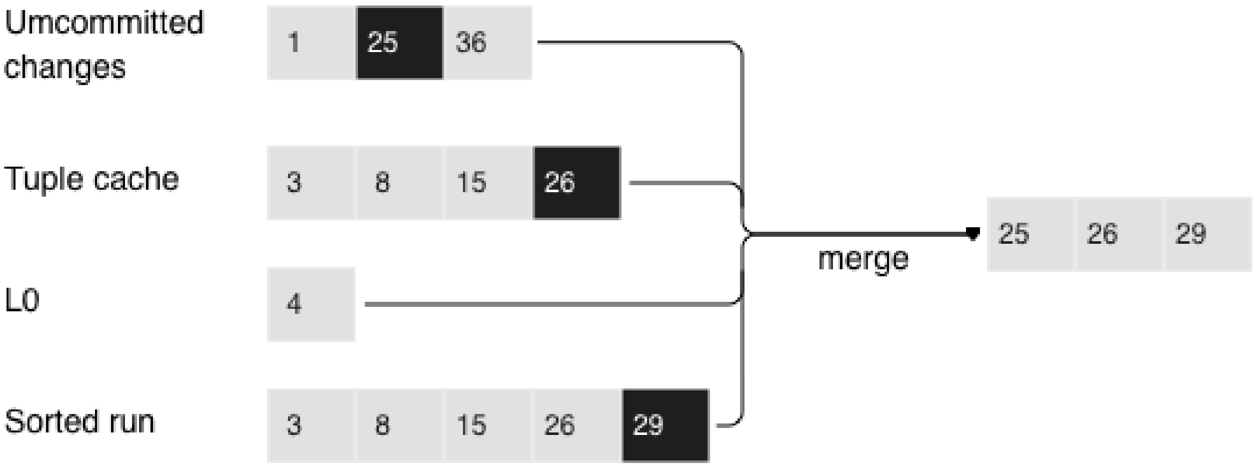
When doing a lookup in an LSM tree, what we need to find is not the element itself, but the most recent operation associated with it. If it's a deletion, then the tree doesn't contain this element. If it's an insertion, we need to grab the topmost value in the pyramid, and the search can be stopped after finding the first matching key. In the worst-case scenario, that is if the tree doesn't hold the needed element, the algorithm will have to sequentially visit all of the levels, starting from L0.



Unfortunately, this scenario is quite common in real life. For example, when inserting a value into a tree, it's necessary to make sure there are no duplicates among primary/unique keys. So to speed up membership checks, LSM trees use a probabilistic data structure called a "Bloom filter", which will be covered a bit later, in a section on how vinyl works under the hood.

Range searching

In the case of a single-key search, the algorithm stops after encountering the first match. However, when searching within a certain key range (for example, looking for all the users with the last name "Ivanov"), it's necessary to scan all tree levels.



Searching within a range of [24,30)

The required range is formed the same way as when compacting several runs: the algorithm picks the key with the largest LSN out of all the sources, ignoring the other associated operations, then moves on to the next key and repeats the procedure.

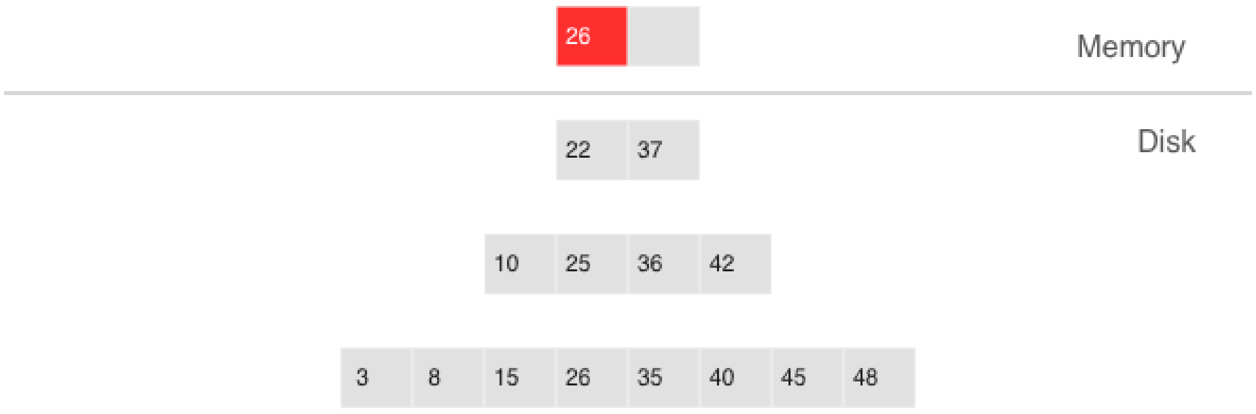
Deletion

Why would one store deletions? And why doesn't it lead to a tree overflow in the case of for i=1,10000000 put(i) delete(i) end?

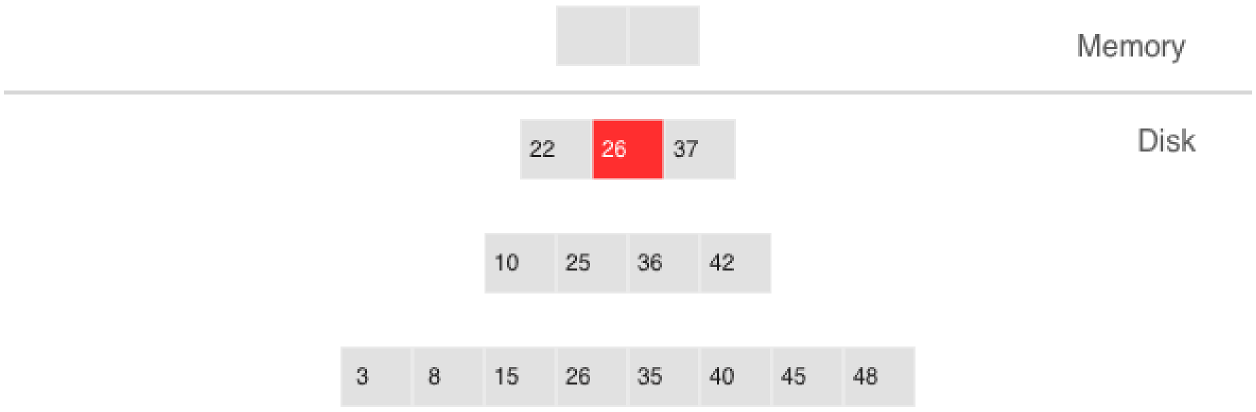
With regards to lookups, deletions signal the absence of a value being searched; with compactions, they clear the tree of "garbage" records with older LSNs.

While the data is in RAM only, there's no need to store deletions. Similarly, you don't need to keep them following a compaction if they affect, among other things, the lowest tree level, which contains the oldest dump. Indeed, if a value can't be found at the lowest level, then it doesn't exist in the tree.

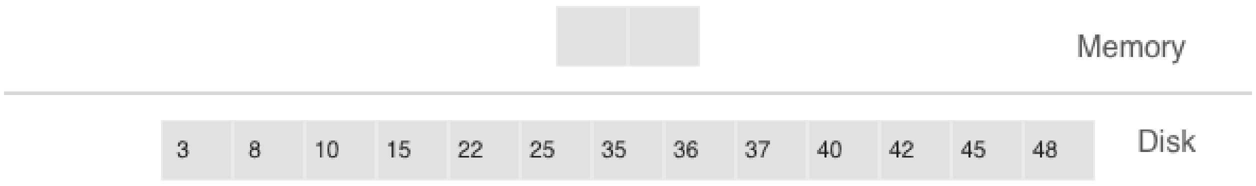
- We can't delete from append-only files
- Tombstones (delete markers) are inserted into L0 instead



Deletion, step 1: a tombstone is inserted into L0



Deletion, step 2: the tombstone passes through intermediate levels



Deletion, step 3: in the case of a major compaction, the tombstone is removed from the tree

If a deletion is known to come right after the insertion of a unique value, which is often the case when modifying a value in a secondary index, then the deletion can safely be filtered out while compacting intermediate tree levels. This optimization is implemented in vinyl.

Advantages of an LSM tree

Apart from decreasing write amplification, the approach that involves periodically dumping level L0 and compacting levels L1-Lk has a few advantages over the approach to writes adopted by B-trees:

- Dumps and compactions write relatively large files: typically, the L0 size is 50-100 Mb, which is thousands of times larger than the size of a B-tree block.
- This large size allows efficiently compressing data before writing it. Tarantool compresses data automatically, which further decreases write amplification.
- There is no fragmentation overhead, since there's no padding/empty space between the elements inside a run.
- All operations create new runs instead of modifying older data in place. This allows avoiding those nasty locks that everyone hates so much. Several operations can run in parallel without causing any conflicts. This also simplifies making backups and moving data to replicas.
- Storing older versions of data allows for the efficient implementation of transaction support by using multiversion concurrency control.

Disadvantages of an LSM tree and how to deal with them

One of the key advantages of the B-tree as a search data structure is its predictability: all operations take no longer than $log_B(N)$ to run. Conversely, in a classical LSM tree, both read and write speeds can differ by a factor of hundreds (best case scenario) or even thousands (worst case scenario). For example, adding just one element to L0 can cause it to overflow, which can trigger a chain reaction in levels L1, L2, and so on. Lookups may find the needed element in L0 or may need to scan all of the tree levels. It's also necessary to optimize reads within a single level to achieve speeds comparable to those of a B-tree. Fortunately, most disadvantages can be mitigated or even eliminated with additional algorithms and data structures. Let's take a closer look at these disadvantages and how they're dealt with in Tarantool.

Unpredictable write speed

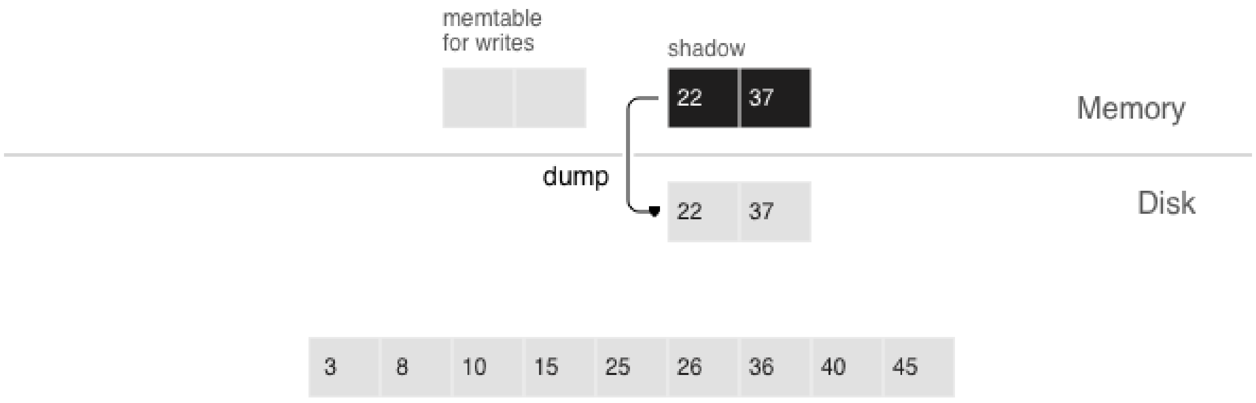
In an LSM tree, insertions almost always affect L0 only. How do you avoid idle time when the memory area allocated for L0 is full?

Clearing L0 involves two lengthy operations: writing to disk and memory deallocation. To avoid idle time while L0 is being dumped, Tarantool uses writeaheads. Suppose the L0 size is 256 Mb. The disk write speed is 10 Mbps. Then it would take 26 seconds to dump L0. The insertion speed is 10,000 RPS, with each key having a size of 100 bytes. While L0 is being dumped, it's necessary to reserve 26 Mb of RAM, effectively slicing the L0 size down to 230 Mb.

Tarantool does all of these calculations automatically, constantly updating the rolling average of the DBMS workload and the histogram of the disk speed. This allows using L0 as efficiently as possible and it prevents write requests from timing out. But in the case of workload surges, some wait time is still possible. That's why we also introduced an insertion timeout (the vinyl_timeout parameter), which is set to 60 seconds by default. The write operation itself is executed in dedicated threads. The number of these threads (2 by default) is controlled by the vinyl_write_threads parameter. The default value of 2 allows doing dumps and compactions in parallel, which is also necessary for ensuring system predictability.

In Tarantool, compactions are always performed independently of dumps, in a separate execution thread. This is made possible by the append-only nature of an LSM tree: after dumps runs are never changed, and compactions simply create new runs.

Delays can also be caused by L0 rotation and the deallocation of memory dumped to disk: during a dump, L0 memory is owned by two operating system threads, a transaction processing thread and a write thread. Even though no elements are being added to the rotated L0, it can still be used for lookups. To avoid read locks when doing lookups, the write thread doesn't deallocate the dumped memory, instead delegating this task to the transaction processor thread. Following a dump, memory deallocation itself happens instantaneously: to achieve this, L0 uses a special allocator that deallocates all of the memory with a single operation.

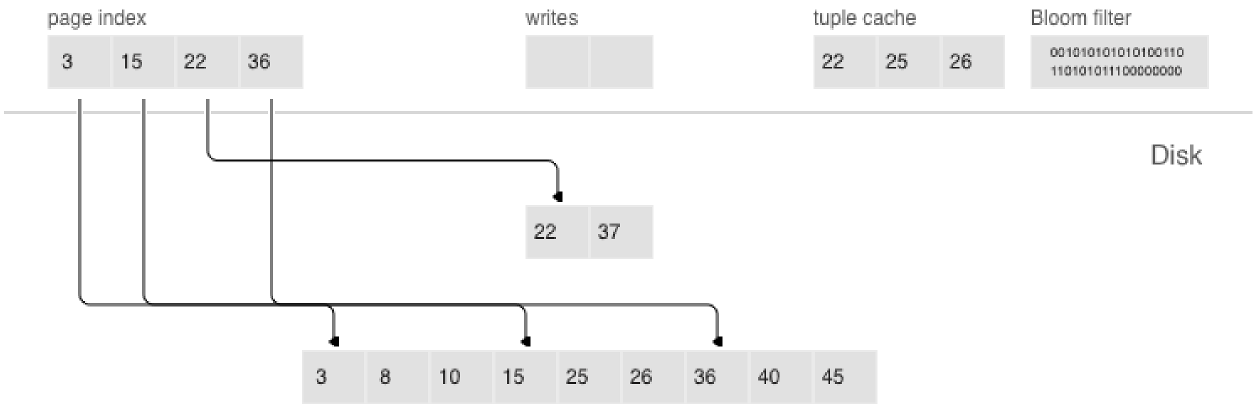


- anticipatory dump
- throttling

The dump is performed from the so-called "shadow" L0 without blocking new insertions and lookups

Unpredictable read speed

Optimizing reads is the most difficult optimization task with regards to LSM trees. The main complexity factor here is the number of levels: any optimization causes not only much slower lookups, but also tends to require significantly larger RAM resources. Fortunately, the append-only nature of LSM trees allows us to address these problems in ways that would be nontrivial for traditional data structures.



- page index
- bloom filters
- tuple range cache
- multi-level compaction

Compression and page index

In B-trees, data compression is either the hardest problem to crack or a great marketing tool—rather than something really useful. In LSM trees, compression works as follows:

During a dump or compaction all of the data within a single run is split into pages. The page size (in bytes) is controlled by the vinyl_page_size parameter and can be set separately for each index. A page doesn't have to be exactly of vinyl_page_size size—depending on the data it holds, it can be a little bit smaller or larger. Because of this, pages never have any empty space inside.

Data is compressed by Facebook's streaming algorithm called "zstd". The first key of each page, along with the page offset, is added to a "page index", which is a separate file that allows the quick retrieval of any page. After a dump or compaction, the page index of the created run is also written to disk.

All .index files are cached in RAM, which allows finding the necessary page with a single lookup in a .run file (in vinyl, this is the extension of files resulting from a dump or compaction). Since data within a page is sorted, after it's read and decompressed, the needed key can be found using a regular binary search. Decompression and reads are handled by separate threads, and are controlled by the vinyl_read_threads parameter.

Tarantool uses a universal file format: for example, the format of a .run file is no different from that of an .xlog file (log file). This simplifies backup and recovery as well as the usage of external tools.

Bloom filters

Even though using a page index enables scanning fewer pages per run when doing a lookup, it's still necessary to traverse all of the tree levels. There's a special case, which involves checking if particular data is absent when scanning all of the tree levels and it's unavoidable: I'm talking about insertions into a unique index. If the data being inserted already exists, then inserting the same data into a unique index should lead to an error. The only way to throw an error in an LSM tree before a transaction is committed is to do a search before inserting the data. Such reads form a class of their own in the DBMS world and are called "hidden" or "parasitic" reads.

Another operation leading to hidden reads is updating a value in a field on which a secondary index is defined. Secondary keys are regular LSM trees that store differently ordered data. In most cases, in order not to have to store all of the data in all of the indexes, a value associated with a given key is kept in whole only in the primary index (any index that stores both a key and a value is called "covering" or "clustered"), whereas the secondary index only stores the fields on which a secondary index is defined, and the values of the fields that are part of the primary index. Thus, each time a change is made to a value in a field on which a secondary index is defined, it's necessary to first remove the old key from the secondary index—and only then can the new key be inserted. At update time, the old value is unknown, and it is this value that needs to be read in from the primary key "under the hood".

For example:

```
update t1 set city='Moscow' where id=1
```

To minimize the number of disk reads, especially for nonexistent data, nearly all LSM trees use probabilistic data structures, and Tarantool is no exception. A classical Bloom filter is made up of several (usually 3-to-5) bit arrays. When data is written, several hash functions are calculated for each key in order to get corresponding array positions. The bits at these positions are then set to 1. Due to possible hash collisions, some bits might be set to 1 twice. We're most interested in the bits that remain 0 after all keys have been added. When looking for an element within a run, the same hash functions are applied to produce bit positions in the arrays. If any of the bits at these positions is 0, then the element is definitely not in the run. The probability of a false positive in a Bloom filter is calculated using Bayes' theorem: each hash function is an independent random variable, so the probability of a collision simultaneously occurring in all of the bit arrays is infinitesimal.

The key advantage of Bloom filters in Tarantool is that they're easily configurable. The only parameter that can be specified separately for each index is called vinyl_bloom_fpr (FPR stands for "false positive ratio") and it has the default value of 0.05, which translates to a 5% FPR. Based on this parameter, Tarantool automatically creates Bloom filters of the optimal size for partial- key and full-key searches. The Bloom filters are stored in the .index file, along with the page index, and are cached in RAM.

Caching

A lot of people think that caching is a silver bullet that can help with any performance issue. "When in doubt, add more cache". In vinyl, caching is viewed rather as a means of reducing the overall workload and consequently, of getting a more stable response time for those requests that don't hit the cache. vinyl boasts a unique type of cache among transactional systems called a "range tuple cache". Unlike, say, RocksDB or MySQL, this cache doesn't store pages, but rather ranges of index values obtained from disk, after having performed a compaction spanning all tree levels. This allows the use of caching for both single-key and key-range searches. Since this method of caching stores only hot data and not, say, pages (you may need only some data from a page), RAM is used in the most efficient way possible. The cache size is controlled by the vinyl_cache parameter.

Garbage collection control

Chances are that by now you've started losing focus and need a well-deserved dopamine reward. Feel free to take a break, since working through the rest of the article is going to take some serious mental effort.

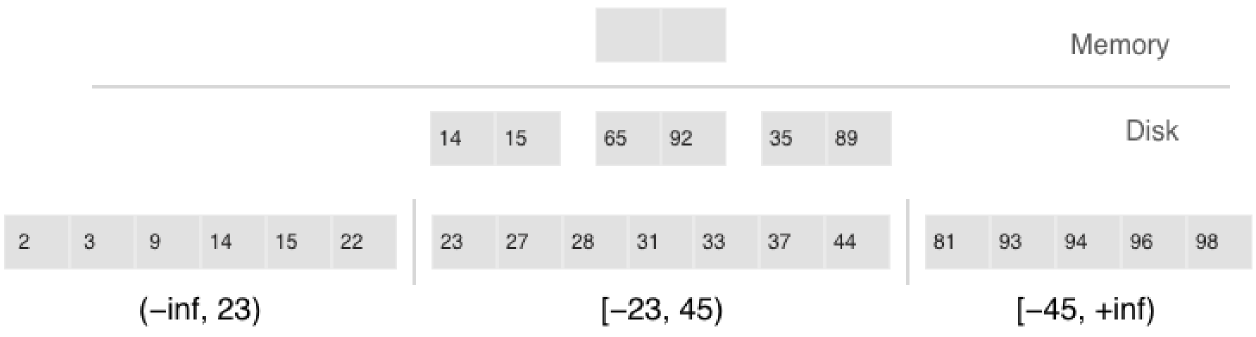
An LSM tree in vinyl is just a small piece of the puzzle. Even with a single table (or so-called "space"), vinyl creates and maintains several LSM trees, one for each index. But even a single index can be comprised of dozens of LSM trees. Let's try to understand why this might be necessary.

Recall our example with a tree containing 100,000,000 records, 100 bytes each. As time passes, the lowest LSM level may end up holding a 10 Gb run. During compaction, a temporary run of approximately the same size will be created. Data at intermediate levels takes up some space as well, since the tree may store several operations associated with a single key. In total, storing 10 Gb of actual data may require up to 30 Gb of free space: 10 Gb for the last tree level, 10 Gb for a temporary run, and 10 Gb for the remaining data. But what if the data size is not 10 Gb, but 1 Tb? Requiring that the available disk space always be several times greater than the actual data size is financially unpractical, not to mention that it may take dozens of hours to create a 1 Tb run. And in the case of an emergency shutdown or system restart, the process would have to be started from scratch.

Here's another scenario. Suppose the primary key is a monotonically increasing sequence—for example, a time series. In this case, most insertions will fall into the right part of the key range, so it wouldn't make much sense to do a compaction just to append a few million more records to an already huge run.

But what if writes predominantly occur in a particular region of the key range, whereas most reads take place in a different region? How do you optimize the form of the LSM tree in this case? If it's too high, read performance is impacted; if it's too low—write speed is reduced.

Tarantool "factorizes" this problem by creating multiple LSM trees for each index. The approximate size of each subtree may be controlled by the vinyl_range_size configuration parameter. We call such subtrees "ranges".



Factorizing large LSM trees via ranging

- Ranges reflect a static layout of sorted runs
- Slices connect a sorted run into a range

Initially, when the index has few elements, it consists of a single range. As more elements are added, its total size may exceed the maximum range size. In that case a special operation called "split" divides the tree into two equal parts. The tree is split at the middle element in the range of keys stored in the tree. For example, if the tree initially stores the full range of -inf. . . +inf, then after splitting it at the middle key X, we get two subtrees: one that stores the range of -inf. . . X, and the other storing the range of X. . . +inf. With this approach, we always know which subtree to use for writes and which one for reads. If the tree contained deletions and each of the neighboring ranges grew smaller as a result, the opposite operation called "coalesce" combines two neighboring trees into one.

Split and coalesce don't entail a compaction, the creation of new runs, or other resource-intensive operations. An LSM tree is just a collection of runs. vinyl has a special metadata log that helps keep track of which run belongs to which subtree(s). This has the .vylog extension and its format is compatible with an .xlog file. Similarly to an .xlog file, the metadata log gets rotated at each checkpoint. To avoid the creation of extra runs with split and coalesce, we have also introduced an auxiliary entity called "slice". It's a reference to a run containing a key range and it's stored only in the metadata log. Once the reference counter drops to zero, the corresponding file gets removed. When it's necessary to perform a split or to coalesce, Tarantool creates slice objects for each new tree, removes older slices, and writes these operations to the metadata log, which literally stores records that look like this: <tree id, slice id> or <slice id, run id, min, max>.

This way all of the heavy lifting associated with splitting a tree into two subtrees is postponed until a compaction and then is performed automatically. A huge advantage of dividing all of the keys into ranges is the ability to independently control the L0 size as well as the dump and compaction processes for each subtree, which makes these processes manageable and predictable. Having a separate metadata log also simplifies the implementation of both "truncate" and "drop". In vinyl, they're processed instantly, since they only work with the metadata log, while garbage collection is done in the background.

Advanced features of vinyl

Upsert

In the previous sections, we mentioned only two operations stored by an LSM tree: deletion and replacement. Let's take a look at how all of the other operations can be represented. An insertion can be represented via a replacement—you just need to make sure there are no other elements with the specified key. To perform an update, it's necessary to read the older value from the tree, so it's easier to represent this operation as a replacement as well—this speeds up future read requests by the key. Besides, an update must return the new value, so there's no avoiding hidden reads.

In B-trees, the cost of hidden reads is negligible: to update a block, it first needs to be read from disk anyway. Creating a special update operation for an LSM tree that doesn't cause any hidden reads is really tempting.

Such an operation must contain not only a default value to be inserted if a key has no value yet, but also a list of update operations to perform if a value does exist.

At transaction execution time, Tarantool just saves the operation in an LSM tree, then “executes” it later, during a compaction.

The upsert operation:

```
space:upsert(tuple, {{operator, field, value}, ... })
```

- Non-reading update or insert
- Delayed execution
- Background upsert squashing prevents upserts from piling up

Unfortunately, postponing the operation execution until a compaction doesn’t leave much leeway in terms of error handling. That’s why Tarantool tries to validate upserts as fully as possible before writing them to an LSM tree. However, some checks are only possible with older data on hand, for example when the update operation is trying to add a number to a string or to remove a field that doesn’t exist.

A semantically similar operation exists in many products including PostgreSQL and MongoDB. But anywhere you look, it’s just syntactic sugar that combines the update and replace operations without avoiding hidden reads. Most probably, the reason is that LSM trees as data storage structures are relatively new.

Even though an upsert is a very important optimization and implementing it cost us a lot of blood, sweat, and tears, we must admit that it has limited applicability. If a table contains secondary keys or triggers, hidden reads can’t be avoided. But if you have a scenario where secondary keys are not required and the update following the transaction completion will certainly not cause any errors, then the operation is for you.

I’d like to tell you a short story about an upsert. It takes place back when vinyl was only beginning to “mature” and we were using an upsert in production for the first time. We had what seemed like an ideal environment for it: we had tons of keys, the current time was being used as values; update operations were inserting keys or modifying the current time; and we had few reads. Load tests yielded great results.

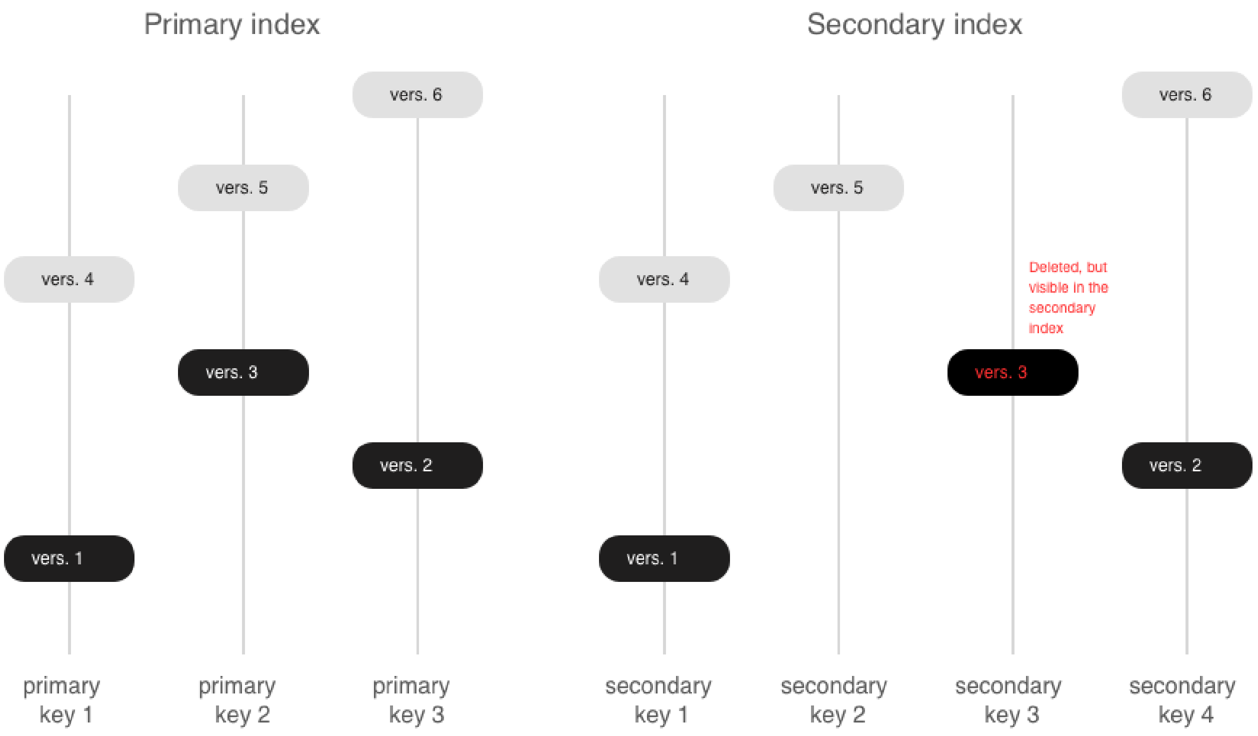
Nevertheless, after a couple of days, the Tarantool process started eating up 100% of our CPU, and the system performance dropped close to zero.

We started digging into the issue and found out that the distribution of requests across keys was significantly different from what we had seen in the test environment. It was. . . well, quite nonuniform. Most keys were updated once or twice a day, so the database was idle for the most part, but there were much hotter keys with tens of thousands of updates per day. Tarantool handled those just fine. But in the case of lookups by key with tens of thousands of upserts, things quickly went downhill. To return the most recent value, Tarantool had to read and “replay” the whole history consisting of all of the upserts. When designing upserts, we had hoped this would happen automatically during a compaction, but the process never even got to that stage: the L0 size was more than enough, so there were no dumps.

We solved the problem by adding a background process that performed readaheads on any keys that had more than a few dozen upserts piled up, so all those upserts were squashed and substituted with the read value.

Secondary keys

Update is not the only operation where optimizing hidden reads is critical. Even the replace operation, given secondary keys, has to read the older value: it needs to be independently deleted from the secondary indexes, and inserting a new element might not do this, leaving some garbage behind.



If secondary indexes are not unique, then collecting "garbage" from them can be put off until a compaction, which is what we do in Tarantool. The append-only nature of LSM trees allowed us to implement full-blown serializable transactions in vinyl. Read-only requests use older versions of data without blocking any writes. The transaction manager itself is fairly simple for now: in classical terms, it implements the MVTO (multiversion timestamp ordering) class, whereby the winning transaction is the one that finished earlier. There are no locks and associated deadlocks. Strange as it may seem, this is a drawback rather than an advantage: with parallel execution, you can increase the number of successful transactions by simply holding some of them on lock when necessary. We're planning to improve the transaction manager soon. In the current release, we focused on making the algorithm behave 100% correctly and predictably. For example, our transaction manager is one of the few on the NoSQL market that supports so-called "gap locks".

4.3 Tarantool Cartridge

Cluster management in Tarantool is powered by the Tarantool Cartridge framework.

Here we explain how you can benefit with Tarantool Cartridge, a framework for developing, deploying, and managing applications based on Tarantool.

This documentation contains the following sections:

4.3.1 Tarantool Cartridge

A framework for distributed applications development.

Contents

About Tarantool Cartridge

Tarantool Cartridge allows you to easily develop Tarantool-based applications and run them on one or more Tarantool instances organized into a cluster.

This is the recommended alternative to the old-school practices of application development for Tarantool.

As a software development kit (SDK), Tarantool Cartridge provides you with utilities and an application template to help:

- easily set up a development environment for your applications;
- plug the necessary Lua modules.

The resulting package can be installed and started on one or multiple servers as one or multiple instantiated services – independent or organized into a cluster.

A Tarantool cluster is a collection of Tarantool instances acting in concert. While a single Tarantool instance can leverage the performance of a single server and is vulnerable to failure, the cluster spans multiple servers, utilizes their cumulative CPU power, and is fault-tolerant.

To fully utilize the capabilities of a Tarantool cluster, you need to develop applications keeping in mind they are to run in a cluster environment.

As a cluster management tool, Tarantool Cartridge provides your cluster-aware applications with the following key benefits:

- horizontal scalability and load balancing via built-in automatic sharding;
- asynchronous replication;
- automatic failover;
- centralized cluster control via GUI or API;
- automatic configuration synchronization;
- instance functionality segregation.

A Tarantool Cartridge cluster can segregate functionality between instances via built-in and custom (user-defined) cluster roles. You can toggle instances on and off on the fly during cluster operation. This allows you to put different types of workloads (e.g., compute- and transaction-intensive ones) on different physical servers with dedicated hardware.

Tarantool Cartridge has an external utility called cartridge-cli which provides you with utilities and an application template to help:

- easily set up a development environment for your applications;
- plug the necessary Lua modules;
- pack the applications in an environment-independent way: together with module binaries and Tarantool executables.

Getting started

Prerequisites

To get a template application that uses Tarantool Cartridge and run it, you need to install several packages:

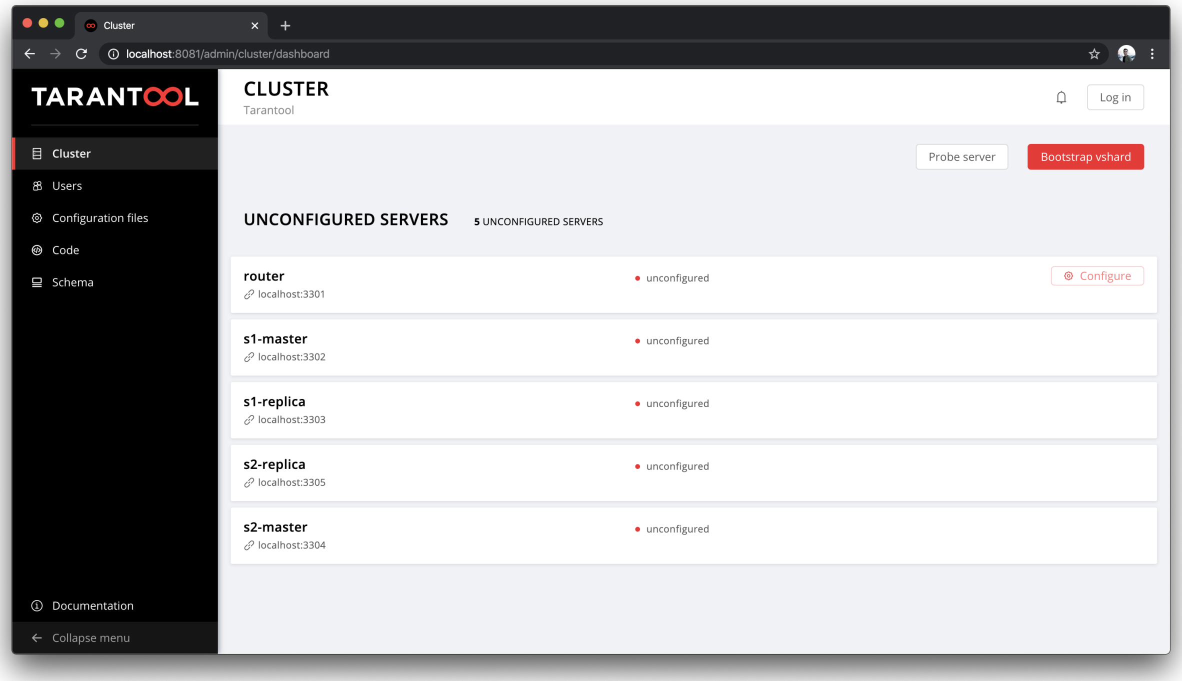
- tarantool and tarantool-dev (see these instructions);
- cartridge-cli (see these instructions)
- git, gcc, cmake and make.

Create your first application

Long story short, copy-paste this into the console:

```
cartridge create --name myapp
cd myapp
cartridge build
cartridge start
```

That's all! Now you can visit http://localhost:8081 and see your application's Admin Web UI:



router localhost:3301 unconfigured
s1-master localhost:3302 unconfigured
s1-replica localhost:3303 unconfigured
s2-replica localhost:3305 unconfigured
s2-master localhost:3304 unconfigured

Next steps

See:

- A more detailed getting started guide
- More application examples

- Cartridge documentation
- Cartridge API reference

Contributing

The most essential contribution is your feedback, don't hesitate to open an issue. If you'd like to propose some changes in code, see the contribution guide.

4.3.2 Developer's guide

For a quick start, skip the details below and jump right away to the Cartridge getting started guide.

For a deep dive into what you can develop with Tarantool Cartridge, go on with the Cartridge developer's guide.

Introduction

To develop and start an application, in short, you need to go through the following steps:

1. Install Tarantool Cartridge and other components of the development environment.
2. Create a project.
3. Develop the application. In case it is a cluster-aware application, implement its logic in a custom (user-defined) cluster role to initialize the database in a cluster environment.
4. Deploy the application to target server(s). This includes configuring and starting the instance(s).
5. In case it is a cluster-aware application, deploy the cluster.

The following sections provide details for each of these steps.

Installing Tarantool Cartridge

1. Install cartridge-cli, a command-line tool for developing, deploying, and managing Tarantool applications.
2. Install git, a version control system.
3. Install npm, a package manager for node.js.
4. Install the unzip utility.

Creating a project

To set up your development environment, create a project using the Tarantool Cartridge project template. In any directory, say:

```
$ cartridge create --name <app_name> /path/to/
```

This will automatically set up a Git repository in a new /path/to/<app_name>/ directory, tag it with version 0.1.0, and put the necessary files into it.

In this Git repository, you can develop the application (by simply editing the default files provided by the template), plug the necessary modules, and then easily pack everything to deploy on your server(s).

The project template creates the <app_name>/ directory with the following contents:

- <app_name>-scm-1.rockspec file where you can specify the application dependencies.
- deps.sh script that resolves dependencies from the .rockspec file.
- init.lua file which is the entry point for your application.
- .git file necessary for a Git repository.
- .gitignore file to ignore the unnecessary files.
- env.lua file that sets common rock paths so that the application can be started from any directory.
- custom-role.lua file that is a placeholder for a custom (user-defined) cluster role.

The entry point file (init.lua), among other things, loads the cartridge module and calls its initialization function:

```
...
local cartridge = require('cartridge')
...
cartridge.cfg({
-- cartridge options example
  workdir = '/var/lib/tarantool/app',
  advertise_uri = 'localhost:3301',
  cluster_cookie = 'super-cluster-cookie',
  ...
}, {
-- box options example
  memtx_memory = 1000000000,
  ... })
 ...
```

The cartridge.cfg() call renders the instance operable via the administrative console but does not call box.cfg() to configure instances.

Warning: Calling the box.cfg() function is forbidden.

The cluster itself will do it for you when it is time to:

- bootstrap the current instance once you:
  - run cartridge.bootstrap() via the administrative console, or
  - click Create in the web interface;
- join the instance to an existing cluster once you:
  - run cartridge.join_server({uri = 'other_instance_uri'}) via the console, or
  - click Join (an existing replica set) or Create (a new replica set) in the web interface.

Notice that you can specify a cookie for the cluster (cluster_cookie parameter) if you need to run several clusters in the same network. The cookie can be any string value.

Now you can develop an application that will run on a single or multiple independent Tarantool instances (e.g. acting as a proxy to third-party databases) – or will run in a cluster.

If you plan to develop a cluster-aware application, first familiarize yourself with the notion of cluster roles.

Cluster roles

Cluster roles are Lua modules that implement some specific functions and/or logic. In other words, a Tarantool Cartridge cluster segregates instance functionality in a role-based way.

Since all instances running cluster applications use the same source code and are aware of all the defined roles (and plugged modules), you can dynamically enable and disable multiple different roles without restarts, even during cluster operation.

Note that every instance in a replica set performs the same roles and you cannot enable/disable roles individually on some instances. In other words, configuration of enabled roles is set up per replica set. See a step-by-step configuration example in this guide.

Built-in roles

The cartridge module comes with two built-in roles that implement automatic sharding:

- vshard-router that handles the vshard's compute-intensive workload: routes requests to storage nodes.
- vshard-storage that handles the vshard's transaction-intensive workload: stores and manages a subset of a dataset.

Note: For more information on sharding, see the vshard module documentation.

With the built-in and custom roles, you can develop applications with separated compute and transaction handling – and enable relevant workload-specific roles on different instances running on physical servers with workload-dedicated hardware.

Custom roles

You can implement custom roles for any purposes, for example:

- define stored procedures;
- implement extra features on top of vshard;
- go without vshard at all;
- implement one or multiple supplementary services such as e-mail notifier, replicator, etc.

To implement a custom cluster role, do the following:

1. Take the app/roles/custom.lua file in your project as a sample. Rename this file as you wish, e.g. app/roles/custom-role.lua, and implement the role's logic. For example:

```
-- Implement a custom role in app/roles/custom-role.lua
#!/usr/bin/env tarantool
local role_name = 'custom-role'

local function init()
...
end

local function stop()
...
end
```

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```

return {
    role_name = role_name,
    init = init,
    stop = stop,
}
```

Here the role_name value may differ from the module name passed to the cartridge.cfg() function. If the role_name variable is not specified, the module name is the default value.

Note: Role names must be unique as it is impossible to register multiple roles with the same name.

2. Register the new role in the cluster by modifying the cartridge.cfg() call in the init.lua entry point file:

```
-- Register a custom role in init.lua
...
local cartridge = require('cartridge')
...
cartridge.cfg({
  workdir = ...,
  advertise_uri = ...,
  roles = {'custom-role'},
})
...
```

where custom-role is the name of the Lua module to be loaded.

The role module does not have required functions, but the cluster may execute the following ones during the role's life cycle:

- init() is the role's initialization function.

  Inside the function's body you can call any box functions: create spaces, indexes, grant permissions, etc. Here is what the initialization function may look like:

```
local function init(opts)
    -- The cluster passes an 'opts' Lua table containing an 'is_master' flag.
    if opts.is_master then
        local customer = box.schema.space.create('customer',
            { if_not_exists = true }
        )
        customer:format({
            {'customer_id', 'unsigned'},
            {'bucket_id', 'unsigned'},
            {'name', 'string'},
        })
        customer:create_index('customer_id', {
            parts = {'customer_id'},
            if_not_exists = true,
        })
    end
end
```

Note:

  - Neither vshard-router nor vshard-storage manage spaces, indexes, or formats. You should do it within a custom role: add a box.schema.space.create() call to your first cluster role, as shown in the example above.
  - The function's body is wrapped in a conditional statement that lets you call box functions on masters only. This protects against replication collisions as data propagates to replicas automatically.

- stop() is the role's termination function. Implement it if initialization starts a fiber that has to be stopped or does any job that needs to be undone on termination.
- validate_config() and apply_config() are functions that validate and apply the role's configuration. Implement them if some configuration data needs to be stored cluster-wide.

Next, get a grip on the role's life cycle to implement the functions you need.

Defining role dependencies

You can instruct the cluster to apply some other roles if your custom role is enabled.

For example:

```
-- Role dependencies defined in app/roles/custom-role.lua
local role_name = 'custom-role'
...
return {
    role_name = role_name,
    dependencies = {'cartridge.roles.vshard-router'},
    ...
}
```

Here vshard-router role will be initialized automatically for every instance with custom-role enabled.

Using multiple vshard storage groups

Replica sets with vshard-storage roles can belong to different groups. For example, hot or cold groups meant to independently process hot and cold data.

Groups are specified in the cluster's configuration:

```
-- Specify groups in init.lua
cartridge.cfg({
    vshard_groups = {'hot', 'cold'},
    ...
})
```

If no groups are specified, the cluster assumes that all replica sets belong to the default group.

With multiple groups enabled, every replica set with a vshard-storage role enabled must be assigned to a particular group. The assignment can never be changed.

Another limitation is that you cannot add groups dynamically (this will become available in future).

Finally, mind the syntax for router access. Every instance with a vshard-router role enabled initializes multiple routers. All of them are accessible through the role:

```
local router_role = cartridge.service_get('vshard-router')
router_role.get('hot'):call(...)
```

If you have no roles specified, you can access a static router as before (when Tarantool Cartridge was unaware of groups):

```
local vhsard = require('vshard')
vshard.router.call(...)
```

However, when using the current group-aware API, you must call a static router with a colon:

```
local router_role = cartridge.service_get('vshard-router')
local default_router = router_role.get() -- or router_role.get('default')
default_router:call(...)
```

Role's life cycle (and the order of function execution)

The cluster displays the names of all custom roles along with the built-in vshard-* roles in the web interface. Cluster administrators can enable and disable them for particular instances – either via the web interface or via the cluster public API. For example:

```
cartridge.admin.edit_replicaset('replicaset-uuid', {roles = {'vshard-router', 'custom-role'}})
```

If you enable multiple roles on an instance at the same time, the cluster first initializes the built-in roles (if any) and then the custom ones (if any) in the order the latter were listed in cartridge.cfg().

If a custom role has dependent roles, the dependencies are registered and validated first, prior to the role itself.

The cluster calls the role's functions in the following circumstances:

- The init() function, typically, once: either when the role is enabled by the administrator or at the instance restart. Enabling a role once is normally enough.
- The stop() function – only when the administrator disables the role, not on instance termination.
- The validate_config() function, first, before the automatic box.cfg() call (database initialization), then – upon every configuration update.
- The apply_config() function upon every configuration update.

As a tryout, let's task the cluster with some actions and see the order of executing the role's functions:

- Join an instance or create a replica set, both with an enabled role:
  1. validate_config()
  2. init()
  3. apply_config()
- Restart an instance with an enabled role:
  1. validate_config()
  2. init()
  3. apply_config()
- Disable role: stop().
- Upon the cartridge.confapplier.patch_clusterwide() call:

   1. validate_config()
   2. apply_config()

- Upon a triggered failover:
   1. validate_config()
   2. apply_config()

Considering the described behavior:

- The init() function may:
   - Call box functions.
   - Start a fiber and, in this case, the stop() function should take care of the fiber's termination.
   - Configure the built-in HTTP server.
   - Execute any code related to the role's initialization.
- The stop() functions must undo any job that needs to be undone on role's termination.
- The validate_config() function must validate any configuration change.
- The apply_config() function may execute any code related to a configuration change, e.g., take care of an expirationd fiber.

The validation and application functions together allow you to change the cluster-wide configuration as described in the next section.

Configuring custom roles

You can:

- Store configurations for your custom roles as sections in cluster-wide configuration, for example:

```
# in YAML configuration file
my_role:
  notify_url: "https://localhost:8080"
```

```
-- in init.lua file
local notify_url = 'http://localhost'
function my_role.apply_config(conf, opts)
  local conf = conf['my_role'] or {}
  notify_url = conf.notify_url or 'default'
end
```

- Download and upload cluster-wide configuration using the web interface or API (via GET/PUT queries to admin/config endpoint like curl localhost:8081/admin/config and curl -X PUT -d "{'my_parameter': 'value'}" localhost:8081/admin/config).
- Utilize it in your role's apply_config() function.

Every instance in the cluster stores a copy of the configuration file in its working directory (configured by cartridge.cfg({workdir = ...})):

- /var/lib/tarantool/<instance_name>/config.yml for instances deployed from RPM packages and managed by systemd.
- /home/<username>/tarantool_state/var/lib/tarantool/config.yml for instances deployed from tar+gz archives.

The cluster's configuration is a Lua table, downloaded and uploaded as YAML. If some application-specific configuration data, e.g. a database schema as defined by DDL (data definition language), needs to be stored on every instance in the cluster, you can implement your own API by adding a custom section to the table. The cluster will help you spread it safely across all instances.

Such section goes in the same file with topology-specific and vshard-specific sections that the cluster generates automatically. Unlike the generated, the custom section's modification, validation, and application logic has to be defined.

The common way is to define two functions:

- validate_config(conf_new, conf_old) to validate changes made in the new configuration (conf_new) versus the old configuration (conf_old).
- apply_config(conf, opts) to execute any code related to a configuration change. As input, this function takes the configuration to apply (conf, which is actually the new configuration that you validated earlier with validate_config()) and options (the opts argument that includes is_master, a Boolean flag described later).

Important: The validate_config() function must detect all configuration problems that may lead to apply_config() errors. For more information, see the next section.

When implementing validation and application functions that call box ones for some reason, mind the following precautions:

- Due to the role's life cycle, the cluster does not guarantee an automatic box.cfg() call prior to calling validate_config().

  If the validation function calls any box functions (e.g., to check a format), make sure the calls are wrapped in a protective conditional statement that checks if box.cfg() has already happened:

  ```
  -- Inside the validate_config() function:

  if type(box.cfg) == 'table' then

      -- Here you can call box functions

  end
  ```

- Unlike the validation function, apply_config() can call box functions freely as the cluster applies custom configuration after the automatic box.cfg() call.

  However, creating spaces, users, etc., can cause replication collisions when performed on both master and replica instances simultaneously. The appropriate way is to call such box functions on masters only and let the changes propagate to replicas automatically.

  Upon the apply_config(conf, opts) execution, the cluster passes an is_master flag in the opts table which you can use to wrap collision-inducing box functions in a protective conditional statement:

  ```
  -- Inside the apply_config() function:

  if opts.is_master then

      -- Here you can call box functions

  end
  ```

Custom configuration example

Consider the following code as part of the role's module (custom-role.lua) implementation:

```
#!/usr/bin/env tarantool
-- Custom role implementation

local cartridge = require('cartridge')

local role_name = 'custom-role'

-- Modify the config by implementing some setter (an alternative to HTTP PUT)
local function set_secret(secret)
    local custom_role_cfg = cartridge.confapplier.get_deepcopy(role_name) or {}
    custom_role_cfg.secret = secret
    cartridge.confapplier.patch_clusterwide({
        [role_name] = custom_role_cfg,
    })
end
-- Validate
local function validate_config(cfg)
    local custom_role_cfg = cfg[role_name] or {}
    if custom_role_cfg.secret ~= nil then
        assert(type(custom_role_cfg.secret) == 'string', 'custom-role.secret must be a string')
    end
    return true
end
-- Apply
local function apply_config(cfg)
    local custom_role_cfg = cfg[role_name] or {}
    local secret = custom_role_cfg.secret or 'default-secret'
    -- Make use of it
end

return {
    role_name = role_name,
    set_secret = set_secret,
    validate_config = validate_config,
    apply_config = apply_config,
}
```

Once the configuration is customized, do one of the following:

- continue developing your application and pay attention to its versioning;
- (optional) enable authorization in the web interface.
- in case the cluster is already deployed, apply the configuration cluster-wide.

Applying custom role's configuration

With the implementation showed by the example, you can call the set_secret() function to apply the new configuration via the administrative console – or an HTTP endpoint if the role exports one.

The set_secret() function calls cartridge.confapplier.patch_clusterwide() which performs a two-phase commit:

1. It patches the active configuration in memory: copies the table and replaces the "custom-role" section in the copy with the one given by the set_secret() function.
2. The cluster checks if the new configuration can be applied on all instances except disabled and expelled. All instances subject to update must be healthy and alive according to the membership module.
3. (Preparation phase) The cluster propagates the patched configuration. Every instance validates it with the validate_config() function of every registered role. Depending on the validation's result:
   - If successful (i.e., returns true), the instance saves the new configuration to a temporary file named config.prepare.yml within the working directory.
   - (Abort phase) Otherwise, the instance reports an error and all the other instances roll back the update: remove the file they may have already prepared.
4. (Commit phase) Upon successful preparation of all instances, the cluster commits the changes. Every instance:
   1. Creates the active configuration's hard-link.
   2. Atomically replaces the active configuration file with the prepared one. The atomic replacement is indivisible – it can either succeed or fail entirely, never partially.
   3. Calls the apply_config() function of every registered role.

If any of these steps fail, an error pops up in the web interface next to the corresponding instance. The cluster does not handle such errors automatically, they require manual repair.

You will avoid the repair if the validate_config() function can detect all configuration problems that may lead to apply_config() errors.

Using the built-in HTTP server

The cluster launches an httpd server instance during initialization (cartridge.cfg()). You can bind a port to the instance via an environmental variable:

```
-- Get the port from an environmental variable or the default one:
local http_port = os.getenv('HTTP_PORT') or '8080'

local ok, err = cartridge.cfg({
   ...
   -- Pass the port to the cluster:
   http_port = http_port,
   ...
})
```

To make use of the httpd instance, access it and configure routes inside the init() function of some role, e.g. a role that exposes API over HTTP:

```
local function init(opts)

...

   -- Get the httpd instance:
   local httpd = cartridge.service_get('httpd')
   if httpd ~= nil then
       -- Configure a route to, for example, metrics:
       httpd:route({
               method = 'GET',
```

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```
            path = '/metrics',
            public = true,
         },
         function(req)
            return req:render({json = stat.stat()})
         end
      )
   end
end
```

For more information on using Tarantool's HTTP server, see its documentation.

Implementing authorization in the web interface

To implement authorization in the web interface of every instance in a Tarantool cluster:

1. Implement a new, say, auth module with a check_password function. It should check the credentials of any user trying to log in to the web interface.

   The check_password function accepts a username and password and returns an authentication success or failure.

   ```
   -- auth.lua

   -- Add a function to check the credentials
   local function check_password(username, password)

       -- Check the credentials any way you like

       -- Return an authentication success or failure
       if not ok then
           return false
       end
       return true
   end
   ...
   ```

2. Pass the implemented auth module name as a parameter to cartridge.cfg(), so the cluster can use it:

   ```
   -- init.lua

   local ok, err = cartridge.cfg({
       auth_backend_name = 'auth',
       -- The cluster will automatically call 'require()' on the 'auth' module.
       ...
   })
   ```

   This adds a Log in button to the upper right corner of the web interface but still lets the unsigned users interact with the interface. This is convenient for testing.

   Note: Also, to authorize requests to cluster API, you can use the HTTP basic authorization header.

3. To require the authorization of every user in the web interface even before the cluster bootstrap, add the following line:

```
-- init.lua

local ok, err = cartridge.cfg({
    auth_backend_name = 'auth',
    auth_enabled = true,
    ...
})
```

With the authentication enabled and the auth module implemented, the user will not be able to even bootstrap the cluster without logging in. After the successful login and bootstrap, the authentication can be enabled and disabled cluster-wide in the web interface and the auth_enabled parameter is ignored.

Application versioning

Tarantool Cartridge understands semantic versioning as described at semver.org. When developing an application, create new Git branches and tag them appropriately. These tags are used to calculate version increments for subsequent packing.

For example, if your application has version 1.2.1, tag your current branch with 1.2.1 (annotated or not).

To retrieve the current version from Git, say:

```
$ git describe --long --tags
1.2.1-12-g74864f2
```

This output shows that we are 12 commits after the version 1.2.1. If we are to package the application at this point, it will have a full version of 1.2.1-12 and its package will be named <app_name>-1.2.1-12.rpm.

Non-semantic tags are prohibited. You will not be able to create a package from a branch with the latest tag being non-semantic.

Once you package your application, the version is saved in a VERSION file in the package root.

Using .cartridge.ignore files

You can add a .cartridge.ignore file to your application repository to exclude particular files and/or directories from package builds.

For the most part, the logic is similar to that of .gitignore files. The major difference is that in .cartridge.ignore files the order of exceptions relative to the rest of the templates does not matter, while in .gitignore files the order does matter.

.cartridge.ignore entry	ignores every...
target/	folder (due to the trailing /) named target, recursively
target	file or folder named target, recursively
/target	file or folder named target in the top-most directory (due to the leading /)
/target/	folder named target in the top-most directory (leading and trailing /)
*.class	every file or folder ending with .class, recursively
#comment	nothing, this is a comment (the first character is a #)
\#comment	every file or folder with name #comment (\ for escaping)
target/logs/	every folder named logs which is a subdirectory of a folder named target
target/*/logs/	every folder named logs two levels under a folder named target (* doesn't include /)
target/**/logs/	every folder named logs somewhere under a folder named target (** includes /)
*.py[co]	every file or folder ending in .pyc or .pyo; however, it doesn't match .py!
*.py[!co]	every file or folder ending in anything other than c or o
*.file[0-9]	every file or folder ending in digit
*.file[!0-9]	every file or folder ending in anything other than digit
*	every
/*	everything in the top-most directory (due to the leading /)
**/*.tar.gz	every *.tar.gz file or folder which is one or more levels under the starting folder
!file	every file or folder will be ignored even if it matches other patterns

Failover architecture

An important concept in cluster topology is appointing a leader. Leader is an instance which is responsible for performing key operations. To keep things simple, you can think of a leader as of the only writable master. Every replica set has its own leader, and there's usually not more than one.

Which instance will become a leader depends on topology settings and failover configuration.

An important topology parameter is the failover priority within a replica set. This is an ordered list of instances. By default, the first instance in the list becomes a leader, but with the failover enabled it may be changed automatically if the first one is malfunctioning.

Instance configuration upon a leader change

When Cartridge configures roles, it takes into account the leadership map (consolidated in the failover.lua module). The leadership map is composed when the instance enters the ConfiguringRoles state for the first time. Later the map is updated according to the failover mode.

Every change in the leadership map is accompanied by instance re-configuration. When the map changes, Cartridge updates the read_only setting and calls the apply_config callback for every role. It also specifies the is_master flag (which actually means is_leader, but hasn't been renamed yet due to historical reasons).

It's important to say that we discuss a distributed system where every instance has its own opinion. Even if all opinions coincide, there still may be races between instances, and you (as an application developer) should take them into account when designing roles and their interaction.

Leader appointment rules

The logic behind leader election depends on the failover mode: disabled, eventual, or stateful.

Disabled mode

This is the simplest case. The leader is always the first instance in the failover priority. No automatic switching is performed. When it's dead, it's dead.

Eventual failover

In the eventual mode, the leader isn't elected consistently. Instead, every instance in the cluster thinks that the leader is the first healthy instance in the failover priority list, while instance health is determined according to the membership status (the SWIM protocol).

The member is considered healthy if both are true:

1. It reports either ConfiguringRoles or RolesConfigured state;
2. Its SWIM status is either alive or suspect.

A suspect member becomes dead after the failover_timout expires.

Leader election is done as follows. Suppose there are two replica sets in the cluster:

- a single router "R",
- two storages, "S1" and "S2".

Then we can say: all the three instances (R, S1, S2) agree that S1 is the leader.

The SWIM protocol guarantees that eventually all instances will find a common ground, but it's not guaranteed for every intermediate moment of time. So we may get a conflict.

For example, soon after S1 goes down, R is already informed and thinks that S2 is the leader, but S2 hasn't received the gossip yet and still thinks he's not. This is a conflict.

Similarly, when S1 recovers and takes the leadership, S2 may be unaware of that yet. So, both S1 and S2 consider themselves as leaders.

Moreover, SWIM protocol isn't perfect and still can produce false-negative gossips (announce the instance is dead when it's not).

Stateful failover

Similarly to the eventual mode, every instance composes its own leadership map, but now the map is fetched from an external state provider (that's why this failover mode called "stateful"). Nowadays there are two state providers supported – etcd and stateboard (standalone Tarantool instance). State provider serves as a domain-specific key-value storage (simply replicaset_uuid -> leader_uuid) and a locking mechanism.

Changes in the leadership map are obtained from the state provider with the long polling technique.

All decisions are made by the coordinator – the one that holds the lock. The coordinator is implemented as a built-in Cartridge role. There may be many instances with the coordinator role enabled, but only one of them can acquire the lock at the same time. We call this coordinator the "active" one.

The lock is released automatically when the TCP connection is closed, or it may expire if the coordinator becomes unresponsive (in stateboard it's set by the stateboard's --lock_delay option, for etcd it's a part of clusterwide configuration), so the coordinator renews the lock from time to time in order to be considered alive.

The coordinator makes a decision based on the SWIM data, but the decision algorithm is slightly different from that in case of eventual failover:

- Right after acquiring the lock from the state provider, the coordinator fetches the leadership map.
- If there is no leader appointed for the replica set, the coordinator appoints the first leader according to the failover priority, regardless of the SWIM status.
- If a leader becomes dead, the coordinator makes a decision. A new leader is the first healthy instance from the failover priority list. If an old leader recovers, no leader change is made until the current leader down. Changing failover priority doesn't affect this.
- Every appointment (self-made or fetched) is immune for a while (controlled by the IMMUNITY_TIMEOUT option).

The case: external provider outage

In this case instances do nothing: the leader remains a leader, read-only instances remain read-only. If any instance restarts during an external state provider outage, it composes an empty leadership map: it doesn't know who actually is a leader and thinks there is none.

The case: coordinator outage

An active coordinator may be absent in a cluster either because of a failure or due to disabling the role everywhere. Just like in the previous case, instances do nothing about it: they keep fetching the leadership map from the state provider. But it will remain the same until a coordinator appears.

Manual leader promotion

It differs a lot depending on the failover mode.

In the disabled and eventual modes, you can only promote a leader by changing the failover priority (and applying a new clusterwide configuration).

In the stateful mode, the failover priority doesn't make much sense (except for the first appointment). Instead, you should use the promotion API (the Lua cartridge.failover_promote or the GraphQL mutation {cluster{failover_promote()}}) which pushes manual appointments to the state provider.

The stateful failover mode implies consistent promotion: before becoming writable, each instance performs the wait_lsn operation to sync up with the previous one.

Information about the previous leader (we call it a vclockkeeper) is also stored on the external storage. Even when the old leader is demoted, it remains the vclockkeeper until the new leader successfully awaits and persists its vclock on the external storage.

If replication is stuck and consistent promotion isn't possible, a user has two options: to revert promotion (to re-promote the old leader) or to force it inconsistently (all kinds of failover_promote API has force_inconsistency flag).

Consistent promotion doesn't work for replicasets with all_rw flag enabled and for single-instance replicasets. In these two cases an instance doesn't even try to query vclockkeeper and to perform wait_lsn. But the coordinator still appoints a new leader if the current one dies.

Fencing

Neither eventual nor stateful failover modes don't protect a replicaset from the presence of multiple leaders when the network is partitioned. But fencing does. It enforces at-most-one leader policy in a replicaset.

Fencing operates as a fiber that occasionally checks connectivity with the state provider and with replicas. Fencing fiber runs on vclockkeepers; it starts right after consistent promotion succeeds. Replicasets which don't need consistency (single-instance and all_rw) don't defense, though.

The condition for fencing actuation is the loss of both the state provider quorum and at least one replica. Otherwise, if either state provider is healthy or all replicas are alive, the fencing fiber waits and doesn't intervene.

When fencing is actuated, it generates a fake appointment locally and sets the leader to nil. Consequently, the instance becomes read-only. Subsequent recovery is only possible when the quorum reestablishes; replica connection isn't a must for recovery. Recovery is performed according to the rules of consistent switchover unless some other instance has already been promoted to a new leader.

Failover configuration

These are clusterwide parameters:

- mode: "disabled" / "eventual" / "stateful".
- state_provider: "tarantool" / "etcd".
- failover_timeout – time (in seconds) to mark suspect members as dead and trigger failover (default: 20).
- tarantool_params: {uri = "...", password = "..."}.
- etcd2_params: {endpoints = {...}, prefix = "/", lock_delay = 10, username = "", password = ""}.
- fencing_enabled: true / false (default: false).
- fencing_timeout – time to actuate fencing after the check fails (default: 10).
- fencing_pause – the period of performing the check (default: 2).

It's required that failover_timeout > fencing_timeout >= fencing_pause.

Lua API

See:

- cartridge.failover_get_params,
- cartridge.failover_set_params,
- cartridge.failover_promote.

GraphQL API

Use your favorite GraphQL client (e.g. Altair) for requests introspection:

- query {cluster{failover_params{}}},
- mutation {cluster{failover_params(){}}},
- mutation {cluster{failover_promote()}}.

Stateboard configuration

Like other Cartridge instances, the stateboard supports cartridge.argprase options:

- listen
- workdir
- password
- lock_delay

Similarly to other argparse options, they can be passed via command-line arguments or via environment variables, e.g.:

```
.rocks/bin/stateboard --workdir ./dev/stateboard --listen 4401 --password qwerty
```

Fine-tuning failover behavior

Besides failover priority and mode, there are some other private options that influence failover operation:

- LONGPOLL_TIMEOUT (failover) – the long polling timeout (in seconds) to fetch new appointments (default: 30);
- NETBOX_CALL_TIMEOUT (failover/coordinator) – stateboard client's connection timeout (in seconds) applied to all communications (default: 1);
- RECONNECT_PERIOD (coordinator) – time (in seconds) to reconnect to the state provider if it's unreachable (default: 5);
- IMMUNITY_TIMEOUT (coordinator) – minimal amount of time (in seconds) to wait before overriding an appointment (default: 15).

Configuring instances

Cartridge orchestrates a distributed system of Tarantool instances – a cluster. One of the core concepts is clusterwide configuration. Every instance in a cluster stores a copy of it.

Clusterwide configuration contains options that must be identical on every cluster node, such as the topology of the cluster, failover and vshard configuration, authentication parameters and ACLs, and user-defined configuration.

Clusterwide configuration doesn't provide instance-specific parameters: ports, workdirs, memory settings, etc.

Configuration basics

Instance configuration includes two sets of parameters:

- cartridge.cfg() parameters;
- box.cfg() parameters.

You can set any of these parameters in:

1. Command line arguments.
2. Environment variables.

3. YAML configuration file.
4. init.lua file.

The order here indicates the priority: command-line arguments override environment variables, and so forth.

No matter how you start the instances, you need to set the following cartridge.cfg() parameters for each instance:

- advertise_uri – either <HOST>:<PORT>, or <HOST>:, or <PORT>. Used by other instances to connect to the current one. DO NOT specify 0.0.0.0 – this must be an external IP address, not a socket bind.
- http_port – port to open administrative web interface and API on. Defaults to 8081. To disable it, specify "http_enabled": False.
- workdir – a directory where all data will be stored: snapshots, wal logs, and cartridge configuration file. Defaults to ..

If you start instances using cartridge CLI or systemctl, save the configuration as a YAML file, for example:

```
my_app.router: {"advertise_uri": "localhost:3301", "http_port": 8080}
my_app.storage_A: {"advertise_uri": "localhost:3302", "http_enabled": False}
my_app.storage_B: {"advertise_uri": "localhost:3303", "http_enabled": False}
```

With cartridge CLI, you can pass the path to this file as the --cfg command-line argument to the cartridge start command – or specify the path in cartridge CLI configuration (in ./.cartridge.yml or ~/.cartridge.yml):

```
cfg: cartridge.yml
run_dir: tmp/run
apps_path: /usr/local/share/tarantool
```

With systemctl, save the YAML file to /etc/tarantool/conf.d/ (the default systemd path) or to a location set in the TARANTOOL_CFG environment variable.

If you start instances with tarantool init.lua, you need to pass other configuration options as command-line parameters and environment variables, for example:

```
$ tarantool init.lua --alias router --memtx-memory 100 --workdir "~/db/3301" --advertise_uri "localhost:3301" --
↪http_port "8080"
```

Internal representation of clusterwide configuration

In the file system, clusterwide configuration is represented by a file tree. Inside workdir of any configured instance you can find the following directory:

```
config/
├── auth.yml
├── topology.yml
└── vshard_groups.yml
```

This is the clusterwide configuration with three default config sections – auth, topology, and vshard_groups.

Due to historical reasons clusterwide configuration has two appearances:

- old-style single-file config.yml with all sections combined, and
- modern multi-file representation mentioned above.

Before cartridge v2.0 it used to look as follows, and this representation is still used in HTTP API and luatest helpers.

```
# config.yml
---
auth: {...}
topology: {...}
vshard_groups: {...}
...
```

Beyond these essential sections, clusterwide configuration may be used for storing some other role-specific data. Clusterwide configuration supports YAML as well as plain text sections. It can also be organized in nested subdirectories.

In Lua it's represented by the ClusterwideConfig object (a table with metamethods). Refer to the cartridge.clusterwide-config module documentation for more details.

Two-phase commit

Cartridge manages clusterwide configuration to be identical everywhere using the two-phase commit algorithm implemented in the cartridge.twophase module. Changes in clusterwide configuration imply applying it on every instance in the cluster.

Almost every change in cluster parameters triggers a two-phase commit: joining/expelling a server, editing replica set roles, managing users, setting failover and vshard configuration.

Two-phase commit requires all instances to be alive and healthy, otherwise it returns an error.

For more details, please, refer to the cartridge.config_patch_clusterwide API reference.

Managing role-specific data

Beside system sections, clusterwide configuration may be used for storing some other role-specific data. It supports YAML as well as plain text sections. And it can also be organized in nested subdirectories.

Role-specific sections are used by some third-party roles, i.e. sharded-queue and cartridge-extensions.

A user can influence clusterwide configuration in various ways. You can alter configuration using Lua, HTTP or GraphQL API. Also there are luatest helpers available.

HTTP API

It works with old-style single-file representation only. It's useful when there are only few sections needed.

Example:

```
cat > config.yml << CONFIG
---
custom_section: {}
...
CONFIG
```

Upload new config:

```
curl -v "localhost:8081/admin/config" -X PUT --data-binary @config.yml
```

Download it:

```
curl -v "localhost:8081/admin/config" -o config.yml
```

It's suitable for role-specific sections only. System sections (topology, auth, vshard_groups, users_acl) can be neither uploaded nor downloaded.

If authorization is enabled, use the curl option --user username:password.

GraphQL API

GraphQL API, by contrast, is only suitable for managing plain-text sections in the modern multi-file appearance. It is mostly used by WebUI, but sometimes it's also helpful in tests:

```
g.cluster.main_server:graphql({query = [[
    mutation($sections: [ConfigSectionInput!]) {
        cluster {
            config(sections: $sections) {
                filename
                content
            }
        }
    }]],
    variables = {sections = {
      {
        filename = 'custom_section.yml',
        content = '---\n{}\n...',
      }
    }}
})
```

Unlike HTTP API, GraphQL affects only the sections mentioned in the query. All the other sections remain unchanged.

Similarly to HTTP API, GraphQL cluster {config} query isn't suitable for managing system sections.

Lua API

It's not the most convenient way to configure third-party role, but it may be useful for role development. Please, refer to the corresponding API reference:

- cartridge.config_patch_clusterwide
- cartridge.config_get_deepcopy
- cartridge.config_get_readonly

Example (from sharded-queue, simplified):

```
function create_tube(tube_name, tube_opts)
    local tubes = cartridge.config_get_deepcopy('tubes') or {}
    tubes[tube_name] = tube_opts or {}

    return cartridge.config_patch_clusterwide({tubes = tubes})
end

local function validate_config(conf)
```

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```
    local tubes = conf.tubes or {}
    for tube_name, tube_opts in pairs(tubes) do
        -- validate tube_opts
    end
    return true
end

local function apply_config(conf, opts)
    if opts.is_master then
        local tubes = cfg.tubes or {}
        -- create tubes according to the configuration
    end
    return true
end
```

Luatest helpers

Cartridge test helpers provide methods for configuration management:

- cartridge.test-helpers.cluster:upload_config,
- cartridge.test-helpers.cluster:download_config.

Internally they wrap the HTTP API.

Example:

```
g.before_all(function()
    g.cluster = helpers.Cluster.new(...)
    g.cluster:upload_config({some_section = 'some_value'})
    t.assert_equals(
        g.cluster:download_config(),
        {some_section = 'some_value'}
    )
end)
```

Deploying an application

After you've developed your application locally, you can deploy it to a test or production environment.

"Deploy" includes packing the application into a specific distribution format, installing to the target system, and running the application.

You have four options to deploy a Tarantool Cartridge application:

- as an rpm package (for production);
- as a deb package (for production);
- as a tar+gz archive (for testing, or as a workaround for production if root access is unavailable).
- from sources (for local testing only).

Deploying as an rpm or deb package

The choice between DEB and RPM depends on the package manager of the target OS. For example, DEB is native for Debian Linux, and RPM – for CentOS.

1. Pack the application into a distributable:

   ```
   $ cartridge pack rpm APP_NAME
   # -- OR --
   $ cartridge pack deb APP_NAME
   ```

   This will create an RPM package (e.g. ./my_app-0.1.0-1.rpm) or a DEB package (e.g. ./my_app-0.1.0-1.deb).

2. Upload the package to target servers, with systemctl supported.

3. Install:

   ```
   $ yum install APP_NAME-VERSION.rpm
   # -- OR --
   $ dpkg -i APP_NAME-VERSION.deb
   ```

4. Configure the instance(s). Create a file called /etc/tarantool/conf.d/instances.yml. For example:

   ```
   my_app:
     cluster_cookie: secret-cookie

   my_app.instance-1:
     http_port: 8081
     advertise_uri: localhost:3301

   my_app.instance-2:
     http_port: 8082
     advertise_uri: localhost:3302
   ```

   See details here.

5. Start Tarantool instances with the corresponding services. You can do it using systemctl, for example:

   ```
   # starts a single instance
   $ systemctl start my_app

   # starts multiple instances
   $ systemctl start my_app@router
   $ systemctl start my_app@storage_A
   $ systemctl start my_app@storage_B
   ```

6. In case it is a cluster-aware application, proceed to deploying the cluster.

Note: If you're migrating your application from local test environment to production, you can re-use your test configuration at this step:

1. In the cluster web interface of the test environment, click Configuration files > Download to save the test configuration.
2. In the cluster web interface of the production environment, click Configuration files > Upload to upload the saved configuration.

Deploying as a tar+gz archive

1. Pack the application into a distributable:

   ```
   $ cartridge pack tgz APP_NAME
   ```

   This will create a tar+gz archive (e.g. ./my_app-0.1.0-1.tgz).

2. Upload the archive to target servers, with tarantool and (optionally) cartridge-cli installed.

3. Extract the archive:

   ```
   $ tar -xzvf APP_NAME-VERSION.tgz
   ```

4. Configure the instance(s). Create a file called /etc/tarantool/conf.d/instances.yml. For example:

   ```
   my_app:
     cluster_cookie: secret-cookie

   my_app.instance-1:
     http_port: 8081
     advertise_uri: localhost:3301

   my_app.instance-2:
     http_port: 8082
     advertise_uri: localhost:3302
   ```

   See details here.

5. Start Tarantool instance(s). You can do it using:

   - tarantool, for example:

     ```
     $ tarantool init.lua # starts a single instance
     ```

   - or cartridge, for example:

     ```
     # in application directory
     $ cartridge start # starts all instances
     $ cartridge start .router_1 # starts a single instance

     # in multi-application environment
     $ cartridge start my_app # starts all instances of my_app
     $ cartridge start my_app.router # starts a single instance
     ```

6. In case it is a cluster-aware application, proceed to deploying the cluster.

   Note: If you're migrating your application from local test environment to production, you can re-use your test configuration at this step:

   1. In the cluster web interface of the test environment, click Configuration files > Download to save the test configuration.
   2. In the cluster web interface of the production environment, click Configuration files > Upload to upload the saved configuration.

Deploying from sources

This deployment method is intended for local testing only.

1. Pull all dependencies to the .rocks directory:

   $ tarantoolctl rocks make

2. Configure the instance(s). Create a file called /etc/tarantool/conf.d/instances.yml. For example:

   ```
   my_app:
     cluster_cookie: secret-cookie

   my_app.instance-1:
     http_port: 8081
     advertise_uri: localhost:3301

   my_app.instance-2:
     http_port: 8082
     advertise_uri: localhost:3302
   ```

   See details here.

3. Start Tarantool instance(s). You can do it using:

   - tarantool, for example:

     ```
     $ tarantool init.lua # starts a single instance
     ```

   - or cartridge, for example:

     ```
     # in application directory
     cartridge start # starts all instances
     cartridge start .router_1 # starts a single instance

     # in multi-application environment
     cartridge start my_app # starts all instances of my_app
     cartridge start my_app.router # starts a single instance
     ```

4. In case it is a cluster-aware application, proceed to deploying the cluster.

   Note: If you're migrating your application from local test environment to production, you can re-use your test configuration at this step:

   1. In the cluster web interface of the test environment, click Configuration files > Download to save the test configuration.
   2. In the cluster web interface of the production environment, click Configuration files > Upload to upload the saved configuration.

Starting/stopping instances

Depending on your deployment method, you can start/stop the instances using tarantool, cartridge CLI, or systemctl.

Start/stop using tarantool

With tarantool, you can start only a single instance:

```
$ tarantool init.lua # the simplest command
```

You can also specify more options on the command line or in environment variables.

To stop the instance, use Ctrl+C.

Start/stop using cartridge CLI

With cartridge CLI, you can start one or multiple instances:

```
$ cartridge start [APP_NAME[.INSTANCE_NAME]] [options]
```

The options are:

--script FILE Application's entry point. Defaults to:

- TARANTOOL_SCRIPT, or
- ./init.lua when running from the app's directory, or
- :apps_path/:app_name/init.lua in a multi-app environment.

--apps_path PATH Path to apps directory when running in a multi-app environment. Defaults to /usr/share/tarantool.

--run_dir DIR Directory with pid and sock files. Defaults to TARANTOOL_RUN_DIR or /var/run/tarantool.

--cfg FILE Cartridge instances YAML configuration file. Defaults to TARANTOOL_CFG or ./instances.yml. The instances.yml file contains cartridge.cfg() parameters described in the configuration section of this guide.

--foreground Do not daemonize.

For example:

```
cartridge start my_app --cfg demo.yml --run_dir ./tmp/run --foreground
```

It starts all tarantool instances specified in cfg file, in foreground, with enforced environment variables.

When APP_NAME is not provided, cartridge parses it from ./*.rockspec filename.

When INSTANCE_NAME is not provided, cartridge reads cfg file and starts all defined instances:

```
# in application directory
cartridge start # starts all instances
cartridge start .router_1 # start single instance

# in multi-application environment
cartridge start my_app # starts all instances of my_app
cartridge start my_app.router # start a single instance
```

To stop the instances, say:

```
$ cartridge stop [APP_NAME[.INSTANCE_NAME]] [options]
```

These options from the cartridge start command are supported:

- --run_dir DIR
- --cfg FILE

Start/stop using systemctl

- To run a single instance:

  ```
  $ systemctl start APP_NAME
  ```

  This will start a systemd service that will listen to the port specified in instance configuration (http_port parameter).

- To run multiple instances on one or multiple servers:

  ```
  $ systemctl start APP_NAME@INSTANCE_1
  $ systemctl start APP_NAME@INSTANCE_2
  ...
  $ systemctl start APP_NAME@INSTANCE_N
  ```

  where APP_NAME@INSTANCE_N is the instantiated service name for systemd with an incremental N – a number, unique for every instance, added to the port the instance will listen to (e.g., 3301, 3302, etc.)

- To stop all services on a server, use the systemctl stop command and specify instance names one by one. For example:

  ```
  $ systemctl stop APP_NAME@INSTANCE_1 APP_NAME@INSTANCE_2 ... APP_
  ↪NAME@INSTANCE_<N>
  ```

When running instances with systemctl, keep these practices in mind:

- You can specify instance configuration in a YAML file.

  This file can contain these options; see an example here).

  Save this file to /etc/tarantool/conf.d/ (the default systemd path) or to a location set in the TARANTOOL_CFG environment variable (if you've edited the application's systemd unit file). The file name doesn't matter: it can be instances.yml or anything else you like.

  Here's what systemd is doing further:

  – obtains app_name (and instance_name, if specified) from the name of the application's systemd unit file (e.g. APP_NAME@default or APP_NAME@INSTANCE_1);

  – sets default console socket (e.g. /var/run/tarantool/APP_NAME@INSTANCE_1.control), PID file (e.g. /var/run/tarantool/APP_NAME@INSTANCE_1.pid) and workdir (e.g. /var/lib/tarantool/<APP_NAME>.<INSTANCE_NAME>). Environment=TARANTOOL_WORKDIR=${workdir}.%i

  Finally, cartridge looks across all YAML files in /etc/tarantool/conf.d for a section with the appropriate name (e.g. app_name that contains common configuration for all instances, and app_name.instance_1 that contain instance-specific configuration). As a result, Cartridge options workdir, console_sock, and pid_file in the YAML file cartridge.cfg become useless, because systemd overrides them.

- The default tool for querying logs is journalctl. For example:

```
# show log messages for a systemd unit named APP_NAME.INSTANCE_1
$ journalctl -u APP_NAME.INSTANCE_1

# show only the most recent messages and continuously print new ones
$ journalctl -f -u APP_NAME.INSTANCE_1
```

If really needed, you can change logging-related box.cfg options in the YAML configuration file: see log and other related options.

Error handling guidelines

Almost all errors in Cartridge follow the return nil, err style, where err is an error object produced by Tarantool's errors module. Cartridge doesn't raise errors except for bugs and functions contracts mismatch. Developing new roles should follow these guidelines as well.

Error objects in Lua

Error classes help to locate the problem's source. For this purpose, an error object contains its class, stack traceback, and a message.

```lua
local errors = require('errors')
local DangerousError = errors.new_class("DangerousError")

local function some_fancy_function()

    local something_bad_happens = true

    if something_bad_happens then
        return nil, DangerousError:new("Oh boy")
    end

    return "success" -- not reachable due to the error
end

print(some_fancy_function())
```

```
nil DangerousError: Oh boy
stack traceback:
    test.lua:9: in function 'some_fancy_function'
    test.lua:15: in main chunk
```

For uniform error handling, errors provides the :pcall API:

```lua
local ret, err = DangerousError:pcall(some_fancy_function)
print(ret, err)
```

```
nil DangerousError: Oh boy
stack traceback:
    test.lua:9: in function <test.lua:4>
    [C]: in function 'xpcall'
    .rocks/share/tarantool/errors.lua:139: in function 'pcall'
    test.lua:15: in main chunk
```

`lua print(DangerousError:pcall(error, 'what could possibly go wrong?')) `

```
nil DangerousError: what could possibly go wrong?
stack traceback:
    [C]: in function 'xpcall'
    .rocks/share/tarantool/errors.lua:139: in function 'pcall'
    test.lua:15: in main chunk
```

For errors.pcall there is no difference between the return nil, err and error() approaches.

Note that errors.pcall API differs from the vanilla Lua pcall. Instead of true the former returns values returned from the call. If there is an error, it returns nil instead of false, plus an error message.

Remote net.box calls keep no stack trace from the remote. In that case, errors.netbox_eval comes to the rescue. It will find a stack trace from local and remote hosts and restore metatables.

```
> conn = require('net.box').connect('localhost:3301')
> print( errors.netbox_eval(conn, 'return nil, DoSomethingError:new("oops")') )
nil     DoSomethingError: oops
stack traceback:
        eval:1: in main chunk
during net.box eval on localhost:3301
stack traceback:
        [string "return print( errors.netbox_eval("]:1: in main chunk
        [C]: in function 'pcall'
```

However, vshard implemented in Tarantool doesn't utilize the errors module. Instead it uses its own errors. Keep this in mind when working with vshard functions.

Data included in an error object (class name, message, traceback) may be easily converted to string using the tostring() function.

GraphQL

GraphQL implementation in Cartridge wraps the errors module, so a typical error response looks as follows:

```
{
    "errors":[{
        "message":"what could possibly go wrong?",
        "extensions":{
            "io.tarantool.errors.stack":"stack traceback: ...",
            "io.tarantool.errors.class_name":"DangerousError"
        }
    }]
}
```

Read more about errors in the GraphQL specification.

If you're going to implement a GraphQL handler, you can add your own extension like this:

```
local err = DangerousError:new('I have extension')
err.graphql_extensions = {code = 403}
```

It will lead to the following response:

```
{
    "errors":[{
        "message":"I have extension",
        "extensions":{
```

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```
            "io.tarantool.errors.stack":"stack traceback: ...",
            "io.tarantool.errors.class_name":"DangerousError",
            "code":403
        }
    }]
}
```

HTTP

In a nutshell, an errors object is a table. This means that it can be swiftly represented in JSON. This approach is used by Cartridge to handle errors via http:

```
local err = DangerousError:new('Who would have thought?')

local resp = req:render({
    status = 500,
    headers = {
        ['content-type'] = "application/json; charset=utf-8"
    },
    json = json.encode(err),
})
```

```
{
    "line":27,
    "class_name":"DangerousError",
    "err":"Who would have thought?",
    "file":".../app/roles/api.lua",
    "stack":"stack traceback:..."
}
```

4.3.3 Administrator's guide

This guide explains how to deploy and manage a Tarantool cluster with Tarantool Cartridge.

Note: For more information on managing Tarantool instances, see the server administration section of the Tarantool manual.

Before deploying the cluster, familiarize yourself with the notion of cluster roles and deploy Tarantool instances according to the desired cluster topology.

Deploying the cluster

To deploy the cluster, first, configure your Tarantool instances according to the desired cluster topology, for example:

```
my_app.router: {"advertise_uri": "localhost:3301", "http_port": 8080, "workdir": "./tmp/router"}
my_app.storage_A_master: {"advertise_uri": "localhost:3302", "http_enabled": False, "workdir": "./tmp/
↪storage-a-master"}
my_app.storage_A_replica: {"advertise_uri": "localhost:3303", "http_enabled": False, "workdir": "./tmp/
↪storage-a-replica"}
```

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```
my_app.storage_B_master: {"advertise_uri": "localhost:3304", "http_enabled": False, "workdir": "./tmp/
↪storage-b-master"}
my_app.storage_B_replica: {"advertise_uri": "localhost:3305", "http_enabled": False, "workdir": "./tmp/
↪storage-b-replica"}
```

Then start the instances, for example using cartridge CLI:

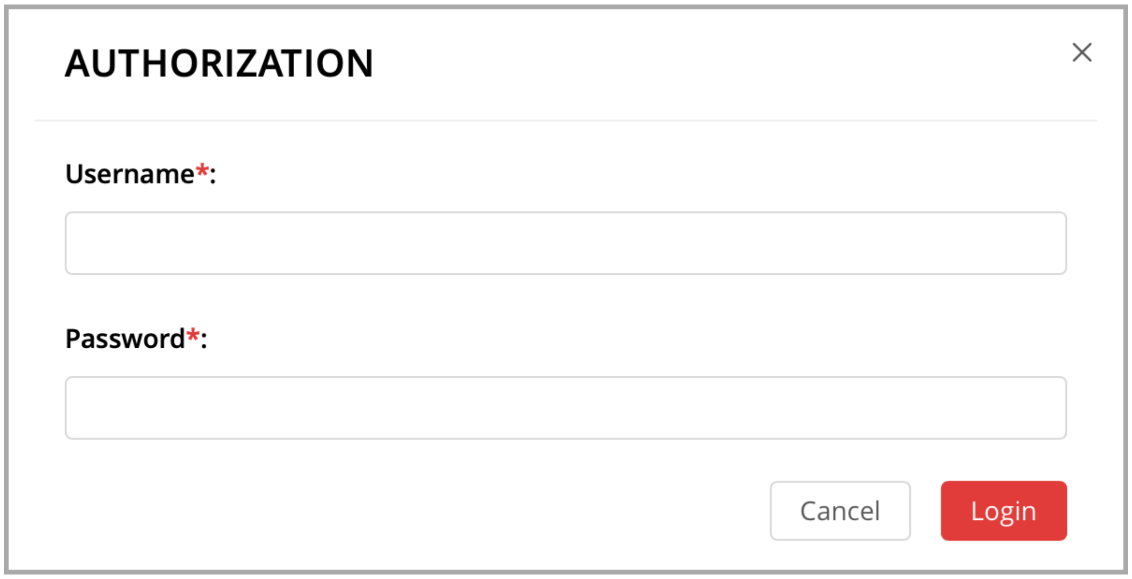
```
cartridge start my_app --cfg demo.yml --run_dir ./tmp/run --foreground
```

And bootstrap the cluster. You can do this via the Web interface which is available at http://<instance_hostname>:<instance_http_port> (in this example, http://localhost:8080).

In the web interface, do the following:

1. Depending on the authentication state:

   - If enabled (in production), enter your credentials and click Login:



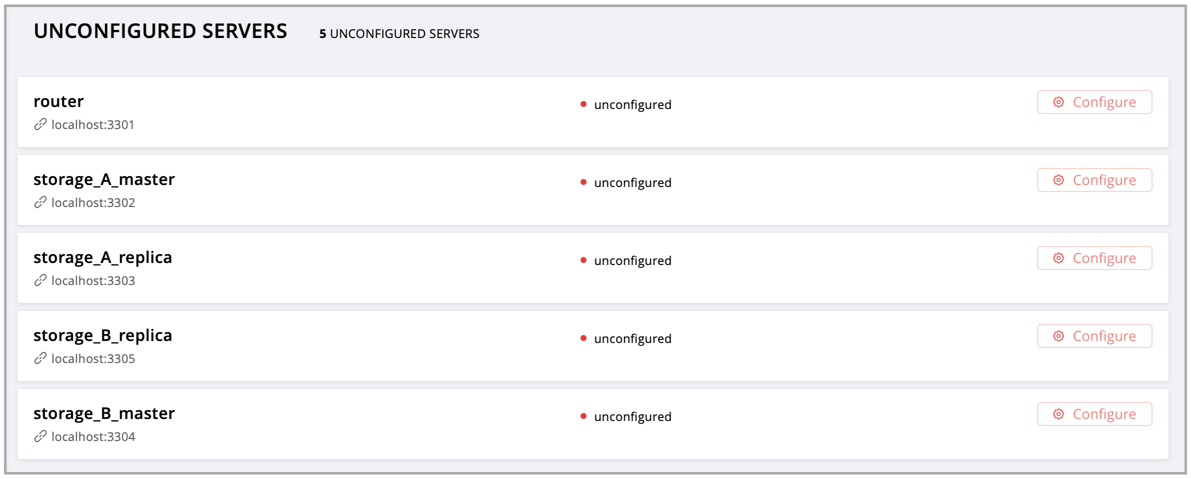
AUTHORIZATION

Username*:

Password*:

   - If disabled (for easier testing), simply proceed to configuring the cluster.

2. Click Configure next to the first unconfigured server to create the first replica set – solely for the router (intended for compute-intensive workloads).

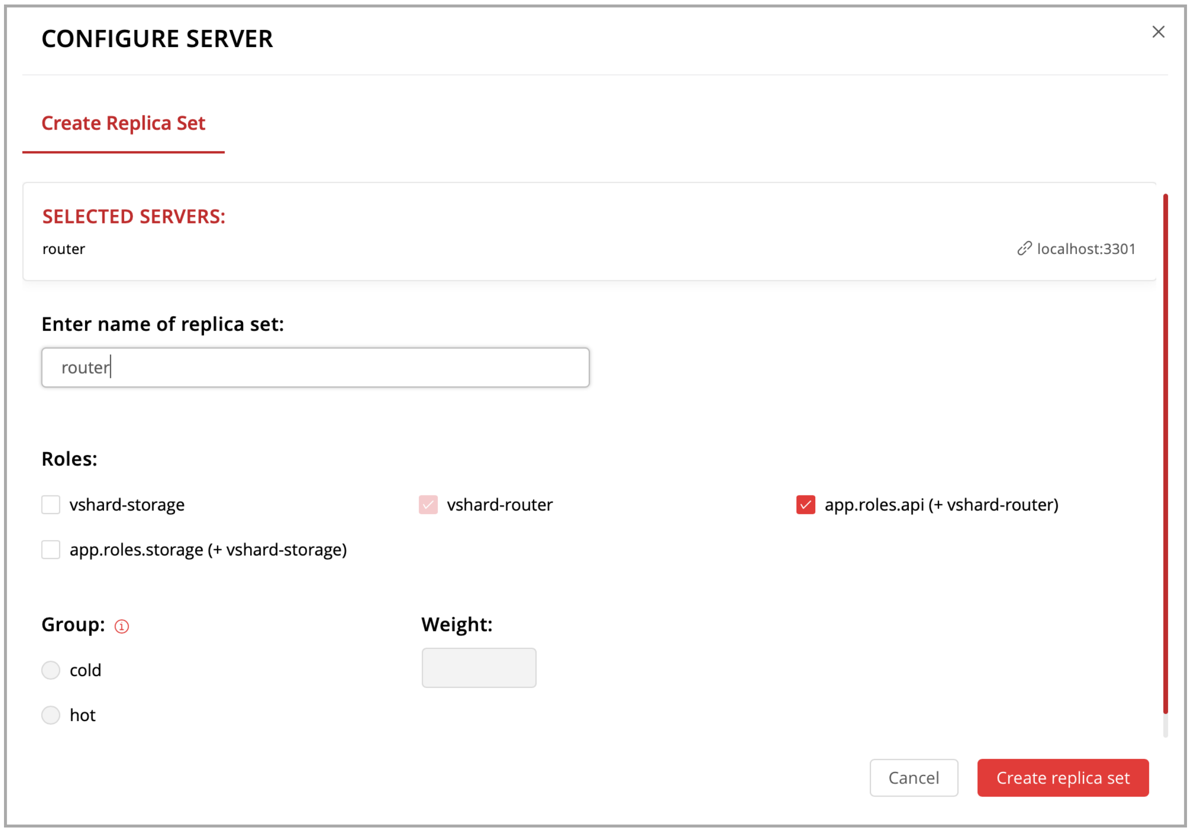


UNCONFIGURED SERVERS   5 UNCONFIGURED SERVERS

router localhost:3301	● unconfigured	Configure
storage_A_master localhost:3302	● unconfigured	Configure
storage_A_replica localhost:3303	● unconfigured	Configure
storage_B_replica localhost:3305	● unconfigured	Configure
storage_B_master localhost:3304	● unconfigured	Configure

In the pop-up window, check the vshard-router role – or any custom role that has vshard-router as a dependent role (in this example, this is a custom role named app.roles.api).

(Optional) Specify a display name for the replica set, for example router.



CONFIGURE SERVER

Create Replica Set

SELECTED SERVERS:

router   localhost:3301

Enter name of replica set: router

Roles:

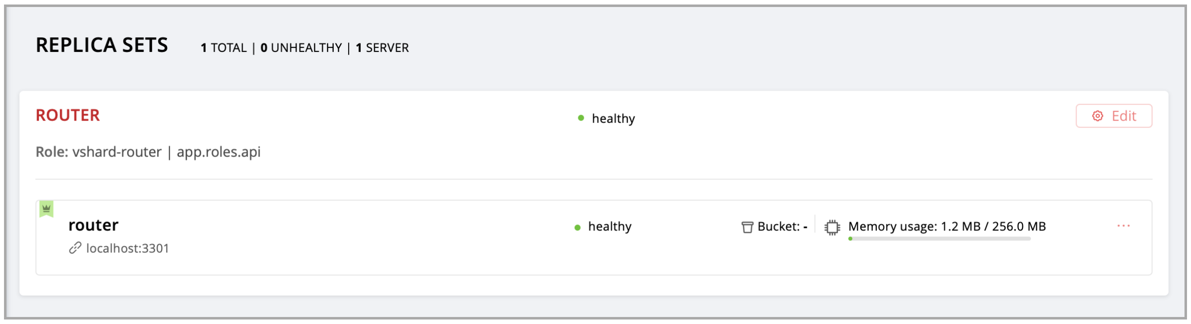
- [ ] vshard-storage
- [✓] vshard-router
- [✓] app.roles.api (+ vshard-router)
- [ ] app.roles.storage (+ vshard-storage)

Group:
- ○ cold
- ○ hot

Weight:

Note: As described in the built-in roles section, it is a good practice to enable workload-specific cluster roles on instances running on physical servers with workload-specific hardware.

Click Create replica set and see the newly-created replica set in the web interface:


REPLICA SETS 1 TOTAL | 0 UNHEALTHY | 1 SERVER

ROUTER ● healthy Edit

Role: vshard-router | app.roles.api

router ● healthy Bucket: - Memory usage: 1.2 MB / 256.0 MB

localhost:3301

> Warning: Be careful: after an instance joins a replica set, you CAN NOT revert this or make the instance join any other replica set.

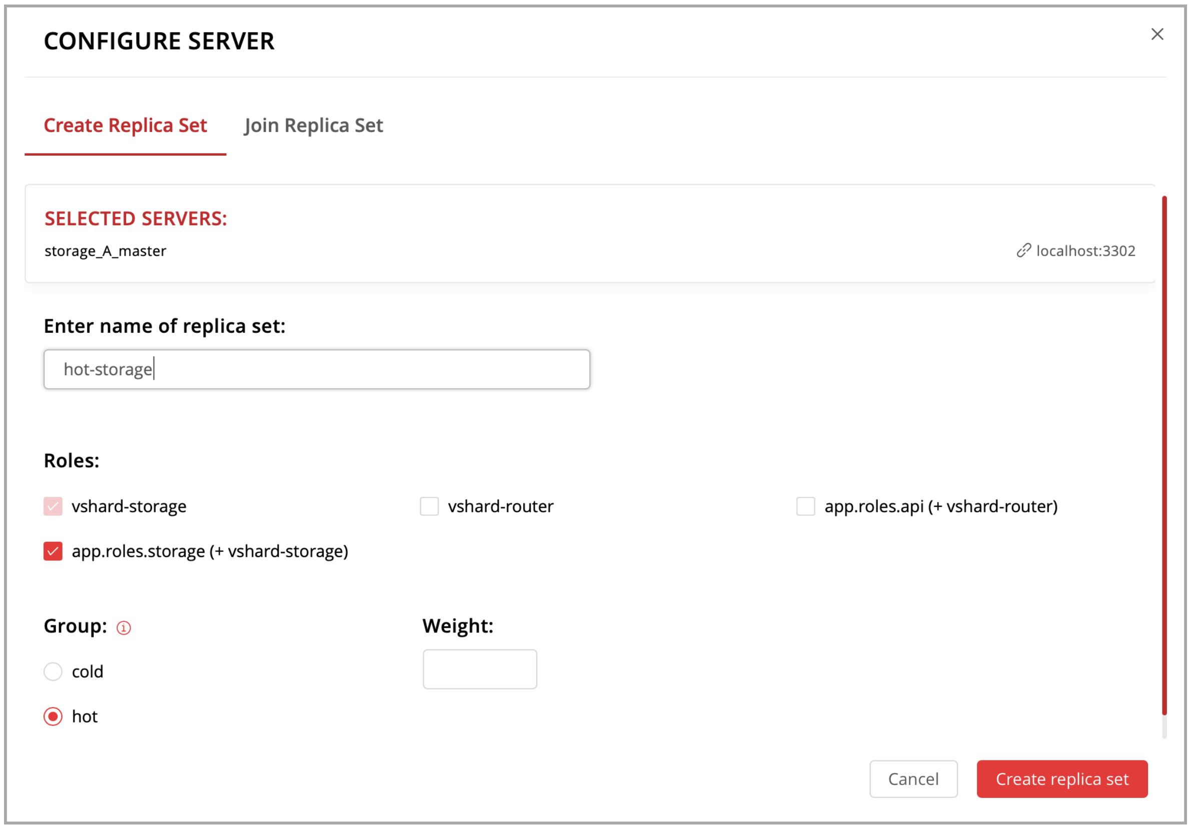
3. Create another replica set – for a master storage node (intended for transaction-intensive workloads).

   Check the vshard-storage role – or any custom role that has vshard-storage as a dependent role (in this example, this is a custom role named app.roles.storage).

   (Optional) Check a specific group, for example hot. Replica sets with vshard-storage roles can belong to different groups. In our example, these are hot or cold groups meant to process hot and cold data independently. These groups are specified in the cluster's configuration file; by default, a cluster has no groups.

   (Optional) Specify a display name for the replica set, for example hot-storage.

   Click Create replica set.


CONFIGURE SERVER

Create Replica Set | Join Replica Set

SELECTED SERVERS:

storage_A_master — localhost:3302

Enter name of replica set: hot-storage

Roles:

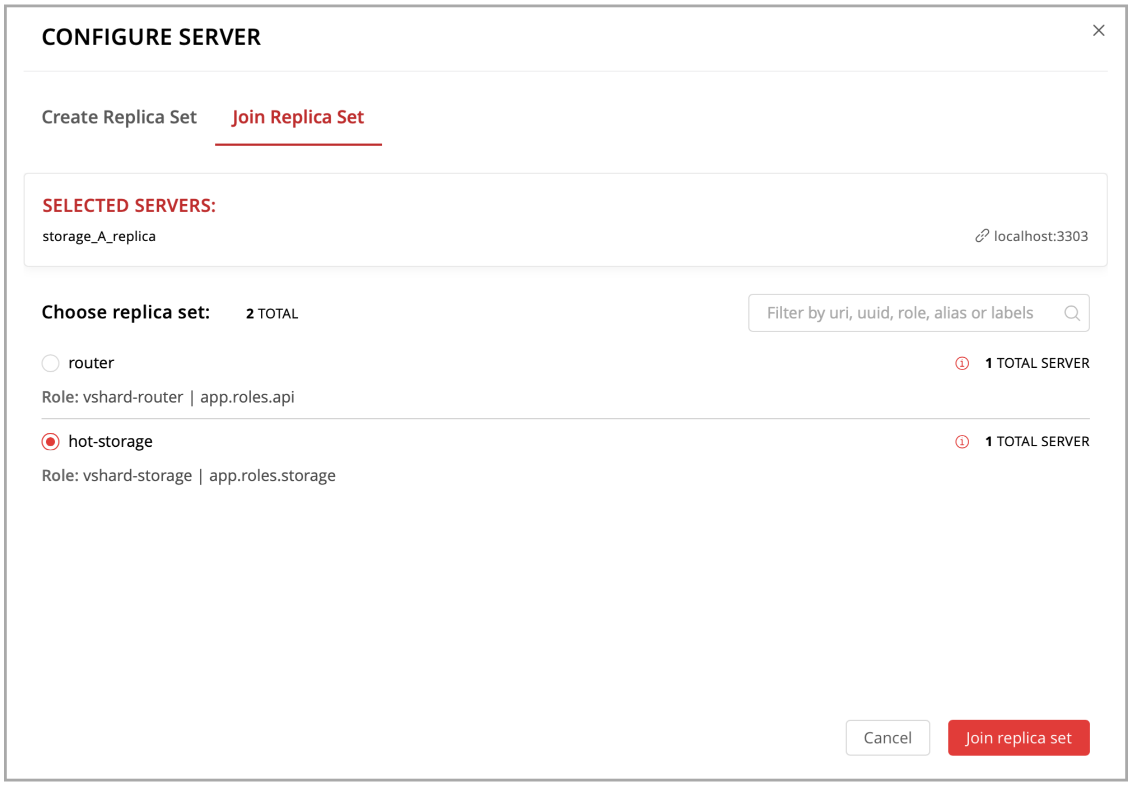
[✓ vshard-storage] vshard-router app.roles.api (+ vshard-router)

[✓ app.roles.storage (+ vshard-storage)]

Group: cold [✓ hot]

Weight:

4. (Optional) If required by topology, populate the second replica set with more storage nodes:
   1. Click Configure next to another unconfigured server dedicated for transaction-intensive workloads.
   2. Click Join Replica Set tab.
   3. Select the second replica set, and click Join replica set to add the server to it.


CONFIGURE SERVER

Create Replica Set | Join Replica Set

SELECTED SERVERS:
storage_A_replica localhost:3303

Choose replica set: 2 TOTAL

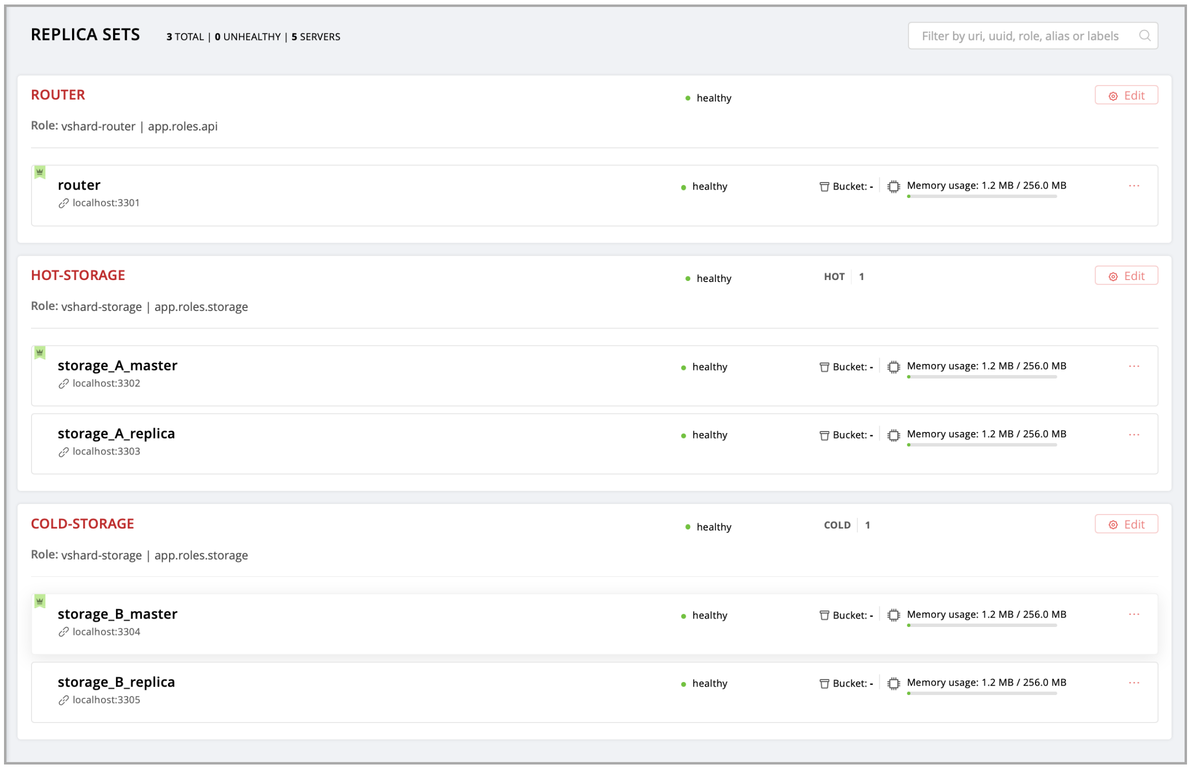
Filter by uri, uuid, role, alias or labels

○ router — 1 TOTAL SERVER
Role: vshard-router | app.roles.api

● hot-storage — 1 TOTAL SERVER
Role: vshard-storage | app.roles.storage

5. Depending on cluster topology:
   - add more instances to the first or second replica sets, or
   - create more replica sets and populate them with instances meant to handle a specific type of workload (compute or transactions).

   For example:


REPLICA SETS 3 TOTAL | 0 UNHEALTHY | 5 SERVERS

ROUTER ● healthy Edit
Role: vshard-router | app.roles.api
router localhost:3301 ● healthy Bucket: - Memory usage: 1.2 MB / 256.0 MB

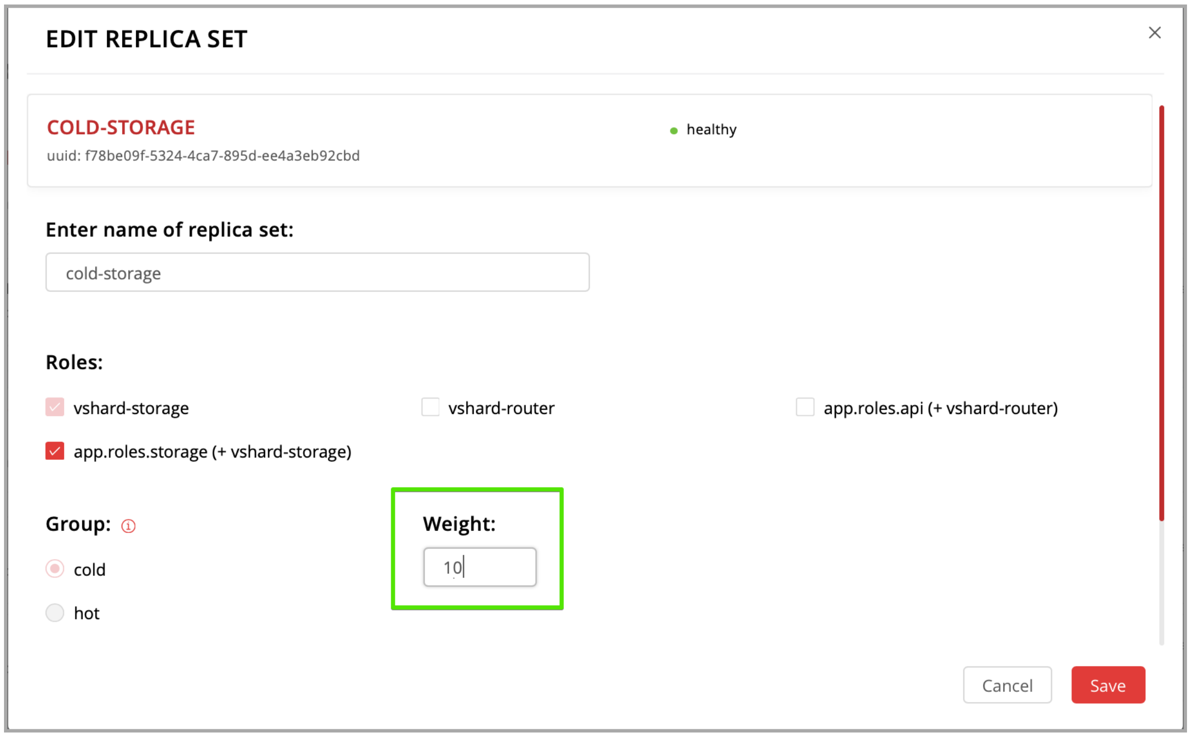
HOT-STORAGE ● healthy HOT 1 Edit
Role: vshard-storage | app.roles.storage
storage_A_master localhost:3302 ● healthy Bucket: - Memory usage: 1.2 MB / 256.0 MB
storage_A_replica localhost:3303 ● healthy Bucket: - Memory usage: 1.2 MB / 256.0 MB

COLD-STORAGE ● healthy COLD 1 Edit
Role: vshard-storage | app.roles.storage
storage_B_master localhost:3304 ● healthy Bucket: - Memory usage: 1.2 MB / 256.0 MB
storage_B_replica localhost:3305 ● healthy Bucket: - Memory usage: 1.2 MB / 256.0 MB

6. (Optional) By default, all new vshard-storage replica sets get a weight of 1 before the vshard bootstrap in the next step.

   Note: In case you add a new replica set after vshard bootstrap, as described in the topology change section, it will get a weight of 0 by default.

   To make different replica sets store different numbers of buckets, click Edit next to a replica set, change its default weight, and click Save:


EDIT REPLICA SET

COLD-STORAGE ● healthy
uuid: f78be09f-5324-4ca7-895d-ee4a3eb92cbd

Enter name of replica set:
cold-storage

Roles:
✓ vshard-storage ☐ vshard-router ☐ app.roles.api (+ vshard-router)
✓ app.roles.storage (+ vshard-storage)

Group: [✓ cold] hot

Weight:
10

For more information on buckets and replica set's weights, see the vshard module documentation.

7. Bootstrap vshard by clicking the corresponding button, or by saying cartridge.admin. boostrap_vshard() over the administrative console.

   This command creates virtual buckets and distributes them among storages.

   From now on, all cluster configuration can be done via the web interface.

Updating the configuration

Cluster configuration is specified in a YAML configuration file. This file includes cluster topology and role descriptions.

All instances in Tarantool cluster have the same configuration. To this end, every instance stores a copy of the configuration file, and the cluster keeps these copies in sync: as you submit updated configuration in the Web interface, the cluster validates it (and rejects inappropriate changes) and distributes automatically across the cluster.

To update the configuration:

1. Click Configuration files tab.
2. (Optional) Click Downloaded to get hold of the current configuration file.
3. Update the configuration file.

   You can add/change/remove any sections except system ones: topology, vshard, and vshard_groups.

   To remove a section, simply remove it from the configuration file.
4. Compress the configuration file as a .zip archive and click Upload configuration button to upload it.

You will see a message in the lower part of the screen saying whether configuration was uploaded successfully, and an error description if the new configuration was not applied.

Managing the cluster

This chapter explains how to:

- change the cluster topology,
- enable automatic failover,
- switch the replica set's master manually,
- deactivate replica sets, and
- expel instances.

Changing the cluster topology

Upon adding a newly deployed instance to a new or existing replica set:

1. The cluster validates the configuration update by checking if the new instance is available using the membership module.

   Note: The membership module works over the UDP protocol and can operate before the box.cfg function is called.

   All the nodes in the cluster must be healthy for validation success.

2. The new instance waits until another instance in the cluster receives the configuration update and discovers it, again, using the membership module. On this step, the new instance does not have a UUID yet.

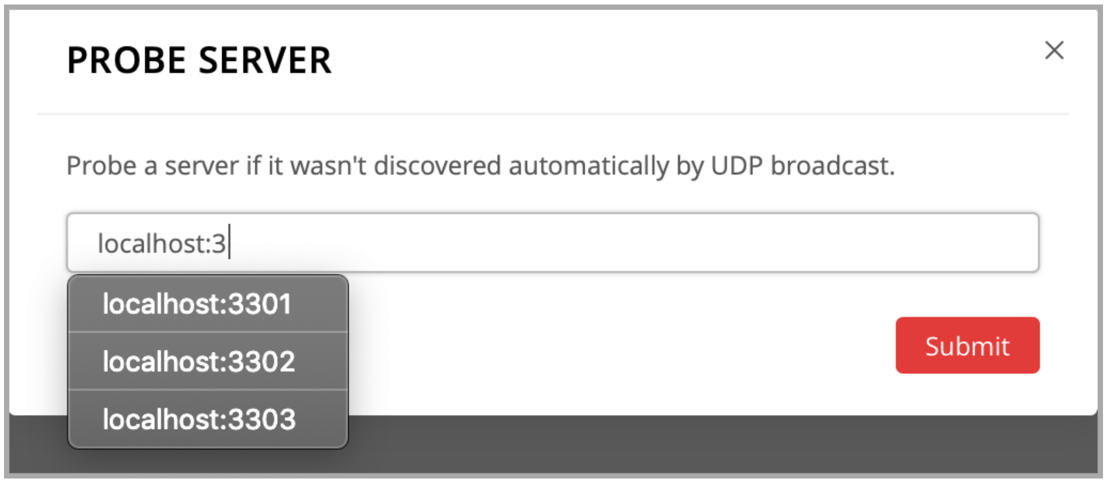
3. Once the instance realizes its presence is known to the cluster, it calls the box.cfg function and starts living its life.

An optimal strategy for connecting new nodes to the cluster is to deploy a new zero-weight replica set instance by instance, and then increase the weight. Once the weight is updated and all cluster nodes are notified of the configuration change, buckets start migrating to new nodes.

To populate the cluster with more nodes, do the following:

1. Deploy new Tarantool instances as described in the deployment section.

   If new nodes do not appear in the Web interface, click Probe server and specify their URIs manually.



PROBE SERVER

Probe a server if it wasn't discovered automatically by UDP broadcast.

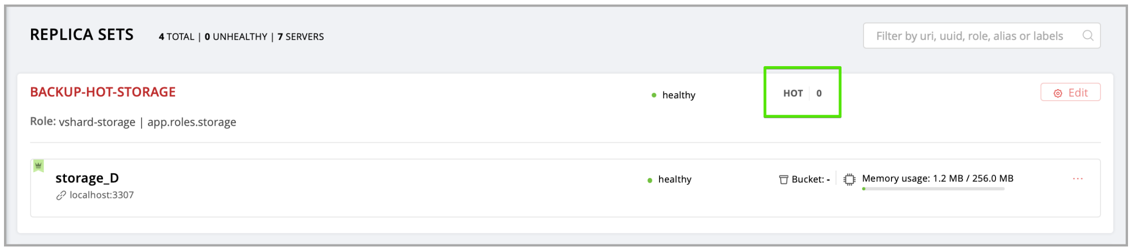
localhost:3

If a node is accessible, it will appear in the list.

2. In the Web interface:

   - Create a new replica set with one of the new instances: click Configure next to an unconfigured server, check the necessary roles, and click Create replica set:

     Note: In case you are adding a new vshard-storage instance, remember that all such instances get a 0 weight by default after the vshard bootstrap which happened during the initial cluster deployment.

     REPLICA SETS 4 TOTAL | 0 UNHEALTHY | 7 SERVERS

     BACKUP-HOT-STORAGE ● healthy HOT 0

     Role: vshard-storage | app.roles.storage

     storage_D ● healthy Bucket: - Memory usage: 1.2 MB / 256.0 MB

     localhost:3307

   - Or add the instances to existing replica sets: click Configure next to an unconfigured server, click Join replica set tab, select a replica set, and click Join replica set.

   If necessary, repeat this for more instances to reach the desired redundancy level.

3. In case you are deploying a new vshard-storage replica set, populate it with data when you are ready: click Edit next to the replica set in question, increase its weight, and click Save to start data rebalancing.

As an alternative to the web interface, you can view and change cluster topology via GraphQL. The cluster's endpoint for serving GraphQL queries is /admin/api. You can use any third-party GraphQL client like GraphiQL or Altair.

Examples:

- listing all servers in the cluster:

```
query {
    servers { alias uri uuid }
}
```

- listing all replica sets with their servers:

```
query {
    replicasets {
        uuid
        roles
        servers { uri uuid }
    }
}
```

- joining a server to a new replica set with a storage role enabled:

```
mutation {
    join_server(
        uri: "localhost:33003"
        roles: ["vshard-storage"]
    )
}
```

Data rebalancing

Rebalancing (resharding) is initiated periodically and upon adding a new replica set with a non-zero weight to the cluster. For more information, see the rebalancing process section of the vshard module documentation.

The most convenient way to trace through the process of rebalancing is to monitor the number of active buckets on storage nodes. Initially, a newly added replica set has 0 active buckets. After a few minutes, the background rebalancing process begins to transfer buckets from other replica sets to the new one. Rebalancing continues until the data is distributed evenly among all replica sets.

To monitor the current number of buckets, connect to any Tarantool instance over the administrative console, and say:

```
tarantool> vshard.storage.info().bucket
---
- receiving: 0
  active: 1000
  total: 1000
  garbage: 0
  sending: 0
...
```

The number of buckets may be increasing or decreasing depending on whether the rebalancer is migrating buckets to or from the storage node.

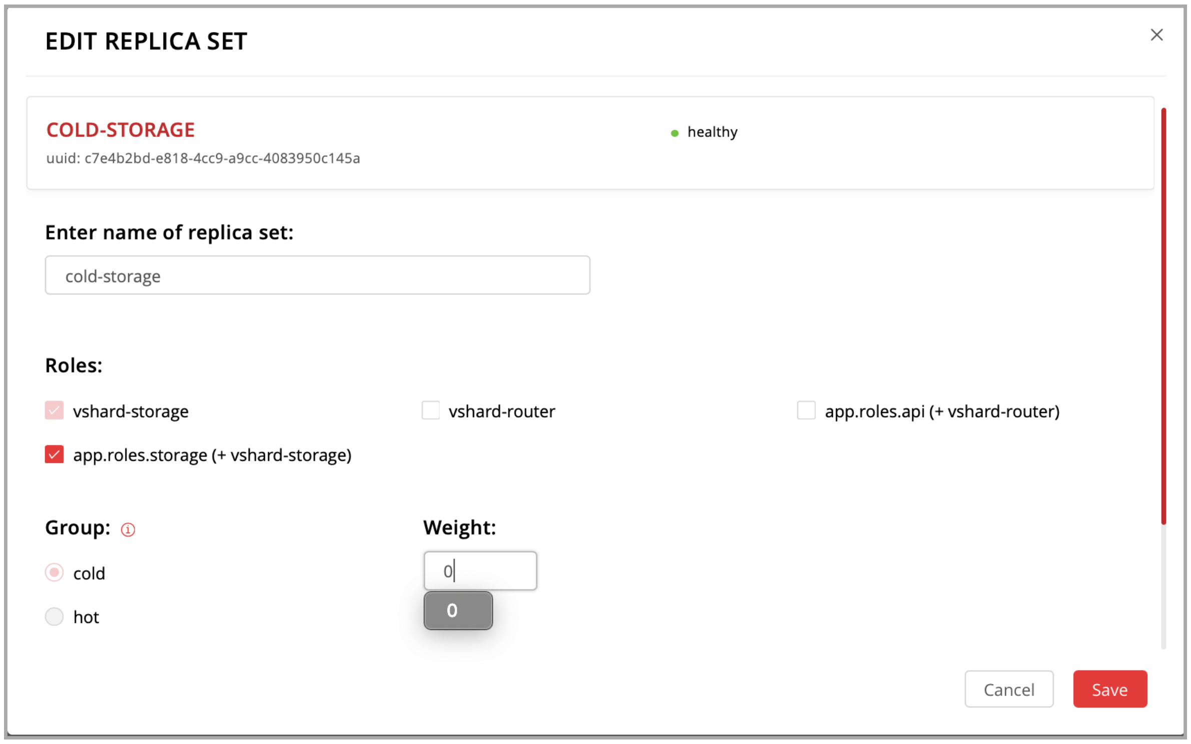
For more information on the monitoring parameters, see the monitoring storages section.

Deactivating replica sets

To deactivate an entire replica set (e.g., to perform maintenance on it) means to move all of its buckets to other sets.

To deactivate a set, do the following:

1. Click Edit next to the set in question.
2. Set its weight to 0 and click Save:


EDIT REPLICA SET

COLD-STORAGE ● healthy
uuid: c7e4b2bd-e818-4cc9-a9cc-4083950c145a

Enter name of replica set:
cold-storage

Roles:
[✓ vshard-storage] vshard-router app.roles.api (+ vshard-router)
[✓ app.roles.storage (+ vshard-storage)]

Group: [✓ cold] hot

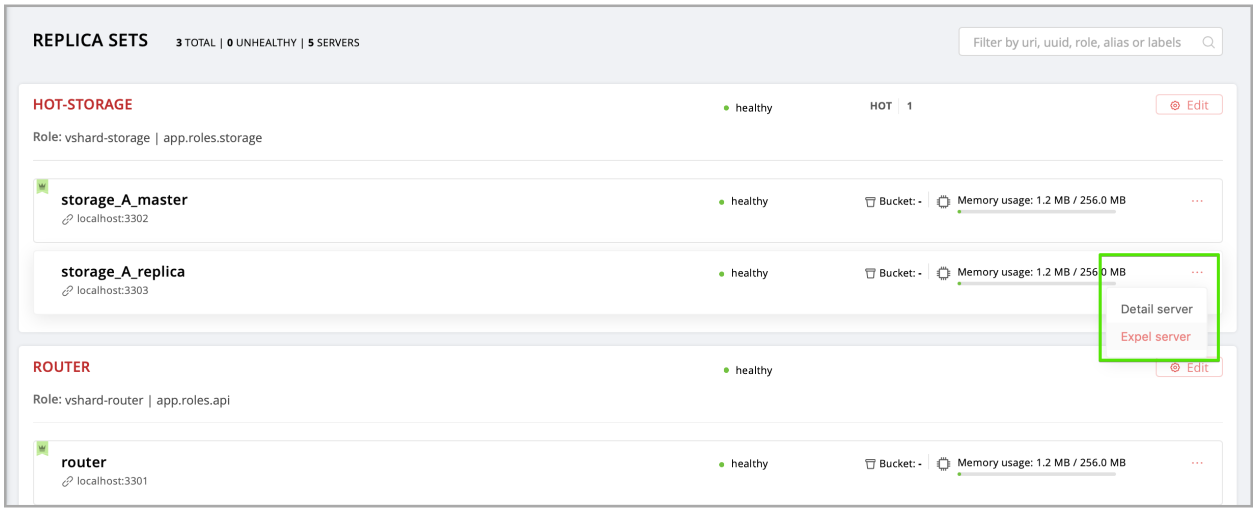
Weight: 0

3. Wait for the rebalancing process to finish migrating all the set's buckets away. You can monitor the current bucket number as described in the data rebalancing section.

Expelling instances

Once an instance is expelled, it can never participate in the cluster again as every instance will reject it.

To expel an instance, click ... next to it, then click Expel server and Expel:


REPLICA SETS 3 TOTAL | 0 UNHEALTHY | 5 SERVERS

HOT-STORAGE ● healthy HOT 1
Role: vshard-storage | app.roles.storage

storage_A_master localhost:3302 ● healthy Bucket: - Memory usage: 1.2 MB / 256.0 MB

storage_A_replica localhost:3303 ● healthy Bucket: - Memory usage: 1.2 MB / 256.0 MB

ROUTER ● healthy
Role: vshard-router | app.roles.api

router localhost:3301 ● healthy Bucket: - Memory usage: 1.2 MB / 256.0 MB

Note: There are two restrictions:

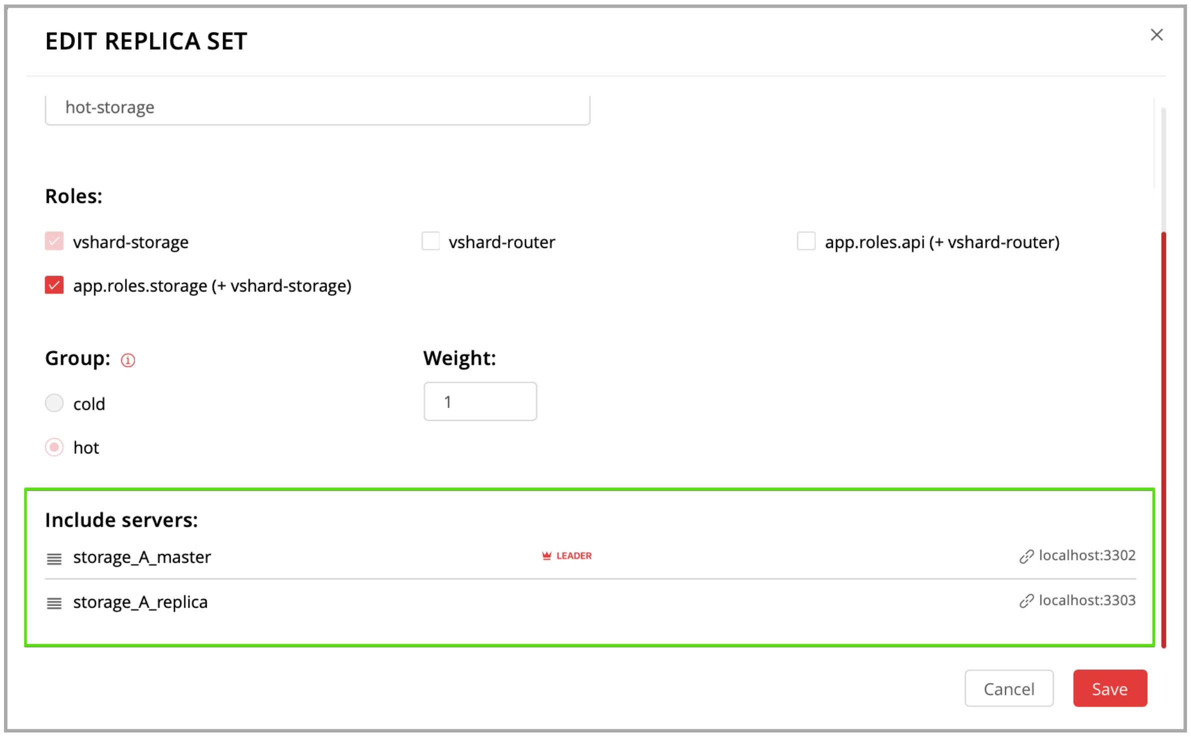
- You can't expel a leader if it has a replica. Switch leadership first.
- You can't expel a vshard-storage if it has buckets. Set the weight to zero and wait until rebalancing is completed.

Enabling automatic failover

In a master-replica cluster configuration with automatic failover enabled, if the user-specified master of any replica set fails, the cluster automatically chooses the next replica from the priority list and grants it the active master role (read/write). When the failed master comes back online, its role is restored and the active master, again, becomes a replica (read-only). This works for any roles.

To set the priority in a replica set:

1. Click Edit next to the replica set in question.
2. Scroll to the bottom of the Edit replica set box to see the list of servers.
3. Drag replicas to their place in the priority list, and click Save:



EDIT REPLICA SET

hot-storage

Roles:

- [✓] vshard-storage
- [ ] vshard-router
- [ ] app.roles.api (+ vshard-router)
- [✓] app.roles.storage (+ vshard-storage)

Group: cold [✓ hot]

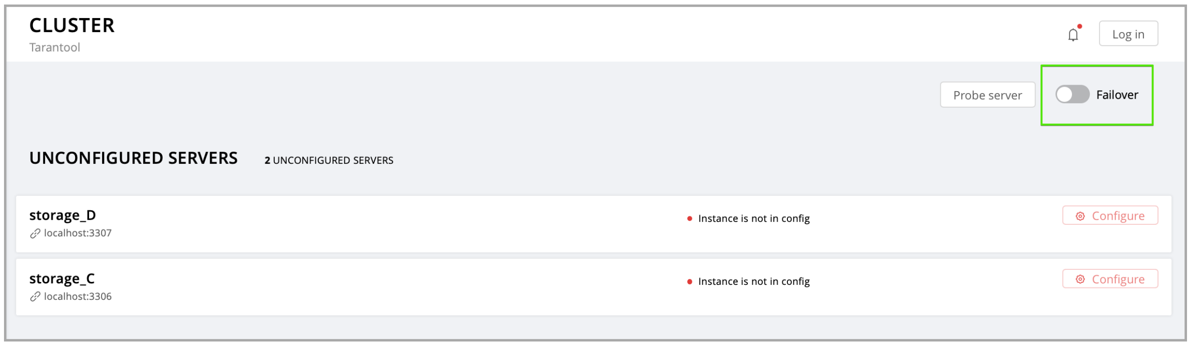
Weight: 1

Include servers:

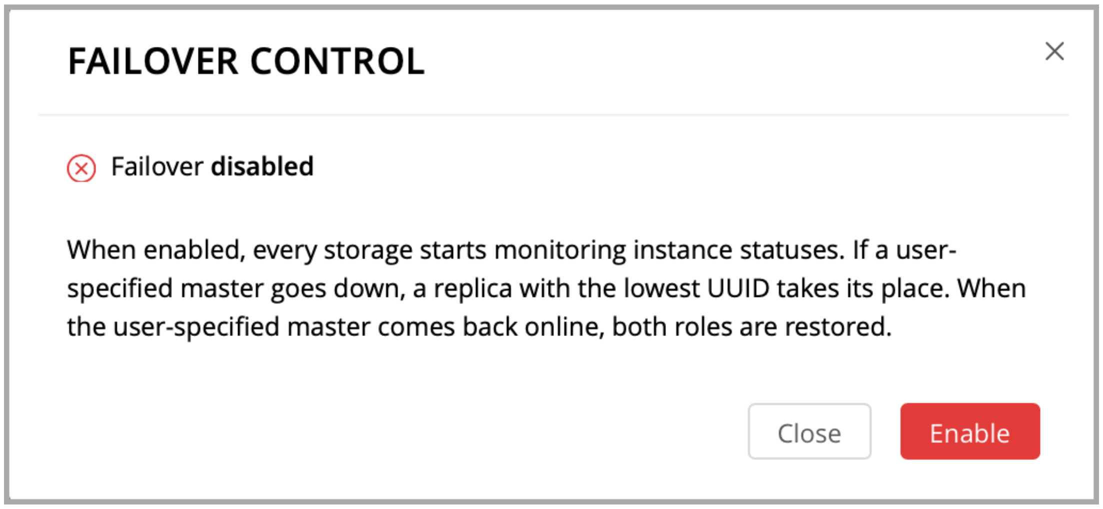
storage_A_master	LEADER	localhost:3302
storage_A_replica		localhost:3303

The failover is disabled by default. To enable it:

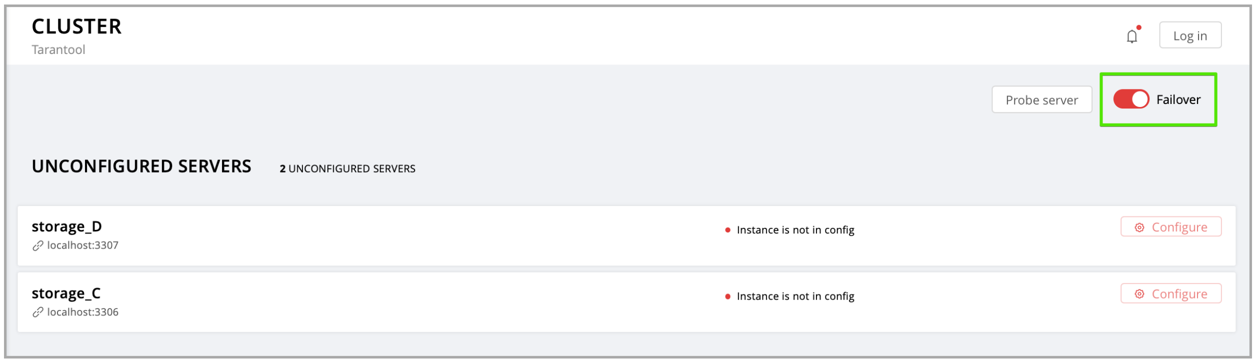
1. Click Failover:


CLUSTER
Tarantool
Log in
Probe server
Failover
UNCONFIGURED SERVERS 2 UNCONFIGURED SERVERS
storage_D
localhost:3307
● Instance is not in config
Configure
storage_C
localhost:3306
● Instance is not in config
Configure

2. In the Failover control box, click Enable:


FAILOVER CONTROL
Failover **disabled**
When enabled, every storage starts monitoring instance statuses. If a user-specified master goes down, a replica with the lowest UUID takes its place. When the user-specified master comes back online, both roles are restored.
Close
Enable

The failover status will change to enabled:

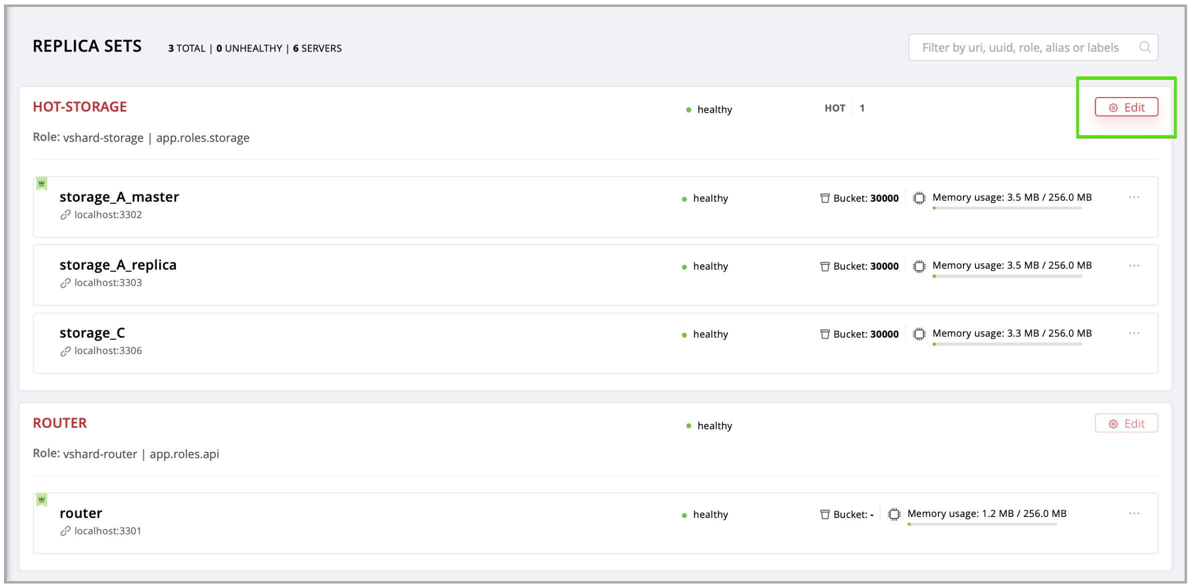

CLUSTER
Tarantool
Log in
Probe server
Failover
UNCONFIGURED SERVERS 2 UNCONFIGURED SERVERS
storage_D
localhost:3307
● Instance is not in config
Configure
storage_C
localhost:3306
● Instance is not in config
Configure

For more information, see the replication section of the Tarantool manual.

Switching the replica set's master

To manually switch the master in a replica set:

1. Click the Edit button next to the replica set in question:



REPLICA SETS 3 TOTAL | 0 UNHEALTHY | 6 SERVERS

Filter by uri, uuid, role, alias or labels

HOT-STORAGE ● healthy HOT 1 Edit

Role: vshard-storage | app.roles.storage

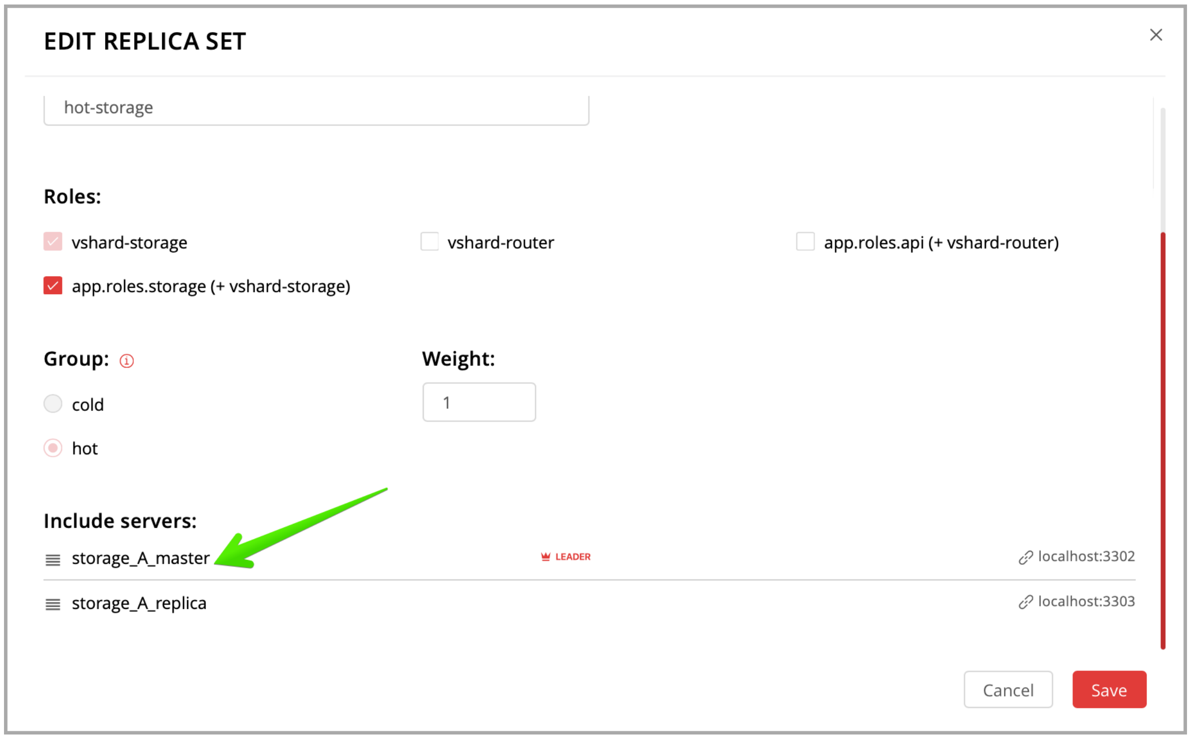
storage_A_master localhost:3302	● healthy	Bucket: 30000	Memory usage: 3.5 MB / 256.0 MB
storage_A_replica localhost:3303	● healthy	Bucket: 30000	Memory usage: 3.5 MB / 256.0 MB
storage_C localhost:3306	● healthy	Bucket: 30000	Memory usage: 3.3 MB / 256.0 MB

ROUTER ● healthy Edit

Role: vshard-router | app.roles.api

router localhost:3301	● healthy	Bucket: -	Memory usage: 1.2 MB / 256.0 MB

2. Scroll to the bottom of the Edit replica set box to see the list of servers. The server on the top is the master.



EDIT REPLICA SET

hot-storage

Roles:

[✓ vshard-storage] vshard-router app.roles.api (+ vshard-router)

[✓ app.roles.storage (+ vshard-storage)]

Group: cold [✓ hot]

Weight: 1

Include servers:

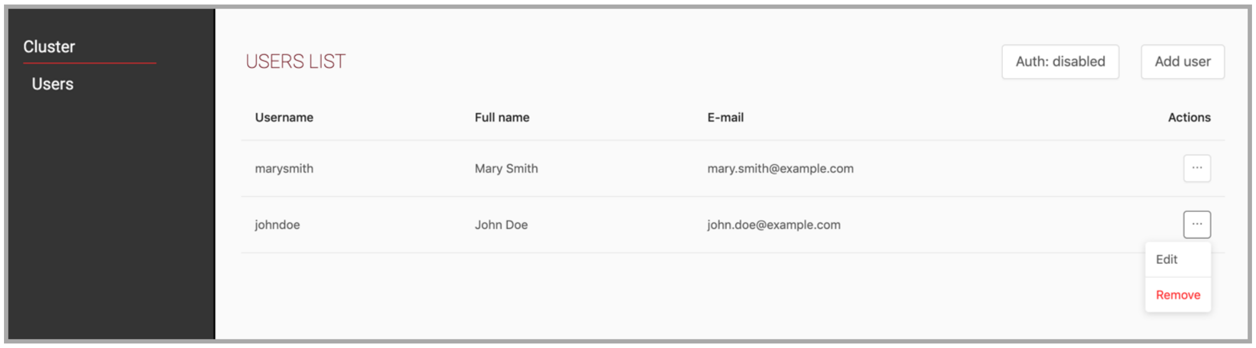
storage_A_master	LEADER	localhost:3302
storage_A_replica		localhost:3303

3. Drag a required server to the top position and click Save.

The new master will automatically enter the read/write mode, while the ex-master will become read-only. This works for any roles.

Managing users

On the Users tab, you can enable/disable authentication as well as add, remove, edit, and view existing users who can access the web interface.



Username	Full name	E-mail	Actions
marysmith	Mary Smith	mary.smith@example.com	···
johndoe	John Doe	john.doe@example.com	···

Notice that the Users tab is available only if authorization in the web interface is implemented.

Also, some features (like deleting users) can be disabled in the cluster configuration; this is regulated by the auth_backend_name option passed to cartridge.cfg().

Resolving conflicts

Tarantool has an embedded mechanism for asynchronous replication. As a consequence, records are distributed among the replicas with a delay, so conflicts can arise.

To prevent conflicts, the special trigger space.before_replace is used. It is executed every time before making changes to the table for which it was configured. The trigger function is implemented in the Lua programming language. This function takes the original and new values of the tuple to be modified as its arguments. The returned value of the function is used to change the result of the operation: this will be the new value of the modified tuple.

For insert operations, the old value is absent, so nil is passed as the first argument.

For delete operations, the new value is absent, so nil is passed as the second argument. The trigger function can also return nil, thus turning this operation into delete.

This example shows how to use the space.before_replace trigger to prevent replication conflicts. Suppose we have a box.space.test table that is modified in multiple replicas at the same time. We store one payload field in this table. To ensure consistency, we also store the last modification time in each tuple of this table and set the space.before_replace trigger, which gives preference to newer tuples. Below is the code in Lua:

```
fiber = require('fiber')
-- define a function that will modify the function test_replace(tuple)
        -- add a timestamp to each tuple in the space
        tuple = box.tuple.new(tuple):update{{'!', 2, fiber.time()}}
        box.space.test:replace(tuple)
end
box.cfg{ } -- restore from the local directory
-- set the trigger to avoid conflicts
box.space.test:before_replace(function(old, new)
        if old ~= nil and new ~= nil and new[2] < old[2] then
                return old -- ignore the request
        end
        -- otherwise apply as is
```

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```
end)
box.cfg{ replication = {...} } -- subscribe
```

Monitoring a cluster via CLI

This section describes parameters you can monitor over the administrative console.

Connecting to nodes via CLI

Each Tarantool node (router/storage) provides an administrative console (Command Line Interface) for debugging, monitoring, and troubleshooting. The console acts as a Lua interpreter and displays the result in the human-readable YAML format. To connect to a Tarantool instance via the console, say:

```
$ tarantoolctl connect <instance_hostname>:<port>
```

where the <instance_hostname>:<port> is the instance's URI.

Monitoring storages

Use vshard.storage.info() to obtain information on storage nodes.

Output example

```
tarantool> vshard.storage.info()
---
- replicasets:
    <replicaset_2>:
    uuid: <replicaset_2>
    master:
        uri: storage:storage@127.0.0.1:3303
    <replicaset_1>:
    uuid: <replicaset_1>
    master:
        uri: storage:storage@127.0.0.1:3301
  bucket: <!-- buckets status
    receiving: 0 <!-- buckets in the RECEIVING state
    active: 2 <!-- buckets in the ACTIVE state
    garbage: 0 <!-- buckets in the GARBAGE state (are to be deleted)
    total: 2 <!-- total number of buckets
    sending: 0 <!-- buckets in the SENDING state
  status: 1 <!-- the status of the replica set
  replication:
    status: disconnected <!-- the status of the replication
    idle: <idle>
  alerts:
  - ['MASTER_IS_UNREACHABLE', 'Master is unreachable: disconnected']
```

Status list

Code	Critical level	Description
0	Green	A replica set works in a regular way.
1	Yellow	There are some issues, but they don't affect a replica set efficiency (worth noticing, but don't require immediate intervention).
2	Orange	A replica set is in a degraded state.
3	Red	A replica set is disabled.

Potential issues

- MISSING_MASTER — No master node in the replica set configuration.

  Critical level: Orange.

  Cluster condition: Service is degraded for data-change requests to the replica set.

  Solution: Set the master node for the replica set in the configuration using API.

- UNREACHABLE_MASTER — No connection between the master and the replica.

  Critical level:

  – If idle value doesn't exceed T1 threshold (1 s.) — Yellow,

  – If idle value doesn't exceed T2 threshold (5 s.) — Orange,

  – If idle value exceeds T3 threshold (10 s.) — Red.

  Cluster condition: For read requests to replica, the data may be obsolete compared with the data on master.

  Solution: Reconnect to the master: fix the network issues, reset the current master, switch to another master.

- LOW_REDUNDANCY — Master has access to a single replica only.

  Critical level: Yellow.

  Cluster condition: The data storage redundancy factor is equal to 2. It is lower than the minimal recommended value for production usage.

  Solution: Check cluster configuration:

  – If only one master and one replica are specified in the configuration, it is recommended to add at least one more replica to reach the redundancy factor of 3.

  – If three or more replicas are specified in the configuration, consider checking the replicas' states and network connection among the replicas.

- INVALID_REBALANCING — Rebalancing invariant was violated. During migration, a storage node can either send or receive buckets. So it shouldn't be the case that a replica set sends buckets to one replica set and receives buckets from another replica set at the same time.

  Critical level: Yellow.

  Cluster condition: Rebalancing is on hold.

  Solution: There are two possible reasons for invariant violation:

  – The rebalancer has crashed.

  - Bucket states were changed manually.

  Either way, please contact Tarantool support.

- HIGH_REPLICATION_LAG — Replica's lag exceeds T1 threshold (1 sec.).

  Critical level:

  - If the lag doesn't exceed T1 threshold (1 sec.) — Yellow;
  - If the lag exceeds T2 threshold (5 sec.) — Orange.

  Cluster condition: For read-only requests to the replica, the data may be obsolete compared with the data on the master.

  Solution: Check the replication status of the replica. Further instructions are given in the Tarantool troubleshooting guide.

- OUT_OF_SYNC — Mal-synchronization occured. The lag exceeds T3 threshold (10 sec.).

  Critical level: Red.

  Cluster condition: For read-only requests to the replica, the data may be obsolete compared with the data on the master.

  Solution: Check the replication status of the replica. Further instructions are given in the Tarantool troubleshooting guide.

- UNREACHABLE_REPLICA — One or multiple replicas are unreachable.

  Critical level: Yellow.

  Cluster condition: Data storage redundancy factor for the given replica set is less than the configured factor. If the replica is next in the queue for rebalancing (in accordance with the weight configuration), the requests are forwarded to the replica that is still next in the queue.

  Solution: Check the error message and find out which replica is unreachable. If a replica is disabled, enable it. If this doesn't help, consider checking the network.

- UNREACHABLE_REPLICASET — All replicas except for the current one are unreachable. Critical level: Red.

  Cluster condition: The replica stores obsolete data.

  Solution: Check if the other replicas are enabled. If all replicas are enabled, consider checking network issues on the master. If the replicas are disabled, check them first: the master might be working properly.

Monitoring routers

Use vshard.router.info() to obtain information on the router.

Output example

```
tarantool> vshard.router.info()
---
- replicasets:
    <replica set UUID>:
      master:
        status: <available / unreachable / missing>
```

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```
        uri: <!-- URI of master
        uuid: <!-- UUID of instance
      replica:
        status: <available / unreachable / missing>
        uri: <!-- URI of replica used for slave requests
        uuid: <!-- UUID of instance
      uuid: <!-- UUID of replica set
    <replica set UUID>: ...
    ...
  status: <!-- status of router
  bucket:
    known: <!-- number of buckets with the known destination
    unknown: <!-- number of other buckets
  alerts: [<alert code>, <alert description>], ...
```

Status list

Code	Critical level	Description
0	Green	The router works in a regular way.
1	Yellow	Some replicas sre unreachable (affects the speed of executing read requests).
2	Orange	Service is degraded for changing data.
3	Red	Service is degraded for reading data.

Potential issues

Note: Depending on the nature of the issue, use either the UUID of a replica, or the UUID of a replica set.

- MISSING_MASTER — The master in one or multiple replica sets is not specified in the configuration.

  Critical level: Orange.

  Cluster condition: Partial degrade for data-change requests.

  Solution: Specify the master in the configuration.

- UNREACHABLE_MASTER — The router lost connection with the master of one or multiple replica sets.

  Critical level: Orange.

  Cluster condition: Partial degrade for data-change requests.

  Solution: Restore connection with the master. First, check if the master is enabled. If it is, consider checking the network.

- SUBOPTIMAL_REPLICA — There is a replica for read-only requests, but this replica is not optimal according to the configured weights. This means that the optimal replica is unreachable.

  Critical level: Yellow.

  Cluster condition: Read-only requests are forwarded to a backup replica.

  Solution: Check the status of the optimal replica and its network connection.

- UNREACHABLE_REPLICASET — A replica set is unreachable for both read-only and data-change requests.

  Critical Level: Red.

  Cluster condition: Partial degrade for read-only and data-change requests.

  Solution: The replica set has an unreachable master and replica. Check the error message to detect this replica set. Then fix the issue in the same way as for UNREACHABLE_REPLICA.

Upgrading schema

When upgrading Tarantool to a newer version, please don't forget to:

1. Stop the cluster
2. Make sure that upgrade_schema option is enabled
3. Start the cluster again

This will automatically apply box.schema.upgrade() on the leader, according to the failover priority in the topology configuration.

Disaster recovery

Please see the disaster recovery section in the Tarantool manual.

Backups

Please see the backups section in the Tarantool manual.

4.3.4 Troubleshooting

First of all, see a similar guide in the Tarantool manual. Below you can find other Cartridge-specific problems considered.

Editing clusterwide configuration in WebUI returns an error

Examples:

- NetboxConnectError: "localhost:3302": Connection refused;
- Prepare2pcError: Instance state is OperationError, can't apply config in this state.

The root problem: all cluster instances are equal, and all of them store a copy of clusterwide configuration, which must be the same. If an instance degrades (can't accept new configuration) – the quorum is lost. This prevents further configuration modifications to avoid inconsistency.

But sometimes inconsistency is needed to repair the system, at least partially and temporarily. It can be achieved by disabling degraded instances.

Solution:

1. Connect to the console of the alive instance.

```
tarantoolctl connect unix/:/var/run/tarantool/<app-name>.<instance-name>.control
```

2. Inspect what's going on.

```
cartridge = require('cartridge')
report = {}
for _, srv in pairs(cartridge.admin_get_servers()) do
    report[srv.uuid] = {uri = srv.uri, status = srv.status, message = srv.message}
end
return report
```

3. If you're ready to proceed, run the following snippet. It'll disable all instances which are not healthy. After that, you can use the WebUI as usual.

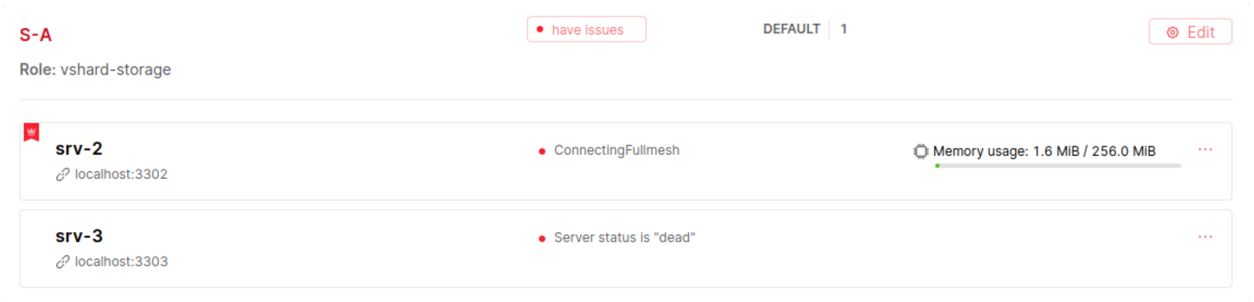
```
disable_list = {}
for uuid, srv in pairs(report) do
    if srv.status ~= 'healthy' then
       table.insert(disable_list, uuid)
    end
end
return cartridge.admin_disable_servers(disable_list)
```

4. When it's necessary to bring disabled instances back, re-enable them in a similar manner:

```
cartridge = require('cartridge')
enable_list = {}
for _, srv in pairs(cartridge.admin_get_servers()) do
    if srv.disabled then
       table.insert(enable_list, srv.uuid)
    end
end
return cartridge.admin_enable_servers(enable_list)
```

An instance is stuck in the ConnectingFullmesh state upon restart

Example:


S-A
Role: vshard-storage
have issues
DEFAULT | 1
Edit
srv-2
localhost:3302
ConnectingFullmesh
Memory usage: 1.6 MiB / 256.0 MiB
srv-3
localhost:3303
Server status is "dead"

The root problem: after restart, the instance tries to connect to all its replicas and remains in the ConnectingFullmesh state until it succeeds. If it can't (due to replica URI unavailability or for any other reason) – it's stuck forever.

Solution:

Set the replication_connect_quorum option to zero. It may be accomplished in two ways:

- By restarting it with the corresponding option set (in environment variables or in the instance configuration file);
- Or without restart – by running the following one-liner:

```
echo "box.cfg({replication_connect_quorum = 0})" | tarantoolctl connect \
unix/:/var/run/tarantool/<app-name>.<instance-name>.control
```

I want to run an instance with a new advertise_uri

The root problem: advertise_uri parameter is persisted in the clusterwide configuration. Even if it changes upon restart, the rest of the cluster keeps using the old one, and the cluster may behave in an odd way.

Solution:

The clusterwide configuration should be updated.

1. Make sure all instances are running and not stuck in the ConnectingFullmesh state (see above).
2. Make sure all instances have discovered each other (i.e. they look healthy in the WebUI).
3. Run the following snippet in the Tarantool console. It'll prepare a patch for the clusterwide configuration.

```
cartridge = require('cartridge')
members = require('membership').members()

edit_list = {}
changelog = {}
for _, srv in pairs(cartridge.admin_get_servers()) do
    for _, m in pairs(members) do
        if m.status == 'alive'
        and m.payload.uuid == srv.uuid
        and m.uri ~= srv.uri
        then
            table.insert(edit_list, {uuid = srv.uuid, uri = m.uri})
            table.insert(changelog, string.format('%s -> %s (%s)', srv.uri, m.uri, m.payload.alias))
            break
        end
    end
end
return changelog
```

   As a result you'll see a brief summary like the following one:

```
localhost:3301> return changelog
---
- - localhost:13301 -> localhost:3301 (srv-1)
  - localhost:13302 -> localhost:3302 (srv-2)
  - localhost:13303 -> localhost:3303 (srv-3)
  - localhost:13304 -> localhost:3304 (srv-4)
  - localhost:13305 -> localhost:3305 (srv-5)
...
```

4. Finally, apply the patch:

```
cartridge.admin_edit_topology({servers = edit_list})
```

The cluster is doomed, I've edited the config manually. How do I reload it?

Warning: Please be aware that it's quite risky and you know what you're doing. There's some useful information about clusterwide configuration anatomy and "normal" management API.

But if you're still determined to reload the configuration manually, you can do (in the Tarantool console):

```
function reload_clusterwide_config()
    local changelog = {}

    local ClusterwideConfig = require('cartridge.clusterwide-config')
    local confapplier = require('cartridge.confapplier')

    -- load config from filesystem
    table.insert(changelog, 'Loading new config...')

    local cfg, err = ClusterwideConfig.load('./config')
    if err ~= nil then
        return changelog, string.format('Failed to load new config: %s', err)
    end

    -- check instance state
    table.insert(changelog, 'Checking instance config state...')

    local roles_configured_state = 'RolesConfigured'
    local connecting_fullmesh_state = 'ConnectingFullmesh'

    local state = confapplier.wish_state(roles_configured_state, 10)

    if state == connecting_fullmesh_state then
        return changelog, string.format(
            'Failed to reach %s config state. Stuck in %s. ' ..
                'Call "box.cfg({replication_connect_quorum = 0})" in instance console and try again',
            roles_configured_state, state
        )
    end

    if state ~= roles_configured_state then
        return changelog, string.format(
            'Failed to reach %s config state. Stuck in %s',
            roles_configured_state, state
        )
    end

    -- apply config changes
    table.insert(changelog, 'Applying config changes...')

    cfg:lock()
    local ok, err = confapplier.apply_config(cfg)
    if err ~= nil then
        return changelog, string.format('Failed to apply new config: %s', err)
    end

    table.insert(changelog, 'Cluster-wide configuration was successfully updated')
```

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```
    return changelog
end

reload_clusterwide_config()
```

This snippet reloads the configuration on a single instance. All other instances continue operating as before.

Note: If further configuration modifications are made with a two-phase commit (e.g. via the WebUI or with the Lua API), the active configuration of an active instance will be spread across the cluster.

Repairing cluster using Cartridge CLI repair command

Cartridge CLI has repair command since version 2.3.0.

It can be used to get current topology, remove instance from cluster, change repicaset leader or change instance advertise URI.

Note: cartridge repair patches the cluster-wide configuration files of application instances placed ON THE LOCAL MACHINE. It means that running cartridge repair on all machines is user responsibility.

Note: It's not enough to apply new configuration: the configuration should be reloaded by the instance. If your application uses cartridge >= 2.0.0, you can simply use --reload flag to reload configuration. Otherwise, you need to restart instances or reload configuration manually.

Changing instance advertise URI

To change instance advertise URI you have to perform these actions:

1. Start instance with a new advertise URI. The easiest way is to change advertise_uri value in the instance configuration file).
2. Make sure instances are running and not stuck in the ConnectingFullmesh state (see above).
3. Get instance UUID: * open server details tab in WebUI; * call cartridge repair list-topology --name <app-name> and find desired instance UUID: * get instance box.info().uuid:

   ```
   echo "return box.info().uuid" | tarantoolctl connect \
   unix/:/var/run/tarantool/<app-name>.<instance-name>.control
   ```

4. Now we need to update instance advertise URI in all instances cluster-wide configuration files on each machine. Run cartridge repair set-advertise-uri with --dry-run flag on each machine to check cluster-wide config changes computed by cartridge-cli:

   ```
   cartridge repair set-advertise-uri \
     --name myapp \
     --dry-run \
     <instance-uuid> <new-advertise-uri>
   ```

5. Run cartridge repair set-advertise-uri without --dry-run flag on each machine to apply config changes computed by cartridge-cli. If your application uses cartridge >= 2.0.0, you can specify --reload flag

to load new cluter-wide configuration on instances. Otherwise, you need to restart instances or reload configuration manually.

```
cartridge repair set-advertise-uri \
  --name myapp \
  --verbose \
  --reload \
  <instance-uuid> <new-advertise-uri>
```

Changing replicaset leader

You can change replicaset leader using cartridge repair command.

1. Get replicaset UUID and new leader UUID (in WebUI or by calling cartridge repair list-topology --name <app-name>).
2. Now we need to update cluster-wide config for all instances on each machine. Run cartridge repair set-leader with --dry-run flag on each machine to check cluster-wide config changes computed by " cartridge-cli":

```
cartridge repair set-leader \
  --name myapp \
  --dry-run \
  <replicaset-uuid> <instance-uuid>
```

3. Run cartridge repair set-advertise-uri without --dry-run flag on each machine to apply config changes computed by cartridge-cli. If your application uses cartridge >= 2.0.0, you can specify --reload flag to load new cluter-wide configuration on instances. Otherwise, you need to restart instances or reload configuration manually.

```
cartridge repair set-leader \
  --name myapp \
  --verbose \
  --reload \
  <replicaset-uuid> <instance-uuid>
```

Removing instance from the cluster

You can remove instance from cluster using cartridge repair command.

1. Get instance UUID: * open server details tab in WebUI; * call cartridge repair list-topology --name <app-name> and find desired instance UUID: * get instance box.info().uuid:

```
echo "return box.info().uuid" | tarantoolctl connect \
unix/:/var/run/tarantool/<app-name>.<instance-name>.control
```

2. Now we need to update cluster-wide config for all instances on each machine. Run cartridge repair remove-instance with --dry-run flag on each machine to check cluster-wide config changes computed by cartridge-cli:

```
cartridge repair remove-instance \
  --name myapp \
  --dry-run \
  <replicaset-uuid>
```

3. Run cartridge repair remove-instance without --dry-run flag on each machine to apply config changes computed by cartridge-cli. If your application uses cartridge >= 2.0.0, you can specify --reload flag to load new cluter-wide configuration on instances. Otherwise, you need to restart instances or reload configuration manually.

```
cartridge repair set-leader \
  --name myapp \
  --verbose \
  --reload \
  <replicaset-uuid> <instance-uuid>
```

4.3.5 Table of contents

Module cartridge

Tarantool framework for distributed applications development.

Cartridge provides you a simple way to manage distributed applications operations. The cluster consists of several Tarantool instances acting in concert. Cartridge does not care about how the instances start, it only cares about the configuration of already running processes.

Cartridge automates vshard and replication configuration, simplifies custom configuration and administrative tasks.

Functions

cfg (opts, box_opts)

Initialize the cartridge module.

After this call, you can operate the instance via Tarantool console. Notice that this call does not initialize the database - box.cfg is not called yet. Do not try to call box.cfg yourself: cartridge will do it when it is time.

Both cartridge.cfg and box.cfg options can be configured with command-line arguments or environment variables.

Parameters:

- opts: Available options are:
  - workdir: (optional string) a directory where all data will be stored: snapshots, wal logs and cartridge config file.(default: ".", overridden byenv TARANTOOL_WORKDIR ,args --workdir)
  - advertise_uri: (optional string) either "<HOST>:<PORT>" or "<HOST>:" or "<PORT>".Used by other instances to connect to the current one.When <HOST> isn't specified, it's detected as the only non-local IP address.If there is more than one IP address available - defaults to "localhost".When <PORT> isn't specified, it's derived as follows:If the TARANTOOL_INSTANCE_NAME has numeric suffix _<N>, then <PORT> = 3300+<N>.Otherwise default <PORT> = 3301 is used.
  - cluster_cookie: (optional string) secret used to separate unrelated applications, whichprevents them from seeing each other during broadcasts.Also used as admin password in HTTP and binary connections and forencrypting internal communications.Allowed symbols are [a-zA-Z0-9_.~-] .(default: "secret-cluster-cookie", overridden byenv TARANTOOL_CLUSTER_COOKIE ,args --cluster-cookie)

  - swim_broadcast: (optional boolean) Announce own advertise_uri over UDP broadcast.Cartridge health-checks are governed by SWIM protocol. To simplifyinstances discovery on start it can UDP broadcast all networksknown from getifaddrs() C call. The broadcast is sent to severalports: default 3301, the <PORT> from the advertise_uri option,and its neighbours <PORT>+1 and <PORT>-1.(Added in v2.3.0-23,default: true, overridden byenv TARANTOOL_SWIM_BROADCAST,args –swim-broadcast)
  - bucket_count: (optional number) bucket count for vshard cluster. See vshard doc for more details.(default: 30000, overridden byenv TARANTOOL_BUCKET_COUNT ,args --bucket-count)
  - vshard_groups: (optional {[string]=VshardGroup,. . . }) vshard storage groups, table keys used as names
  - http_enabled: (optional boolean) whether http server should be started(default: true, overridden byenv TARANTOOL_HTTP_ENABLED,args –http-enabled)
  - http_port: (string or number) port to open administrative UI and API on(default: 8081, derived from‘TARANTOOL_INSTANCE_NAME‘,overridden byenv TARANTOOL_HTTP_PORT,args –http-port)
  - alias: (optional string) human-readable instance name that will be available in administrative UI(default: argparse instance name, overridden byenv TARANTOOL_ALIAS,args –alias)
  - roles: (table) list of user-defined roles that will be availableto enable on the instance_uuid
  - auth_enabled: (optional boolean) toggle authentication in administrative UI and API(default: false)
  - auth_backend_name: (optional string) user-provided set of callbacks related to authentication
  - console_sock: (optional string) Socket to start console listening on.(default: nil, overridden byenv TARANTOOL_CONSOLE_SOCK ,args --console-sock)
  - webui_blacklist: (optional {string,. . . }) List of pages to be hidden in WebUI.(Added in v2.0.1-54, default: {})
  - upgrade_schema: (optional boolean) Run schema upgrade on the leader instance.(Added in v2.0.2-3,default: false , overridden byenv TARANTOOL_UPGRADE_SCHEMA args --upgrade-schema)
  - roles_reload_allowed: (optional boolean) Allow calling cartridge.reload_roles.(Added in v2.3.0-73, default: false)

- box_opts: (optional table) tarantool extra box.cfg options (e.g. memtx_memory),that may require additional tuning

Returns:

true

Or

(nil)

(table) Error description

reload_roles ()

Perform hot-reload of cartridge roles code.

This is an experimental feature, it's only allowed if the application enables it explicitly: cartridge.cfg({roles_reload_allowed = true}) .

Reloading starts by stopping all roles and restoring the initial state. It's supposed that a role cleans up the global state when stopped, but even if it doesn't, cartridge kills all fibers and removes global variables and HTTP routes.

All Lua modules that were loaded during cartridge.cfg are unloaded, including supplementary modules required by a role. Modules, loaded before cartridge.cfg aren't affected.

Instance performs roles reload in a dedicated state ReloadingRoles . If reload fails, the instance enters the ReloadError state, which can later be retried. Otherwise, if reload succeeds, instance proceeds to the ConfiguringRoles state and initializes them as usual with validate_config() , init() , and apply_config() callbacks.

Returns:

(boolean) true

Or

(nil)

(table) Error description

is_healthy ()

Check the cluster health. It is healthy if all instances are healthy.

The function is designed mostly for testing purposes.

Returns:

(boolean) true / false

Tables

VshardGroup

Vshard storage group configuration.

Every vshard storage must be assigned to a group.

Fields:

- bucket_count: (number) Bucket count for the storage group.

Global functions

_G.cartridge_get_schema ()

Get clusterwide DDL schema.

(Added in v1.2.0-28)

Returns:

(string) Schema in YAML format

Or

(nil)

(table) Error description

_G.cartridge_set_schema (schema)

Apply clusterwide DDL schema.

(Added in v1.2.0-28)

Parameters:

- schema: (string) in YAML format

Returns:

(string) The same new schema

Or

(nil)

(table) Error description

Clusterwide DDL schema

get_schema ()

Get clusterwide DDL schema. It's like _G.cartridge_get_schema, but isn't a global variable.

(Added in v2.0.1-54)

Returns:

(string) Schema in YAML format

Or

(nil)

(table) Error description

set_schema (schema)

Apply clusterwide DDL schema. It's like _G.cartridge_set_schema, but isn't a global variable.

(Added in v2.0.1-54)

Parameters:

- schema: (string) in YAML format

Returns:

(string) The same new schema

Or

(nil)

(table) Error description

Cluster administration

ServerInfo

Instance general information.

Fields:

- alias: (string) Human-readable instance name.
- uri: (string)
- uuid: (string)
- disabled: (boolean)
- status: (string) Instance health.
- message: (string) Auxilary health status.
- replicaset: (ReplicasetInfo) Circular reference to a replicaset.
- priority: (number) Leadership priority for automatic failover.
- clock_delta: (number) Difference between remote clock and the current one (inseconds), obtained from the membership module (SWIM protocol).Positive values mean remote clock are ahead of local, and viceversa.
- zone: (string)

ReplicasetInfo

Replicaset general information.

Fields:

- uuid: (string) The replicaset UUID.
- roles: ({string,. . . }) Roles enabled on the replicaset.
- status: (string) Replicaset health.
- master: (ServerInfo) Replicaset leader according to configuration.
- active_master: (ServerInfo) Active leader.
- weight: (number) Vshard replicaset weight.Matters only if vshard-storage role is enabled.
- vshard_group: (string) Name of vshard group the replicaset belongs to.
- all_rw: (boolean) A flag indicating that all servers in the replicaset should be read-write.
- alias: (string) Human-readable replicaset name.
- servers: ({ServerInfo,. . . }) Circular reference to all instances in the replicaset.

admin_get_servers ([uuid])

Get servers list. Optionally filter out the server with the given uuid.

Parameters:

- uuid: (string) (optional)

Returns:

({ServerInfo,. . . })

Or

(nil)

(table) Error description

admin_get_replicasets ([uuid])

Get replicasets list. Optionally filter out the replicaset with given uuid.

Parameters:

- uuid: (string) (optional)

Returns:

({ReplicasetInfo,. . . })

Or

(nil)

(table) Error description

admin_probe_server (uri)

Discover an instance.

Parameters:

- uri: (string)

admin_enable_servers (uuids)

Enable nodes after they were disabled.

Parameters:

- uuids: ({string,. . . })

Returns:

({ServerInfo,. . . })

Or

(nil)

(table) Error description

admin_disable_servers (uuids)

Temporarily diable nodes.

Parameters:

- uuids: ({string,. . . })

Returns:

({ServerInfo,. . . })

Or

(nil)

(table) Error description

admin_bootstrap_vshard ()

Call vshard.router.bootstrap() . This function distributes all buckets across the replica sets.

Returns:

(boolean) true

Or

(nil)

(table) Error description

Automatic failover management

FailoverParams

Failover parameters.

(Added in v2.0.2-2)

Fields:

- mode: (string) Supported modes are "disabled", "eventual" and "stateful"
- state_provider: (optional string) Supported state providers are "tarantool" and "etcd2".
- failover_timeout: (number) (added in v2.3.0-52)Timeout (in seconds), used by membership tomark suspect members as dead (default: 20)
- tarantool_params: (added in v2.0.2-2)
  - uri: (string)
  - password: (string)
- etcd2_params: (added in v2.1.2-26)
  - prefix: (string) Prefix used for etcd keys: <prefix>/lock and‘<prefix>/leaders‘
  - lock_delay: (optional number) Timeout (in seconds), determines lock's time-to-live (default: 10)
  - endpoints: (optional table) URIs that are used to discover and to access etcd cluster instances.(default: {'http://localhost:2379', 'http://localhost:4001'})
  - username: (optional string) (default: "")
  - password: (optional string) (default: "")
- fencing_enabled: (boolean) (added in v2.3.0-57)Abandon leadership when both the state provider quorum and atleast one replica are lost (suitable in stateful mode only,default: false)

- fencing_timeout: (number) (added in v2.3.0-57)Time (in seconds) to actuate fencing after the check fails(default: 10)
- fencing_pause: (number) (added in v2.3.0-57)The period (in seconds) of performing the check(default: 2)

failover_get_params ()

Get failover configuration.

(Added in v2.0.2-2)

Returns:

(FailoverParams)

failover_set_params (opts)

Configure automatic failover.

(Added in v2.0.2-2)

Parameters:

- opts:
  - mode: (optional string)
  - state_provider: (optional string)
  - failover_timeout: (optional number) (added in v2.3.0-52)
  - tarantool_params: (optional table)
  - etcd2_params: (optional table) (added in v2.1.2-26)
  - fencing_enabled: (optional boolean) (added in v2.3.0-57)
  - fencing_timeout: (optional number) (added in v2.3.0-57)
  - fencing_pause: (optional number) (added in v2.3.0-57)

Returns:

(boolean) true if config applied successfully

Or

(nil)

(table) Error description

failover_promote (replicaset_uuid[, opts])

Promote leaders in replicasets.

Parameters:

- replicaset_uuid: (table)] = leader_uuid }
- opts:
  - force_inconsistency: (optional boolean) (default: false)

Returns:

(boolean) true On success

Or

(nil)

(table) Error description

admin_get_failover ()

Get current failover state.

(Deprecated since v2.0.2-2)

admin_enable_failover ()

Enable failover. (Deprecated since v2.0.1-95 in favor of cartridge.failover_set_params)

admin_disable_failover ()

Disable failover. (Deprecated since v2.0.1-95 in favor of cartridge.failover_set_params)

Managing cluster topology

admin_edit_topology (args)

Edit cluster topology. This function can be used for:

- bootstrapping cluster from scratch
- joining a server to an existing replicaset
- creating new replicaset with one or more servers
- editing uri/labels of servers
- disabling and expelling servers

(Added in v1.0.0-17)

Parameters:

- args:
  - servers: (optional {EditServerParams,..})
  - replicasets: (optional {EditReplicasetParams,..})

EditReplicasetParams

Replicatets modifications.

Fields:

- uuid: (optional string)

- alias: (optional string)
- roles: (optional {string,. . . })
- all_rw: (optional boolean)
- weight: (optional number)
- failover_priority: (optional {string,. . . }) array of uuids specifying servers failover priority
- vshard_group: (optional string)
- join_servers: (optional {JoinServerParams,. . . })

EditServerParams

Servers modifications.

Fields:

- uri: (optional string)
- uuid: (string)
- zone: (optional string)
- labels: (optional table)
- disabled: (optional boolean)
- expelled: (optional boolean) Expelling an instance is permanent and can't be undone.It's suitable for situations when the hardware is destroyed,snapshots are lost and there is no hope to bring it back to life.

JoinServerParams

Parameters required for joining a new server.

Fields:

- uri: (string)
- uuid: (optional string)
- zone: (optional string) (Added in v2.4.0-14)
- labels: (optional table)

Clusterwide configuration

config_get_readonly ([section_name])

Get a read-only view on the clusterwide configuration.

Returns either conf[section_name] or entire conf . Any attempt to modify the section or its children will raise an error.

Parameters:

- section_name: (string) (optional)

Returns:

(table)

config_get_deepcopy ([section_name])

Get a read-write deep copy of the clusterwide configuration.

Returns either conf[section_name] or entire conf . Changing it has no effect unless it's used to patch clusterwide configuration.

Parameters:

- section_name: (string) (optional)

Returns:

(table)

config_patch_clusterwide (patch)

Edit the clusterwide configuration. Top-level keys are merged with the current configuration. To remove a top-level section, use patch_clusterwide{key = box.NULL} .

The function uses a two-phase commit algorithm with the following steps:

I. Patches the current configuration.

II. Validates topology on the current server.

III. Executes the preparation phase (prepare_2pc) on every server excluding expelled and disabled servers.

IV. If any server reports an error, executes the abort phase (abort_2pc). All servers prepared so far are rolled back and unlocked.

V. Performs the commit phase (commit_2pc). In case the phase fails, an automatic rollback is impossible, the cluster should be repaired manually.

Parameters:

- patch: (table)

Returns:

(boolean) true

Or

(nil)

(table) Error description

config_force_reapply (uuids)

Forcefully apply config to the given instances.

In particular:

- Abort two-phase commit (remove config.prepare lock)
- Upload the active config from the current instance.

- Apply it (reconfigure all roles)

(Added in v2.3.0-68)

Parameters:

- uuids: ({string,. . . })

Returns:

(boolean) true

Or

(nil)

(table) Error description

Inter-role interaction

service_get (module_name)

Get a module from registry.

Parameters:

- module_name: (string)

Returns:

(nil)

Or

(table) instance

service_set (module_name, instance)

Put a module into registry or drop it. This function typically doesn't need to be called explicitly, the cluster automatically sets all the initialized roles.

Parameters:

- module_name: (string)
- instance: (nil or table)

Returns:

(nil)

Cross-instance calls

rpc_call (role_name, fn_name[, args[, opts]])

Perform a remote procedure call. Find a suitable healthy instance with an enabled role and perform a [net.box conn:call](https://tarantool.io/en/doc/latest/reference/reference_lua/net_box/#net-box-call) on it. rpc.call() can only be used for functions defined in role return table unlike net.box conn:call() , which is used for global functions as well.

Parameters:

- role_name: (string)
- fn_name: (string)
- args: (table) (optional)
- opts:
  - prefer_local: (optional boolean) Don't perform a remote call if possible. When the role is enabledlocally and current instance is healthy the remote netbox call issubstituted with a local Lua function call. When the option isdisabled it never tries to perform call locally and always usesnetbox connection, even to connect self.(default: true)
  - leader_only: (optional boolean) Perform a call only on the replica set leaders.(default: false)
  - uri: (optional string) Force a call to be performed on this particular uri.Disregards member status and opts.prefer_local .Conflicts with opts.leader_only = true .(added in v1.2.0-63)
  - remote_only: (deprecated) Use prefer_local instead.
  - timeout: passed to net.box conn:call options.
  - buffer: passed to net.box conn:call options.
  - on_push: passed to net.box conn:call options.
  - on_push_ctx: passed to net.box conn:call options.

Returns:

conn:call() result

Or

(nil)

(table) Error description

Usage:

```
-- myrole.lua
return {
    role_name = 'myrole',
    add = function(a, b) return a + b end,
}
```

```
-- call it as follows:
cartridge.rpc_call('myrole', 'add', {2, 2}) -- returns 4
```

rpc_get_candidates (role_name[, opts])

List instances suitable for performing a remote call.

Parameters:

- role_name: (string)
- opts:
  - leader_only: (optional boolean) Filter instances which are leaders now.(default: false)

  – healthy_only: (optional boolean) The member is considered healthy ifit reports either ConfiguringRoles or RolesConfigured stateand its SWIM status is either alive or suspect (added in v1.1.0-11, default: true)

Returns:

({string,. . . }) URIs

Authentication and authorization

http_authorize_request (request)

Authorize an HTTP request.

Get username from cookies or basic HTTP authentication.

(Added in v1.1.0-4)

Parameters:

- request: (table)

Returns:

(boolean) Access granted

http_render_response (response)

Render HTTP response.

Inject set-cookie headers into response in order to renew or reset the cookie.

(Added in v1.1.0-4)

Parameters:

- response: (table)

Returns:

(table) The same response with cookies injected

http_get_username ()

Get username for the current HTTP session.

(Added in v1.1.0-4)

Returns:

(string or nil)

Deprecated functions

admin_edit_replicaset (args)

Edit replicaset parameters (deprecated).

(Deprecated since v1.0.0-17 in favor of cartridge.admin_edit_topology)

Parameters:

- args:
  - uuid: (string)
  - alias: (string)
  - roles: (optional {string,. . . })
  - master: (optional {string,. . . }) Failover order
  - weight: (optional number)
  - vshard_group: (optional string)
  - all_rw: (optional boolean)

Returns:

(boolean) true

Or

(nil)

(table) Error description

admin_edit_server (args)

Edit an instance (deprecated).

(Deprecated since v1.0.0-17 in favor of cartridge.admin_edit_topology)

Parameters:

- args:
  - uuid: (string)
  - uri: (optional string)
  - labels: (optional {[string]=string,. . . })

Returns:

(boolean) true

Or

(nil)

(table) Error description

admin_join_server (args)

Join an instance to the cluster (deprecated).

(Deprecated since v1.0.0-17 in favor of cartridge.admin_edit_topology)

Parameters:

- args:

  - uri: (string)
  - instance_uuid: (optional string)
  - replicaset_uuid: (optional string)
  - roles: (optional {string,. . . })
  - timeout: (optional number)
  - zone: (optional string) (Added in v2.4.0-14)
  - labels: (optional {[string]=string,. . . })
  - vshard_group: (optional string)
  - replicaset_alias: (optional string)
  - replicaset_weight: (optional number)

Returns:

(boolean) true

Or

(nil)

(table) Error description

admin_expel_server (uuid)

Expel an instance (deprecated). Forever.

(Deprecated since v1.0.0-17 in favor of cartridge.admin_edit_topology)

Parameters:

- uuid: (string)

Returns:

(boolean) true

Or

(nil)

(table) Error description

Module cartridge.auth

Administrators authentication and authorization.

Local Functions

set_enabled (enabled)

Allow or deny unauthenticated access to the administrator's page. (Changed in v0.11)

This function affects only the current instance. It can't be used after the cluster was bootstrapped. To modify clusterwide config use set_params instead.

Parameters:

- enabled: (boolean)

Returns:

(boolean) true

Or

(nil)

(table) Error description

get_enabled ()

Check if unauthenticated access is forbidden. (Added in v0.7)

Returns:

(boolean) enabled

init ()

Initialize the authentication HTTP API.

Set up login and logout HTTP endpoints.

set_callbacks (callbacks)

Set authentication callbacks.

Parameters:

- callbacks:
  - add_user: (function)
  - get_user: (function)
  - edit_user: (function)
  - list_users: (function)
  - remove_user: (function)
  - check_password: (function)

Returns:

(boolean) true

get_callbacks ()

Get authentication callbacks.

Returns:

(table) callbacks

Configuration

set_params (opts)

Modify authentication params. (Changed in v0.11)

Can't be used before the bootstrap. Affects all cluster instances. Triggers cluster.config_patch_clusterwide
.

Parameters:

- opts:
  - enabled: (optional boolean) (Added in v0.11)
  - cookie_max_age: (optional number)
  - cookie_renew_age: (optional number) (Added in v0.11)

Returns:

(boolean) true

Or

(nil)

(table) Error description

get_params ()

Retrieve authentication params.

Returns:

(AuthParams)

AuthParams

Authentication params.

Fields:

- enabled: (boolean) Wether unauthenticated access is forbidden
- cookie_max_age: (number) Number of seconds until the authentication cookie expires
- cookie_renew_age: (number) Update provided cookie if it's older then this age (in seconds)

Authorizarion

set_lsid_cookie (user)

Create session for current user.

Creates session for user with specified username and user version or clear it if no arguments passed.

(Added in v2.2.0-43)

Parameters:

- user: (table)

get_session_username ()

Get username for the current HTTP session.

(Added in v1.1.0-4)

Returns:

(string or nil)

authorize_request (request)

Authorize an HTTP request.

Get username from cookies or basic HTTP authentication.

(Added in v1.1.0-4)

Parameters:

- request: (table)

Returns:

(boolean) Access granted

render_response (response)

Render HTTP response.

Inject set-cookie headers into response in order to renew or reset the cookie.

(Added in v1.1.0-4)

Parameters:

- response: (table)

Returns:

(table) The same response with cookies injected

User management

UserInfo

User information.

Fields:

- username: (string)
- fullname: (optional string)
- email: (optional string)
- version: (optional number)

add_user (username, password, fullname, email)

Trigger registered add_user callback.

The callback is triggered with the same arguments and must return a table with fields conforming to UserInfo . Unknown fields are ignored.

Parameters:

- username: (string)
- password: (string)
- fullname: (optional string)
- email: (optional string)

Returns:

(UserInfo)

Or

(nil)

(table) Error description

get_user (username)

Trigger registered get_user callback.

The callback is triggered with the same arguments and must return a table with fields conforming to UserInfo . Unknown fields are ignored.

Parameters:

- username: (string)

Returns:

(UserInfo)

Or

(nil)

(table) Error description

edit_user (username, password, fullname, email)

Trigger registered edit_user callback.

The callback is triggered with the same arguments and must return a table with fields conforming to UserInfo . Unknown fields are ignored.

Parameters:

- username: (string)
- password: (optional string)
- fullname: (optional string)
- email: (optional string)

Returns:

(UserInfo)

Or

(nil)

(table) Error description

list_users ()

Trigger registered list_users callback.

The callback is triggered without any arguments. It must return an array of UserInfo objects.

Returns:

({UserInfo,...})

Or

(nil)

(table) Error description

remove_user (username)

Trigger registered remove_user callback.

The callback is triggered with the same arguments and must return a table with fields conforming to UserInfo , which was removed. Unknown fields are ignored.

Parameters:

- username: (string)

Returns:

(UserInfo)

Or

(nil)

(table) Error description

Module cartridge.roles

Role management (internal module).

The module consolidates all the role management functions: cfg , some getters, validate_config and apply_config .

The module is almost stateless, it's only state is a collection of registered roles.

(Added in v1.2.0-20)

Functions

reload ()

Perform hot-reload of cartridge roles code.

This is an experimental feature, it's only allowed if the application enables it explicitly: cartridge.cfg({roles_reload_allowed = true}) .

Reloading starts by stopping all roles and restoring the initial state. It's supposed that a role cleans up the global state when stopped, but even if it doesn't, cartridge kills all fibers and removes global variables and HTTP routes.

All Lua modules that were loaded during cartridge.cfg are unloaded, including supplementary modules required by a role. Modules, loaded before cartridge.cfg aren't affected.

Instance performs roles reload in a dedicated state ReloadingRoles . If reload fails, the instance enters the ReloadError state, which can later be retried. Otherwise, if reload succeeds, instance proceeds to the ConfiguringRoles state and initializes them as usual with validate_config() , init() , and apply_config() callbacks.

Returns:

(boolean) true

Or

(nil)

(table) Error description

Local Functions

cfg (module_names)

Load modules and register them as Cartridge Roles.

This function is internal, it's called as a part of cartridge.cfg.

Parameters:

- module_names: ({string,. . . })

Returns:

(boolean) true

Or

(nil)

(table) Error description

get_all_roles ()

List all registered roles.

Hidden and permanent roles are listed too.

Returns:

({string,..})

get_known_roles ()

List registered roles names.

Hidden roles are not listed as well as permanent ones.

Returns:

({string,..})

get_enabled_roles (roles)

Roles to be enabled on the server. This function returns all roles that will be enabled including their dependencies (bot hidden and not) and permanent roles.

Parameters:

- roles: ({string,. . . } or {[string]=boolean,. . . })

Returns:

({[string]=boolean,. . . })

get_role_dependencies (role_name)

List role dependencies. Including sub-dependencies.

Parameters:

- role_name: (string)

Returns:

({string,..})

validate_config (conf_new, conf_old)

Validate configuration by all roles.

Parameters:

- conf_new: (table)
- conf_old: (table)

Returns:

(boolean) true

Or

(nil)

(table) Error description

apply_config (conf, opts, is_master)

Apply the role configuration.

Parameters:

- conf: (table)
- opts: (table)
- is_master: (boolean)

Returns:

(boolean) true

Or

(nil)

(table) Error description

Module cartridge.issues

Monitor issues across cluster instances.

Cartridge detects the following problems:

Replication:

- "Replication from … to … isn't running" - when box.info.replication.upstream == nil ;
- "Replication from … to … is stopped/orphan/etc. (…)";
- "Replication from … to …: high lag" - when upstream.lag > box.cfg.replication_sync_lag ;
- "Replication from … to …: long idle" - when upstream.idle > 2 * box.cfg.replication_timeout ;

Failover:

- "Can't obtain failover coordinator (…)";
- "There is no active failover coordinator";
- "Failover is stuck on …: Error fetching appointments (…)";
- "Failover is stuck on …: Failover fiber is dead" - this is likely a bug;

Tables

limits

Thresholds for issuing warnings. All settings are local, not clusterwide. They can be changed with corresponding environment variables (TARANTOOL_*) or command-line arguments. See cartridge.argparse module for details.

Fields:

- fragmentation_threshold_critical: (number) default: 0.9.
- fragmentation_threshold_warning: (number) default: 0.6.
- clock_delta_threshold_warning: (number) default: 5.

Module cartridge.argparse

Gather configuration options.

The module tries to read configuration options from multiple sources and then merge them together according to the priority of the source:

- –<VARNAME> command line arguments
- TARANTOOL_<VARNAME> environment variables
- configuration files

You can specify a configuration file using the –cfg <CONFIG_FILE> option or the TARANTOOL_CFG=<CONFIG_FILE> environment variable.

Configuration files are yaml files, divided into sections like the following:

```
default:
  memtx_memory: 10000000
  some_option: "default value"
myapp.router:
  memtx_memory: 1024000000
  some_option: "router specific value"
```

Within the configuration file, argparse looks for multiple matching sections:

- The section named <APP_NAME>.<INSTANCE_NAME> is parsed first. Application name is derived automatically from the rockspec filename in the project directory. Or it can be can be specified manually with the --app-name command line argument or the TARANTOOL_APP_NAME environment variable. Instance name can be specified the same way, either as –instance-name or TARANTOOL_INSTANCE_NAME .
- The common <APP_NAME> section is parsed next.
- Finally, the section [default] with global configuration is parsed with the lowest priority.

Functions

parse ()

Parse command line arguments, environment variables, and configuration files.

Returns:

({argname=value,...})

get_opts (filter)

Filter the results of parsing and cast variables to a given type.

From all configuration options gathered by parse , select only those specified in the filter.

For example, running an application as following:

```
./init.lua --alias router --memtx-memory 100
```

results in:

```
parse()            -> {memtx_memory = "100", alias = "router"}
get_cluster_opts() -> {alias = "router"} -- a string
get_box_opts()     -> {memtx_memory = 100} -- a number
```

Parameters:

- filter: ({argname=type,. . . })

Returns:

({argname=value,. . . })

get_box_opts ()

Shorthand for get_opts(box_opts) .

get_cluster_opts ()

Shorthand for get_opts(cluster_opts) .

Tables

cluster_opts

Common cartridge.cfg options.

Options which are not listed below (like roles) can't be modified with argparse and should be configured in code.

Fields:

- alias: string
- workdir: string
- http_port: number
- http_enabled: boolean
- advertise_uri: string
- cluster_cookie: string
- console_sock: string
- auth_enabled: boolean
- bucket_count: number
- upgrade_schema: boolean
- swim_broadcast: boolean

box_opts

Common [box.cfg](https://www.tarantool.io/en/doc/latest/reference/configuration/) tuning options.

Fields:

- listen: string
- memtx_memory: number
- strip_core: boolean
- memtx_min_tuple_size: number
- memtx_max_tuple_size: number
- memtx_use_mvcc_engine: boolean
- slab_alloc_factor: number
- work_dir: string (deprecated)
- memtx_dir: string
- wal_dir: string
- vinyl_dir: string
- vinyl_memory: number
- vinyl_cache: number
- vinyl_max_tuple_size: number
- vinyl_read_threads: number
- vinyl_write_threads: number
- vinyl_timeout: number
- vinyl_run_count_per_level: number
- vinyl_run_size_ratio: number
- vinyl_range_size: number
- vinyl_page_size: number
- vinyl_bloom_fpr: number
- log: string
- log_nonblock: boolean
- log_level: number
- log_format: string
- io_collect_interval: number
- readahead: number
- snap_io_rate_limit: number
- too_long_threshold: number
- wal_mode: string
- rows_per_wal: number
- wal_max_size: number

- wal_dir_rescan_delay: number
- force_recovery: boolean
- replication: string
- instance_uuid: string
- replicaset_uuid: string
- custom_proc_title: string
- pid_file: string
- background: boolean
- username: string
- coredump: boolean
- checkpoint_interval: number
- checkpoint_wal_threshold: number
- checkpoint_count: number
- read_only: boolean
- hot_standby: boolean
- worker_pool_threads: number
- replication_timeout: number
- replication_sync_lag: number
- replication_sync_timeout: number
- replication_connect_timeout: number
- replication_connect_quorum: number
- replication_skip_conflict: boolean
- replication_synchro_quorum: number
- replication_synchro_timeout: number
- feedback_enabled: boolean
- feedback_host: string
- feedback_interval: number
- net_msg_max: number

Module cartridge.twophase

Clusterwide configuration propagation two-phase algorithm.

(Added in v1.2.0-19)

Functions

patch_clusterwide (patch)

Edit the clusterwide configuration. Top-level keys are merged with the current configuration. To remove a top-level section, use patch_clusterwide{key = box.NULL} .

The function uses a two-phase commit algorithm with the following steps:

I. Patches the current configuration.

II. Validates topology on the current server.

III. Executes the preparation phase (prepare_2pc) on every server excluding expelled and disabled servers.

IV. If any server reports an error, executes the abort phase (abort_2pc). All servers prepared so far are rolled back and unlocked.

V. Performs the commit phase (commit_2pc). In case the phase fails, an automatic rollback is impossible, the cluster should be repaired manually.

Parameters:

- patch: (table)

Returns:

(boolean) true

Or

(nil)

(table) Error description

force_reapply (uuids)

Forcefully apply config to the given instances.

In particular:

- Abort two-phase commit (remove config.prepare lock)
- Upload the active config from the current instance.
- Apply it (reconfigure all roles)

(Added in v2.3.0-68)

Parameters:

- uuids: ({string,. . . })

Returns:

(boolean) true

Or

(nil)

(table) Error description

get_schema ()

Get clusterwide DDL schema.

(Added in v1.2.0-28)

Returns:

(string) Schema in YAML format

Or

(nil)

(table) Error description

set_schema (schema)

Apply clusterwide DDL schema.

(Added in v1.2.0-28)

Parameters:

- schema: (string) in YAML format

Returns:

(string) The same new schema

Or

(nil)

(table) Error description

on_patch (trigger_new, trigger_old)

Set up trigger for for patch_clusterwide.

It will be executed before new new config applied.

If the parameters are (nil, old_trigger) , then the old trigger is deleted.

The trigger function is called with two argument: - conf_new (ClusterwideConfig) - conf_old (ClusterWideConfig)

It is allowed to modify conf_new , but not conf_old . Return values are ignored. If calling a trigger raises an error, patch_clusterwide returns it as nil, err .

(Added in v2.1.0-4)

Parameters:

- trigger_new: (function)
- trigger_old: (function)

Usage:

```
local function inject_data(conf_new, _)
    local data_yml = yaml.encode({foo = 'bar'})
    conf_new:set_plaintext('data.yml', data_yml)
end)

twophase.on_patch(inject_data) -- set custom patch modifier trigger
twophase.on_patch(nil, inject_data) -- drop trigger
```

Local Functions

prepare_2pc (data)

Two-phase commit - preparation stage.

Validate the configuration and acquire a lock setting local variable and writing "config.prepare.yml" file. If the validation fails, the lock isn't acquired and doesn't have to be aborted.

Parameters:

- data: (table) clusterwide config content

Returns:

(boolean) true

Or

(nil)

(table) Error description

commit_2pc ()

Two-phase commit - commit stage.

Back up the active configuration, commit changes to filesystem by renaming prepared file, release the lock, and configure roles. If any errors occur, configuration is not rolled back automatically. Any problem encountered during this call has to be solved manually.

Returns:

(boolean) true

Or

(nil)

(table) Error description

abort_2pc ()

Two-phase commit - abort stage.

Release the lock for further commit attempts.

Returns:

(boolean) true

Module cartridge.failover

Gather information regarding instances leadership.

Failover can operate in two modes:

- In disabled mode the leader is the first server configured in topology.replicasets[].master array.
- In eventual mode the leader isn't elected consistently. Instead, every instance in cluster thinks the leader is the first healthy server in replicaset, while instance health is determined according to membership status (the SWIM protocol).
- In stateful mode leaders appointments are polled from the external storage. (Added in v2.0.2-2)

This module behavior depends on the instance state.

From the very beginning it reports is_rw() == false, is_leader() == false , get_active_leaders() == {} .

The module is configured when the instance enters ConfiguringRoles state for the first time. From that moment it reports actual values according to the mode set in clusterwide config.

(Added in v1.2.0-17)

Functions

get_coordinator ()

Get current stateful failover coordinator

Returns:

(table) coordinator

Or

(nil)

(table) Error description

Local Functions

schedule_clear ()

Cancel all pending reconfigure_all tasks.

schedule_add ()

Schedule new reconfigure_all task.

_get_appointments_disabled_mode ()

Generate appointments according to clusterwide configuration. Used in 'disabled' failover mode.

_get_appointments_eventual_mode ()

Generate appointments according to membership status. Used in 'eventual' failover mode.

_get_appointments_stateful_mode ()

Get appointments from external storage. Used in 'stateful' failover mode.

accept_appointments (replicaset_uuid)

Accept new appointments.

Get appointments wherever they come from and put them into cache. Cached active_leaders table is never modified, but overriden by it's modified copy (if necessary).

Parameters:

- replicaset_uuid: ({[string]=string}) to leader_uuid map

Returns:

(boolean) Whether leadership map has changed

fencing_check ()

Perform the fencing healthcheck.

Fencing is actuated when the instance disconnects from both the state provider and a replica, i.e. the check returns false.

Returns:

(boolean) true / false

failover_loop ()

Repeatedly fetch new appointments and reconfigure roles.

cfg ()

Initialize the failover module.

get_active_leaders ()

Get map of replicaset leaders.

Returns:

{[replicaset_uuid] = instance_uuid,…}

is_leader ()

Check current instance leadership.

Returns:

(boolean) true / false

is_rw ()

Check current instance writability.

Returns:

(boolean) true / false

is_vclockkeeper ()

Check if current instance has persisted his vclock.

Returns:

(boolean) true / false

consistency_needed ()

Check if current configuration implies consistent switchover.

Returns:

(boolean) true / false

force_inconsistency (replicaset_uuid)

Force inconsistent leader switching. Do it by resetting vclockkepers in state provider.

Parameters:

- replicaset_uuid: ({[string]=string,...}) to leader_uuid mapping

Returns:

(boolean) true

Or

(nil)

(table) Error description

wait_consistency (replicaset_uuid)

Wait when promoted instances become vclockkepers.

Parameters:

- replicaset_uuid: ({[string]=string,...}) to leader_uuid mapping

Returns:

(boolean) true

Or

(nil)

(table) Error description

Module cartridge.topology

Topology validation and filtering.

Functions

cluster_is_healthy ()

Check the cluster health. It is healthy if all instances are healthy.

The function is designed mostly for testing purposes.

Returns:

(boolean) true / false

Local Functions

get_leaders_orded (topology_cfg, replicaset_uuid, new_order)

Get full list of replicaset leaders.

Full list is composed of:

- New order array
- Initial order from topology_cfg (with no repetitions)
- All other servers in the replicaset, sorted by uuid, ascending

Neither topology_cfg nor new_order tables are modified. New order validity is ignored too.

Parameters:

- topology_cfg: (table)
- replicaset_uuid: (string)
- new_order: (optional table)

Returns:

({string,. . . }) array of leaders uuids

validate (topology_new, topology_old)

Validate topology configuration.

Parameters:

- topology_new: (table)
- topology_old: (table)

Returns:

(boolean) true

Or

(nil)

(table) Error description

find_server_by_uri (topology_cfg, uri)

Find the server in topology config.

(Added in v1.2.0-17)

Parameters:

- topology_cfg: (table)
- uri: (string)

Returns:

(nil or string) instance_uuid found

refine_servers_uri (topology_cfg)

Merge servers URIs form topology_cfg with fresh membership status.

This function sustains cartridge operability in case of advertise_uri change. The uri map is composed basing on topology_cfg, but if some of them turns out to be dead, the member with corresponding payload.uuid is searched beyond.

(Added in v2.3.0-7)

Parameters:

- topology_cfg: (table)

Returns:

({[uuid]) = uri} with all servers except expelled ones.

probe_missing_members (servers)

Send UDP ping to servers missing from membership table.

Parameters:

- servers: (table)

Returns:

(boolean) true

Or

(nil)

(table) Error description

get_fullmesh_replication (topology_cfg, replicaset_uuid)

Get replication config to set up full mesh.

(Added in v1.2.0-17)

Parameters:

- topology_cfg: (table)
- replicaset_uuid: (string)

Returns:

(table)

Module cartridge.clusterwide-config

The abstraction, representing clusterwide configuration.

Clusterwide configuration is more than just a lua table. It's an object in terms of OOP paradigm.

On filesystem clusterwide config is represented by a file tree.

In Lua it's represented as an object which holds both plaintext files content and unmarshalled lua tables. Unmarshalling is implicit and performed automatically for the sections with .yml file extension.

To access plaintext content there are two functions: get_plaintext and set_plaintext .

Unmarshalled lua tables are accessed without .yml extension by get_readonly and get_deepcopy . Plaintext serves for accessing unmarshalled representation of corresponding sections.

To avoid ambiguity it's prohibited to keep both <FILENAME> and <FILENAME>.yml in the configuration. An attempt to do so would result in return nil, err from new() and load(), and an attempt to call get_readonly/deepcopy would raise an error. Nevertheless one can keep any other extensions because they aren't unmarshalled implicitly.

(Added in v1.2.0-17)

Usage:

```
tarantool> cfg = ClusterwideConfig.new({
         >     -- two files
         >     ['forex.yml'] = '{EURRUB_TOM: 70.33, USDRUB_TOM: 63.18}',
         >     ['text'] = 'Lorem ipsum dolor sit amet',
         > })
---
...
```

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```
tarantool> cfg:get_plaintext()
---
- text: Lorem ipsum dolor sit amet
  forex.yml: '{EURRUB_TOM: 70.33, USDRUB_TOM: 63.18}'
...

tarantool> cfg:get_readonly()
---
- forex.yml: '{EURRUB_TOM: 70.33, USDRUB_TOM: 63.18}'
  forex:
    EURRUB_TOM: 70.33
    USDRUB_TOM: 63.18
  text: Lorem ipsum dolor sit amet
...
```

Functions

new ([data])

Create new object.

Parameters:

- data: ({string=string,. . . }) Plaintext content (optional)

Returns:

(ClusterwideConfig)

Or

(nil)

(table) Error description

save (clusterwide_config, filename)

Write configuration to filesystem.

Write atomicity is achieved by splitting it into two phases: 1. Configuration is saved with a random filename in the same directory 2. Temporal filename is renamed to the destination

Parameters:

- clusterwide_config: (ClusterwideConfig)
- filename: (string)

Returns:

(boolean) true

Or

(nil)

(table) Error description

load (filename)

Load object from filesystem.

This function handles both old-style single YAML and new-style directory with a file tree.

Parameters:

- filename: (string)

Returns:

(ClusterwideConfig)

Or

(nil)

(table) Error description

Local Functions

load_from_file (filename)

Load old-style config from YAML file.

Parameters:

- filename: (string) Filename to load.

Returns:

(ClusterwideConfig)

Or

(nil)

(table) Error description

load_from_dir (path)

Load new-style config from a directory.

Parameters:

- path: (string) Path to the config.

Returns:

(ClusterwideConfig)

Or

(nil)

(table) Error description

remove (string)

Remove config from filesystem atomically.

The atomicity is achieved by splitting it into two phases: 1. Configuration is saved with a random filename in the same directory 2. Temporal filename is renamed to the destination

Parameters:

- string: (path) Directory path to remove.

Returns:

(boolean) true

Or

(nil)

(table) Error description

Module cartridge.rpc

Remote procedure calls between cluster instances.

Functions

get_candidates (role_name[, opts])

List instances suitable for performing a remote call.

Parameters:

- role_name: (string)
- opts:
  - leader_only: (optional boolean) Filter instances which are leaders now.(default: false)
  - healthy_only: (optional boolean) The member is considered healthy ifit reports either ConfiguringRoles or RolesConfigured stateand its SWIM status is either alive or suspect (added in v1.1.0-11, default: true)

Returns:

({string,. . . }) URIs

call (role_name, fn_name[, args[, opts]])

Perform a remote procedure call. Find a suitable healthy instance with an enabled role and perform a [net.box conn:call](https://tarantool.io/en/doc/latest/reference/reference_lua/net_box/#net-box-call) on it. rpc.call() can only be used for functions defined in role return table unlike net.box conn:call() , which is used for global functions as well.

Parameters:

- role_name: (string)
- fn_name: (string)

- args: (table) (optional)
- opts:
  - prefer_local: (optional boolean) Don't perform a remote call if possible. When the role is enabledlocally and current instance is healthy the remote netbox call issubstituted with a local Lua function call. When the option isdisabled it never tries to perform call locally and always usesnetbox connection, even to connect self.(default: true)
  - leader_only: (optional boolean) Perform a call only on the replica set leaders.(default: false)
  - uri: (optional string) Force a call to be performed on this particular uri.Disregards member status and opts.prefer_local .Conflicts with opts.leader_only = true .(added in v1.2.0-63)
  - remote_only: (deprecated) Use prefer_local instead.
  - timeout: passed to net.box conn:call options.
  - buffer: passed to net.box conn:call options.
  - on_push: passed to net.box conn:call options.
  - on_push_ctx: passed to net.box conn:call options.

Returns:

conn:call() result

Or

(nil)

(table) Error description

Usage:

```
-- myrole.lua
return {
    role_name = 'myrole',
    add = function(a, b) return a + b end,
}
```

```
-- call it as follows:
cartridge.rpc_call('myrole', 'add', {2, 2}) -- returns 4
```

Local Functions

get_connection (role_name[, opts])

Connect to an instance with an enabled role.

Parameters:

- role_name: (string)
- opts:
  - prefer_local: (optional boolean)
  - leader_only: (optional boolean)

Returns:

net.box connection

Or

(nil)

(table) Error description

Module cartridge.tar

Handle basic tar format.

<http://www.gnu.org/software/tar/manual/html_node/Standard.html>

While an archive may contain many files, the archive itself is a single ordinary file. Physically, an archive consists of a series of file entries terminated by an end-of-archive entry, which consists of two 512 blocks of zero bytes. A file entry usually describes one of the files in the archive (an archive member), and consists of a file header and the contents of the file. File headers contain file names and statistics, checksum information which tar uses to detect file corruption, and information about file types.

A tar archive file contains a series of blocks. Each block contains exactly 512 (BLOCKSIZE) bytes:

```
+---------+-------+-------+-------+---------+-------+-----
| header1 | file1 |  ...  |  ...  | header2 | file2 | ...
+---------+-------+-------+-------+---------+-------+-----
```

All characters in header blocks are represented by using 8-bit characters in the local variant of ASCII. Each field within the structure is contiguous; that is, there is no padding used within the structure. Each character on the archive medium is stored contiguously. Bytes representing the contents of files (after the header block of each file) are not translated in any way and are not constrained to represent characters in any character set. The tar format does not distinguish text files from binary files, and no translation of file contents is performed.

Functions

pack (files)

Create TAR archive.

Parameters:

- files: ({string=string})

Returns:

(string) The archive

Or

(nil)

(table) Error description

unpack (tar)

Parse TAR archive.

Only regular files are extracted, directories are ommitted.

Parameters:

- tar: (string)

Returns:

({string=string}) Extracted files (their names and content)

Or

(nil)

(table) Error description

Module cartridge.pool

Connection pool.

Reuse tarantool net.box connections with ease.

Functions

connect (uri[, opts])

Connect a remote or get cached connection. Connection is established using net.box.connect() .

Parameters:

- uri: (string)
- opts:
  - wait_connected: (boolean or number) by default, connection creation is blocked until theconnection is established, but passing wait_connected=false makes it return immediately. Also, passing a timeout makes itwait before returning (e.g. wait_connected=1.5 makes it waitat most 1.5 seconds).
  - connect_timeout: (optional number) (deprecated)Use wait_connected instead
  - user: (deprecated) don't use it
  - password: (deprecated) don't use it
  - reconnect_after: (deprecated) don't use it

Returns:

net.box connection

Or

(nil)

(table) Error description

Local Functions

format_uri (uri)

Enrich URI with credentials. Suitable to connect other cluster instances.

Parameters:

- uri: (string) host:port

Returns:

(string) username:password@host:port

map_call (fn_name[, args[, opts]])

Perform a remote call to multiple URIs and map results.

(Added in v1.2.0-17)

Parameters:

- fn_name: (string)
- args: (table) function arguments (optional)
- opts:
  - uri_list: ({string,. . . }) array of URIs for performing remote call
  - timeout: (optional number) passed to net.box conn:call()

Returns:

({URI=value,. . . }) Call results mapping for every URI.

(table) United error object, gathering errors for every URI that failed.

Module cartridge.confapplier

Configuration management primitives.

Implements the internal state machine which helps to manage cluster operation and protects from invalid state transitions.

Functions

get_active_config ()

Get current ClusterwideConfig object of instance

Returns:

cartridge.clusterwide-config or nil, if instance not bootstrapped.

get_readonly ([section_name])

Get a read-only view on the clusterwide configuration.

Returns either conf[section_name] or entire conf . Any attempt to modify the section or its children will raise an error.

Parameters:

- section_name: (string) (optional)

Returns:

(table)

get_deepcopy ([section_name])

Get a read-write deep copy of the clusterwide configuration.

Returns either conf[section_name] or entire conf . Changing it has no effect unless it's used to patch clusterwide configuration.

Parameters:

- section_name: (string) (optional)

Returns:

(table)

Local Functions

set_state (state[, err])

Perform state transition.

Parameters:

- state: (string) New state
- err: (optional)

Returns:

(nil)

wish_state (state[, timeout])

Make a wish for meeting desired state.

Parameters:

- state: (string) Desired state.
- timeout: (number) (optional)

Returns:

(string) Final state, may differ from desired.

validate_config (clusterwide_config_new)

Validate configuration by all roles.

Parameters:

- clusterwide_config_new: (table)

Returns:

(boolean) true

Or

(nil)

(table) Error description

apply_config (clusterwide_config)

Apply the role configuration.

Parameters:

- clusterwide_config: (table)

Returns:

(boolean) true

Or

(nil)

(table) Error description

Module cartridge.test-helpers

Helpers for integration testing.

This module extends luatest.helpers with cartridge-specific classes and helpers.

Fields

Server

Extended luatest.server class to run tarantool instance.

See also:

- cartridge.test-helpers.server

Cluster

Class to run and manage multiple tarantool instances.

See also:

- cartridge.test-helpers.cluster

Etcd

Class to run and manage etcd node.

See also:

- cartridge.test-helpers.etcd

Module cartridge.remote-control

Tarantool remote control server.

Allows to control an instance over TCP by net.box call and eval . The server is designed as a partial replacement for the iproto protocol. It's most useful when box.cfg wasn't configured yet.

Other net.box features aren't supported and will never be.

(Added in v0.10.0-2)

Local Functions

bind (host, port)

Init remote control server.

Bind the port but don't start serving connections yet.

Parameters:

- host: (string)
- port: (string or number)

Returns:

(boolean) true

Or

(nil)

(table) Error description

accept (credentials)

Start remote control server. To connect the server use regular net.box connection.

Access is restricted to the user with specified credentials, which can be passed as `net_box.connect('username:password@host:port')` .

Parameters:

- credentials:
  - username: (string)
  - password: (string)

unbind ()

Stop the server.

It doesn't interrupt any existing connections.

drop_connections ()

Explicitly drop all established connections.

Module cartridge.service-registry

Inter-role interaction.

These functions make different roles interact with each other.

The registry stores initialized modules and accesses them within the one and only current instance. For cross-instance access, use the cartridge.rpc module.

Functions

set (module_name, instance)

Put a module into registry or drop it. This function typically doesn't need to be called explicitly, the cluster automatically sets all the initialized roles.

Parameters:

- module_name: (string)
- instance: (nil or table)

Returns:

(nil)

get (module_name)

Get a module from registry.

Parameters:

- module_name: (string)

Returns:

(nil)

Or

(table) instance

Module custom-role

User-defined role API.

If you want to implement your own role it must conform this API.

Functions

init (opts)

Role initialization callback. Called when role is enabled on an instance. Caused either by editing topology or instance restart.

Parameters:

- opts:
  - is_master: (boolean)

stop (opts)

Role shutdown callback. Called when role is disabled on an instance.

Parameters:

- opts:
  - is_master: (boolean)

validate_config (conf_new, conf_old)

Validate clusterwide configuration callback.

Parameters:

- conf_new: (table)
- conf_old: (table)

apply_config (conf, opts)

Apply clusterwide configuration callback.

Parameters:

- conf: (table) Clusterwide configuration
- opts:
  - is_master: (boolean)

Fields

role_name

Displayed role name. When absent, module name is used instead.

- role_name: (string)

hidden

Hidden role flag. aren't listed in cartridge.admin_get_replicasets().roles and therefore in WebUI. Hidden roled are supposed to be a dependency for another role.

- hidden: (boolean)

permanent

Permanent role flag. Permanent roles will be enabled on every instance in cluster. Implies hidden = true .

- permanent: (boolean)

Module cartridge.lua-api.stat

Administration functions (box.slab.info related).

Local Functions

get_stat (uri)

Retrieve box.slab.info of a remote server.

Parameters:

- uri: (string)

Returns:

(table)

Or

(nil)

(table) Error description

Module cartridge.lua-api.boxinfo

Administration functions (box.info related).

Local Functions

get_info (uri)

Retrieve box.cfg and box.info of a remote server.

Parameters:

- uri: (string)

Returns:

(table)

Or

(nil)

(table) Error description

Module cartridge.lua-api.get-topology

Administration functions (get-topology implementation).

Tables

ReplicasetInfo

Replicaset general information.

Fields:

- uuid: (string) The replicaset UUID.
- roles: ({string,. . . }) Roles enabled on the replicaset.
- status: (string) Replicaset health.
- master: (ServerInfo) Replicaset leader according to configuration.
- active_master: (ServerInfo) Active leader.
- weight: (number) Vshard replicaset weight.Matters only if vshard-storage role is enabled.
- vshard_group: (string) Name of vshard group the replicaset belongs to.
- all_rw: (boolean) A flag indicating that all servers in the replicaset should be read-write.
- alias: (string) Human-readable replicaset name.
- servers: ({ServerInfo,. . . }) Circular reference to all instances in the replicaset.

ServerInfo

Instance general information.

Fields:

- alias: (string) Human-readable instance name.
- uri: (string)
- uuid: (string)
- disabled: (boolean)
- status: (string) Instance health.
- message: (string) Auxilary health status.
- replicaset: (ReplicasetInfo) Circular reference to a replicaset.
- priority: (number) Leadership priority for automatic failover.

- clock_delta: (number) Difference between remote clock and the current one (inseconds), obtained from the membership module (SWIM protocol).Positive values mean remote clock are ahead of local, and viceversa.
- zone: (string)

Local Functions

get_topology ()

Get servers and replicasets lists.

Returns:

({servers={ServerInfo,. . . },replicasets={ReplicasetInfo,. . . }})

Or

(nil)

(table) Error description

Module cartridge.lua-api.edit-topology

Administration functions (edit-topology implementation).

Editing topology

edit_topology (args)

Edit cluster topology. This function can be used for:

- bootstrapping cluster from scratch
- joining a server to an existing replicaset
- creating new replicaset with one or more servers
- editing uri/labels of servers
- disabling and expelling servers

(Added in v1.0.0-17)

Parameters:

- args:
  - servers: (optional {EditServerParams,..})
  - replicasets: (optional {EditReplicasetParams,..})

EditReplicasetParams

Replicatets modifications.

Fields:

- uuid: (optional string)

- alias: (optional string)
- roles: (optional {string,. . . })
- all_rw: (optional boolean)
- weight: (optional number)
- failover_priority: (optional {string,. . . }) array of uuids specifying servers failover priority
- vshard_group: (optional string)
- join_servers: (optional {JoinServerParams,. . . })

JoinServerParams

Parameters required for joining a new server.

Fields:

- uri: (string)
- uuid: (optional string)
- zone: (optional string) (Added in v2.4.0-14)
- labels: (optional table)

EditServerParams

Servers modifications.

Fields:

- uri: (optional string)
- uuid: (string)
- zone: (optional string)
- labels: (optional table)
- disabled: (optional boolean)
- expelled: (optional boolean) Expelling an instance is permanent and can't be undone.It's suitable for situations when the hardware is destroyed,snapshots are lost and there is no hope to bring it back to life.

Module cartridge.lua-api.topology

Administration functions (topology related).

Functions

get_servers ([uuid])

Get servers list. Optionally filter out the server with the given uuid.

Parameters:

- uuid: (string) (optional)

Returns:

({ServerInfo,. . . })

Or

(nil)

(table) Error description

get_replicasets ([uuid])

Get replicasets list. Optionally filter out the replicaset with given uuid.

Parameters:

- uuid: (string) (optional)

Returns:

({ReplicasetInfo,. . . })

Or

(nil)

(table) Error description

probe_server (uri)

Discover an instance.

Parameters:

- uri: (string)

enable_servers (uuids)

Enable nodes after they were disabled.

Parameters:

- uuids: ({string,. . . })

Returns:

({ServerInfo,. . . })

Or

(nil)

(table) Error description

disable_servers (uuids)

Temporarily diable nodes.

Parameters:

- uuids: ({string,. . . })

Returns:

({ServerInfo,. . . })

Or

(nil)

(table) Error description

Local Functions

get_self ()

Get alias, uri and uuid of current instance.

Returns:

(table)

Module cartridge.lua-api.failover

Administration functions (failover related).

Functions

get_params ()

Get failover configuration.

(Added in v2.0.2-2)

Returns:

(FailoverParams)

set_params (opts)

Configure automatic failover.

(Added in v2.0.2-2)

Parameters:

- opts:
  - mode: (optional string)
  - state_provider: (optional string)

  - failover_timeout: (optional number) (added in v2.3.0-52)
  - tarantool_params: (optional table)
  - etcd2_params: (optional table) (added in v2.1.2-26)
  - fencing_enabled: (optional boolean) (added in v2.3.0-57)
  - fencing_timeout: (optional number) (added in v2.3.0-57)
  - fencing_pause: (optional number) (added in v2.3.0-57)

Returns:

(boolean) true if config applied successfully

Or

(nil)

(table) Error description

get_failover_enabled ()

Get current failover state.

(Deprecated since v2.0.2-2)

set_failover_enabled (enabled)

Enable or disable automatic failover.

(Deprecated since v2.0.2-2)

Parameters:

- enabled: (boolean)

Returns:

(boolean) New failover state

Or

(nil)

(table) Error description

promote (replicaset_uuid[, opts])

Promote leaders in replicasets.

Parameters:

- replicaset_uuid: (table)] = leader_uuid }
- opts:
  - force_inconsistency: (optional boolean) (default: false)

Returns:

(boolean) true On success

Or

(nil)

(table) Error description

Tables

FailoverParams

Failover parameters.

(Added in v2.0.2-2)

Fields:

- mode: (string) Supported modes are "disabled", "eventual" and "stateful"
- state_provider: (optional string) Supported state providers are "tarantool" and "etcd2".
- failover_timeout: (number) (added in v2.3.0-52)Timeout (in seconds), used by membership tomark suspect members as dead (default: 20)
- tarantool_params: (added in v2.0.2-2)
  - uri: (string)
  - password: (string)
- etcd2_params: (added in v2.1.2-26)
  - prefix: (string) Prefix used for etcd keys: <prefix>/lock and‘<prefix>/leaders‘
  - lock_delay: (optional number) Timeout (in seconds), determines lock's time-to-live (default: 10)
  - endpoints: (optional table) URIs that are used to discover and to access etcd cluster instances.(default: {`'http://localhost:2379'`, `'http://localhost:4001'`})
  - username: (optional string) (default: "")
  - password: (optional string) (default: "")
- fencing_enabled: (boolean) (added in v2.3.0-57)Abandon leadership when both the state provider quorum and atleast one replica are lost (suitable in stateful mode only,default: false)
- fencing_timeout: (number) (added in v2.3.0-57)Time (in seconds) to actuate fencing after the check fails(default: 10)
- fencing_pause: (number) (added in v2.3.0-57)The period (in seconds) of performing the check(default: 2)

Module cartridge.lua-api.vshard

Administration functions (vshard related).

Functions

bootstrap_vshard ()

Call vshard.router.bootstrap() . This function distributes all buckets across the replica sets.

Returns:

(boolean) true

Or

(nil)

(table) Error description

Module cartridge.lua-api.deprecated

Administration functions (deprecated).

Deprecated functions

join_server (args)

Join an instance to the cluster (deprecated).

(Deprecated since v1.0.0-17 in favor of cartridge.admin_edit_topology)

Parameters:

- args:
  - uri: (string)
  - instance_uuid: (optional string)
  - replicaset_uuid: (optional string)
  - roles: (optional {string,. . . })
  - timeout: (optional number)
  - zone: (optional string) (Added in v2.4.0-14)
  - labels: (optional {[string]=string,. . . })
  - vshard_group: (optional string)
  - replicaset_alias: (optional string)
  - replicaset_weight: (optional number)

Returns:

(boolean) true

Or

(nil)

(table) Error description

edit_server (args)

Edit an instance (deprecated).

(Deprecated since v1.0.0-17 in favor of cartridge.admin_edit_topology)

Parameters:

- args:
  - uuid: (string)
  - uri: (optional string)
  - labels: (optional {[string]=string,...})

Returns:

(boolean) true

Or

(nil)

(table) Error description

expel_server (uuid)

Expel an instance (deprecated). Forever.

(Deprecated since v1.0.0-17 in favor of cartridge.admin_edit_topology)

Parameters:

- uuid: (string)

Returns:

(boolean) true

Or

(nil)

(table) Error description

edit_replicaset (args)

Edit replicaset parameters (deprecated).

(Deprecated since v1.0.0-17 in favor of cartridge.admin_edit_topology)

Parameters:

- args:
  - uuid: (string)
  - alias: (string)
  - roles: (optional {string,...})
  - master: (optional {string,...}) Failover order
  - weight: (optional number)

  - vshard_group: (optional string)
  - all_rw: (optional boolean)

Returns:

(boolean) true

Or

(nil)

(table) Error description

Class cartridge.test-helpers.cluster

Class to run and manage multiple tarantool instances.

Functions

Cluster:new (object)

Build cluster object.

Parameters:

- object:
  - datadir: (string) Data directory for all cluster servers.
  - server_command: (string) Command to run server.
  - cookie: (string) Cluster cookie.
  - base_http_port: (int) Value to calculate server's http_port. (optional)
  - base_advertise_port: (int) Value to calculate server's advertise_port. (optional)
  - use_vshard: (bool) bootstrap vshard after server is started. (optional)
  - replicasets: (tab) Replicasets configuration. List of replicaset_config

Returns:

object

Cluster:server (alias)

Find server by alias.

Parameters:

- alias: (string)

Returns:

cartridge.test-helpers.server

Cluster:apply_topology ()

Execute edit_topology GraphQL request to setup replicasets, apply roles join servers to replicasets.

Cluster:start ()

Bootstraps cluster if it wasn't bootstrapped before. Otherwise starts servers.

Cluster:stop ()

Stop all servers.

Cluster:join_server (server)

Register running server in the cluster.

Parameters:

- server: (Server) Server to be registered.

Cluster:wait_until_healthy (server)

Blocks fiber until cartridge.is_healthy() returns true on main_server.

Parameters:

- server:

Cluster:upload_config (config)

Upload application config, shortcut for cluster.main_server:upload_config(config) .

Parameters:

- config:

See also:

- cartridge.test-helpers.server.Server:upload_config

Cluster:download_config ()

Download application config, shortcut for cluster.main_server:download_config() .

See also:

- cartridge.test-helpers.server.Server:download_config

Cluster:retrying (config, fn[, ...])

Keeps calling fn until it returns without error. Throws last error if config.timeout is elapsed.

Parameters:

- config: (tab) Options for luatest.helpers.retrying .
- fn: (func) Function to call
- ...: Args to run fn with. (optional)

Tables

cartridge.test-helpers.cluster.replicaset_config

Replicaset config.

Fields:

- alias: (string) Prefix to generate server alias automatically. (optional)
- uuid: (string) Replicaset uuid. (optional)
- roles: ({string}) List of roles for servers in the replicaset.
- vshard_group: (optional string) Name of vshard group.
- all_rw: (optional boolan) Make all replicas writable.
- servers: (table or number) List of objects to build Server s with or.. code-block:: lua number of servers in replicaset.

Class cartridge.test-helpers.server

Extended luatest.Server class to run tarantool instance.

Functions

Server:build_env ()

Generates environment to run process with. The result is merged into os.environ().

Returns:

map

Server:start ()

Start the server.

Server:stop ()

Stop server process.

Server:graphql (request, http_options)

Perform GraphQL request.

Parameters:

- request:
  - query: (string) grapqhl query
  - variables: (optional table) variables for graphql query

    - raise: (optional boolean) raise if response contains an error(default: true)

- http_options: (table) passed to http_request options. (optional)

Returns:

(table) parsed response JSON.

Raises:

- HTTPRequest error
- GraphQL error

Server:join_cluster (main_server[, options])

Advertise this server to the cluster.

Parameters:

- main_server: Server to perform GraphQL request on.
- options:
    - timeout: request timeout

Server:setup_replicaset (config)

Update server's replicaset config.

Parameters:

- config:
    - uuid: replicaset uuid
    - roles: list of roles
    - master:
    - weight:

Server:upload_config (config)

Upload application config.

Parameters:

- config: (string or table) * table will be encoded as yaml and posted to /admin/config.

Server:download_config ()

Download application config.

Methods

cartridge.test-helpers.server:new (object)

Build server object.

Parameters:

- object:
  - command: (string) Command to start server process.
  - workdir: (string) Value to be passed in TARANTOOL_WORKDIR .
  - chdir: (bool) Path to cwd before starting a process. (optional)
  - env: (tab) Table to pass as env variables to process. (optional)
  - args: (tab) Args to run command with. (optional)
  - http_port: (int) Value to be passed in TARANTOOL_HTTP_PORT and used to perform HTTP requests. (optional)
  - advertise_port: (int) Value to generate TARANTOOL_ADVERTISE_URI and used for net_box connection.
  - net_box_port: (int) Alias for advertise_port . (optional)
  - net_box_credentials: (tab) Override default net_box credentials. (optional)
  - alias: (string) Instance alias.
  - cluster_cookie: (string) Value to be passed in TARANTOOL_CLUSTER_COOKIE and used as default net_box password.
  - instance_uuid: (string) Server identifier. (optional)
  - replicaset_uuid: (string) Replicaset identifier. (optional)

Returns:

input object

Class cartridge.test-helpers.etcd

Class to run and manage etcd node.

Functions

Etcd:new (object)

Build etcd node object.

Parameters:

- object:
  - name: (string) Human-readable node name.
  - workdir: (string) Path to the data directory.
  - etcd_path: (string) Path to the etcd executable.

- peer_url: (string) URL to listen on for peer traffic.
- client_url: (string) URL to listen on for client traffic.
- env: (tab) Environment variables passed to the process. (optional)
- args: (tab) Command-line arguments passed to the process. (optional)

Returns:

object

Etcd:start ()

Start the node.

Etcd:stop ()

Stop the node.

4.3.6 Cartridge Command Line Interface

Tests passing

Contents

Installation

1. Install third-party software:
   - Install git, a version control system.
   - Install the unzip utility.
   - Install the gcc compiler.
   - Install the cmake and make tools.

2. Install Tarantool 1.10 or higher.

   You can:

   - Install it from a package (see https://www.tarantool.io/en/download/ for OS-specific instructions).
   - Build it from sources (see https://www.tarantool.io/en/download/os-installation/building-from-source/).

3. [On all platforms except MacOS X] If you built Tarantool from sources, you need to manually set up the Tarantool packages repository:

   ```
   curl -L https://tarantool.io/installer.sh | sudo -E bash -s -- --repo-only
   ```

4. Install the cartridge-cli package:

   - for CentOS, Fedora, ALT Linux (RPM package):

     ```
     sudo yum install cartridge-cli
     ```

   - for Debian, Ubuntu (DEB package):

     ```
     sudo apt-get install cartridge-cli
     ```

   - for MacOS X (Homebrew formula):

     ```
     brew install cartridge-cli
     ```

5. Check the installation:

   ```
   cartridge version
   ```

Now you can create and start your first application!

Quick start

To create your first application:

```
cartridge create --name myapp
```

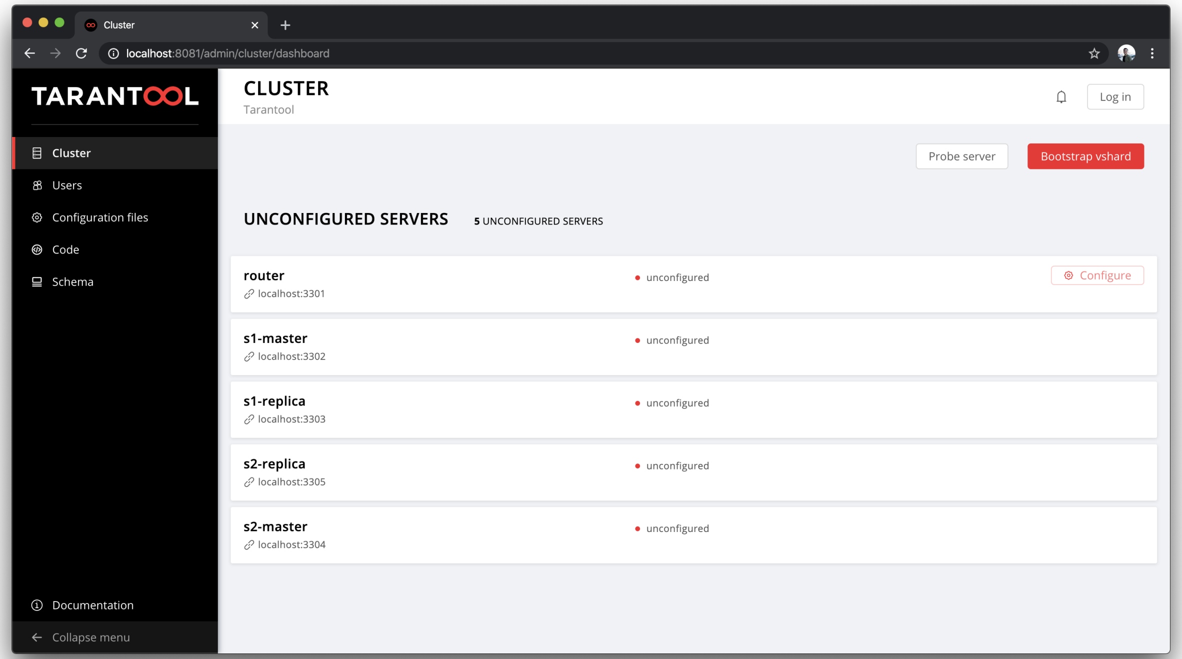
Let's go inside:

```
cd myapp
```

Now build the application and start it:

```
cartridge build
cartridge start
```

That's it! Now you can visit http://localhost:8081 and see your application's Admin Web UI:



router localhost:3301	unconfigured	Configure
s1-master localhost:3302	unconfigured	
s1-replica localhost:3303	unconfigured	
s2-replica localhost:3305	unconfigured	
s2-master localhost:3304	unconfigured	

You can find more details in this README document or you can start with the getting started guide.

Command-line completion

Linux

RPM and DEB cartridge-cli packages contain /etc/bash_completion.d/cartridge Bash completion script. To enable completion after cartridge-cli installation start a new shell or source /etc/bash_completion.d/cartridge completion file. Make sure that you have bash completion installed.

To install Zsh completion, say

```
cartridge gen completion --skip-bash --zsh="${fpath[1]}/_cartridge"
```

To enable shell completion:

```
echo "autoload -U compinit; compinit" >> ~/.zshrc
```

OS X

If you install cartridge-cli from brew, it automatically installs both Bash and Zsh completions.

Usage

For more details, say:

```
cartridge --help
```

The following commands are supported:

- create — create a new application from template;
- build — build the application for local development and testing;
- start — start a Tarantool instance(s);
- stop — stop a Tarantool instance(s);
- status — get current instance(s) status;
- log — get logs of instance(s);
- clean - clean instance(s) files;
- pack — pack the application into a distributable bundle;
- repair — patch cluster configuration files;
- admin - call an admin function provided by the application;
- replicasets - manage cluster replica sets running locally;
- enter and connect - connect to running instance.

The following global flags are supported:

- verbose — verbose mode, additional log messages are shown as well as commands/docker output (such as tarantoolctl rocks make or docker build output);
- debug — debug mode (the same as verbose, but temporary files and directories aren't removed);
- quiet — the mode that hides all logs; only errors are shown.

An application lifecycle

In a nutshell:

1. Create an application (e.g. myapp) from template:

```
cartridge create --name myapp
cd ./myapp
```

2. Build the application for local development and testing:

```
cartridge build
```

3. Run instances locally:

```
cartridge start
cartridge stop
```

4. Pack the application into a distributable (e.g. into an RPM package):

```
cartridge pack rpm
```

Creating an application from template

To create an application from the Cartridge template, say this in any directory:

```
cartridge create [PATH] [flags]
```

The following options ([flags]) are supported:

- --name strin is an application name.
- --from DIR is a path to the application template (see details below).
- --template string is a name of application template to be used. Currently only cartridge template is supported.

Application is created in the <path>/<app-name>/ directory.

By default, cartridge template is used. It contains a simple Cartridge application with:

- one custom role with an HTTP endpoint;
- sample tests and basic test helpers;
- files required for development (like .luacheckrc).

If you have git installed, this will also set up a Git repository with the initial commit, tag it with version 0.1.0, and add a .gitignore file to the project root.

Let's take a closer look at the files inside the <app_name>/ directory:

- application files:
  - app/roles/custom-role.lua a sample custom role with simple HTTP API; can be enabled as app.roles.custom
  - <app_name>-scm-1.rockspec file where you can specify application dependencies
  - init.lua file which is the entry point for your application
  - stateboard.init.lua file which is the entry point for the application stateboard
- special files (used to build and pack the application):
  - cartridge.pre-build
  - cartridge.post-build
  - Dockerfile.build.cartridge
  - Dockerfile.cartridge
- development files:
  - deps.sh script that resolves the dependencies from the .rockspec file and installs test dependencies (like luatest)
  - instances.yml file with instances configuration (used by cartridge start)
  - .cartridge.yml file with Cartridge configuration (used by cartridge start)
  - tmp directory for temporary files (used as a run dir, see .cartridge.yml)
  - .git file necessary for a Git repository
  - .gitignore file where you can specify the files for Git to ignore
  - env.lua file that sets common rock paths so that the application can be started from any directory.
- test files (with sample tests):

```
test
├── helper
│   ├── integration.lua
│   └── unit.lua
│   ├── helper.lua
│   ├── integration
│   │   └── api_test.lua
│   └── unit
│       └── sample_test.lua
```

- configuration files:
  - .luacheckrc
  - .luacov
  - .editorconfig

You can create your own application template and use it with cartridge create with --from flag.

If template directory is a git repository, the .git/ files would be ignored on instantiating template. In the created application a new git repo is initialized.

Template application shouldn't contain .rocks directory. To specify application dependencies use rockspec and cartridge.pre-build files.

Filenames and content can contain text templates.

Available variables are:

- Name — the application name;
- StateboardName — the application stateboard name (<app-name>-stateboard);
- Path - an absolute path to the application.

For example:

```
my-template
├── {{ .Name }}-scm-1.rockspec
└── init.lua
└── stateboard.init.lua
└── test
    └── sample_test.lua
```

init.lua:

```
print("Hi, I am {{ .Name }} application")
print("I also have a stateboard named {{ .StateboardName }}")
```

Building an application

To build your application locally (for local testing), say this in any directory:

```
cartridge build [PATH] [flags]
```

This command requires one argument — the path to your application directory (i.e. to the build source). The default path is . (the current directory).

This command runs:

1. cartridge.pre-build if the pre-build file exists. This builds the application in the [PATH] directory.
2. tarantoolctl rocks make if the rockspec file exists. This installs all Lua rocks to the [PATH] directory.

During step 1 of the cartridge build command, cartridge builds the application inside the application directory – unlike when building the application as part of the cartridge pack command, when the application is built in a temporary build directory and no build artifacts remain in the application directory.

During step 2 – the key step here – cartridge installs all dependencies specified in the rockspec file (you can find this file within the application directory created from template).

(An advanced alternative would be to specify build logic in the rockspec as cmake commands, like we do it for cartridge.)

If your application depends on closed-source rocks, or if the build should contain rocks from a project added as a submodule, then you need to install all these dependencies before calling tarantoolctl rocks make. You can do it using the file cartridge.pre-build in your application root (again, you can find this file within the application directory created from template). In this file, you can specify all rocks to build (e.g. tarantoolctl rocks make --chdir ./third_party/proj). For details, see special files.

As a result, in the application's .rocks directory you will get a fully built application that you can start locally from the application's directory.

Starting/stopping an application locally

start

Now, after the application is built, you can run it locally:

```
cartridge start [INSTANCE_NAME...] [flags]
```

where [INSTANCE_NAME...] means that several instances can be specified.

If no INSTANCE_NAME is provided, all the instances from the Cartridge instances configuration file are taken as arguments (see the --cfg option below).

We also need an application name (APP_NAME) to pass it to the instances while started and to define paths to the instance files (for example, <run-dir>/<APP_NAME>.<INSTANCE_NAME>.pid). By default, the APP_NAME is taken from the application rockspec in the current directory, but also it can be defined explicitly via the --name option (see description below).

Options

The following options ([flags]) are supported:

- --script FILE is the application's entry point. It should be a relative path to the entry point in the project directory or an absolute path. Defaults to init.lua (or to the value of the "script" parameter in the Cartridge configuration file).
- --run-dir DIR is the directory where PID and socket files are stored. Defaults to ./tmp/run (or to the value of the "run-dir" parameter in the Cartridge configuration file).
- --data-dir DIR is the directory where instances' data is stored. Each instance's working directory is <data-dir>/<app-name>.<instance-name>. Defaults to ./tmp/data (or to the value of the "data-dir" parameter in the Cartridge configuration file).
- --log-dir DIR is the directory to store instances logs when running in background. Defaults to ./tmp/log (or to the value of the "log-dir" parameter in the Cartridge configuration file).

- --cfg FILE is the configuration file for Cartridge instances. Defaults to ./instances.yml (or to the value of the "cfg" parameter in the Cartridge configuration file).
- --daemonize, -d starts the instance in background. With this option, Tarantool also waits until the application's main script is finished. For example, it is useful if the init.lua requires time-consuming startup from snapshot, and Tarantool waits for the startup to complete. This is also useful if the application's main script generates errors, and Tarantool can handle them.
- --stateboard starts the application stateboard as well as instances. Ignored if --stateboard-only is specified.
- --stateboard-only starts only the application stateboard. If specified, INSTANCE_NAME... are ignored.
- --name string defines the application name. By default, it is taken from the application rockspec.
- --timeout string Time to wait for instance(s) start in background. Can be specified in seconds or in the duration form (72h3m0.5s). Timeout can't be negative. Timeout 0 means no timeout (wait for instance(s) start forever). The default timeout is 60 seconds (1m0s).

Environment variables

The cartridge start command starts a Tarantool instance with enforced environment variables:

```
TARANTOOL_APP_NAME="<instance-name>"
TARANTOOL_INSTANCE_NAME="<app-name>"
TARANTOOL_CFG="<cfg>"
TARANTOOL_PID_FILE="<run-dir>/<app-name>.<instance-name>.pid"
TARANTOOL_CONSOLE_SOCK="<run-dir>/<app-name>.<instance-name>.control"
TARANTOOL_WORKDIR="<data-dir>/<app-name>.<instance-name>.control"
```

When started in background, a notify socket path is passed additionally:

```
NOTIFY_SOCKET="<data-dir>/<app-name>.<instance-name>.notify"
```

cartridge.cfg() uses TARANTOOL_APP_NAME and TARANTOOL_INSTANCE_NAME to read the instance's configuration from the file provided in TARANTOOL_CFG.

Overriding default options

You can override default options for the cartridge command in the ./.cartridge.yml configuration file.

Here is an example of .cartridge.yml:

```
run-dir: my-run-dir
cfg: my-instances.yml
script: my-init.lua
```

stop

To stop one or more running instances, say:

```
cartridge stop [INSTANCE_NAME...] [flags]
```

By default, SIGTERM is sent to instances.

The following options ([flags]) are supported:

- -f, --force indicates if instance(s) stop should be forced (sends SIGKILL).

The following options from the start command are supported:

- --run-dir DIR
- --cfg FILE
- --stateboard
- --stateboard-only

Note: run-dir should be exactly the same as used in the cartridge start command. PID files stored there are used to stop the running instances.

status

To check the current instance status, use the status command:

```
cartridge status [INSTANCE_NAME...] [flags]
```

The following options from the start command are supported:

- --run-dir DIR
- --cfg FILE
- --stateboard
- --stateboard-only

log

To get logs of the instance running in background, use the log command:

```
cartridge log [INSTANCE_NAME...] [flags]
```

The following options ([flags]) are supported:

- -f, --follow outputs appended data as the log grows.
- -n, --lines int is the number of lines to output (from the end). Defaults to 15.

The following options from the start command are supported:

- --log-dir DIR
- --run-dir DIR
- --cfg FILE
- --stateboard
- --stateboard-only

clean

To remove instance(s) files (log, workdir, console socket, PID-file and notify socket), use the clean command:

```
cartridge clean [INSTANCE_NAME...] [flags]
```

cartridge clean for running instance(s) causes an error.

The following options from the start command are supported:

- --log-dir DIR
- --data-dir DIR
- --run-dir DIR
- --cfg FILE
- --stateboard
- --stateboard-only

Packing an application

To pack your application, say this in any directory:

```
cartridge pack TYPE [PATH] [flags]
```

where:

- TYPE (required) is the distribution type. Supported types:
  - TGZ
  - RPM
  - DEB
  - Docker
- PATH (optional) is the path to the application directory to pack. Defaults to . (the current directory).

Note: If you pack application into RPM or DEB on MacOS without –use-docker flag, the result artifact is broken - it contains rocks and executables that can't be used on Linux. In this case packing fails.

The options ([flags]) are as follows:

- --name string (common for all distribution types) is the application name. It coincides with the package name and the systemd-service name. The default name comes from the package field in the rockspec file.
- --version string (common for all distribution types) is the application's package version. The expected pattern is major.minor.patch[-count][-commit]: if you specify major.minor.patch, it is normalized to major.minor.patch-count. The default version is determined as the result of git describe --tags --long. If the application is not a git repository, you need to set the --version option explicitly.
- --suffix string (common for all distribution types) is the result file (or image) name suffix.
- --unit-template string (used for rpm and deb) is the path to the template for the systemd unit file.

- --instantiated-unit-template string (used for rpm and deb) is the path to the template for the systemd instantiated unit file.
- --stateboard-unit-template string (used for rpm and deb) is the path to the template for the stateboard systemd unit file.
- --use-docker (enforced for docker) forces to build the application in Docker.
- --tag strings (used for docker) is the tag(s) of the Docker image that results from pack docker.
- --from string (used for docker) is the path to the base Dockerfile of the runtime image. Defaults to Dockerfile.cartridge in the application root.
- --build-from string (common for all distribution types, used for building in Docker) is the path to the base Dockerfile of the build image. Defaults to Dockerfile.build.cartridge in the application root.
- --no-cache creates build and runtime images with --no-cache docker flag.
- --cache-from strings images to consider as cache sources for both build and runtime images. See --cache-from flag for docker build command.
- --sdk-path string (common for all distribution types, used for building in Docker) is the path to the SDK to be delivered in the result artifact. Alternatively, you can pass the path via the TARANTOOL_SDK_PATH environment variable (this variable is of lower priority).
- --sdk-local (common for all distribution types, used for building in Docker) is a flag that indicates if the SDK from the local machine should be delivered in the result artifact.

For Tarantool Enterprise, you must specify one (and only one) of the --sdk-local and --sdk-path options.

For rpm, deb, and tgz, we also deliver rocks modules and executables specific for the system where the cartridge pack command is running.

For docker, the resulting runtime image will contain rocks modules and executables specific for the base image (centos:8).

Next, we dive deeper into the packaging process.

Build directory

The first step of the packaging process is to build the application.

By default, application build is done in a temporary directory in ~/.cartridge/tmp/, so the packaging process doesn't affect the contents of your application directory.

You can specify a custom build directory for your application in the CARTRIDGE_TEMPDIR environment variable. If this directory doesn't exists, it will be created, used for building the application, and then removed.

If you specify an existing directory in the CARTRIDGE_TEMPDIR environment variable, the CARTRIDGE_TEMPDIR/cartridge.tmp directory will be used for build and then removed. This directory will be cleaned up before building the application.

Distribution directory

For each distribution type, a temporary directory with application source files is created (further on we address it as application directory). This includes 3 stages.

Stage 1. Cleaning up the application directory

On this stage, some files are filtered out of the application directory:

- First, git clean -X -d -f removes all untracked and ignored files (it works for submodules, too).
- After that, .rocks and .git directories are removed.

Files permissions are preserved, and the code files owner is set to root:root in the resulting package.

All application files should have at least a+r permissions (a+rx for directories). Otherwise, cartridge pack command raises an error.

Stage 2. Building the application

On this stage, cartridge builds the application in the cleaned up application directory.

Stage 3. Cleaning up the files before packing

On this stage, cartridge runs cartridge.post-build (if it exists) to remove junk files (like node_modules) generated during application build.

See an example in special files.

Repairing a cluster

To repair a running application, you can use the cartridge repair command.

There are several simple rules you need to know before using this command:

- Rule #1 of repair is: you do not use it if you aren't sure that it's exactly what you need.
- Rule #2: always use --dry-run before running repair.
- Rule #3: do not hesitate to use the --verbose option.
- Rule #4: do not use the --force option if you aren't sure that it's exactly what you need.

Please, pay attention to the troubleshooting documentation before using repair.

What does repair actually do?

It patches the cluster-wide configuration files of application instances placed on the local machine. Note that it's not enough to apply new configuration: the configuration should be reloaded by the instance.

repair was created to be used on production (but it still can be used for local development). So, it requires the application name option --name. Moreover, remember that the default data directory is /var/lib/tarantool and the default run directory is /var/run/tarantool (both of them can be rewritten by options).

In default mode, repair walks across all cluster-wide configurations placed in <data-dir>/<app-name>.* directories and patches all found configuration files.

If the --dry-run flag is specified, files aren't patched, and only a computed configuration diff is shown.

If configuration files are diverged between instances on the local machine, repair raises an error. But you can specify the --force option to patch different versions of configuration independently.

repair can also reload configuration for all instances if the --reload flag is specified (only if the application uses cartridge >= 2.0.0). Configuration will be reloaded for all instances that are placed in the new configuration using console sockets that are placed in the run directory. Make sure that you specified the right run directory when using --reload flag.

```
cartridge repair [command]
```

The following repair commands are available (see details below):

- list-topology - shows the current topology summary;
- remove-instance - removes an instance from the cluster;
- set-leader - changes a replica set leader;
- set-uri - changes an instance's advertise URI.

All repair commands have these flags:

- --name (required) is an application name.
- --data-dir is a directory where the instances' data is stored (defaults to /var/lib/tarantool).

All commands, except list-topology, have these flags:

- --run-dir is a directory where PID and socket files are stored (defaults to /var/run/tarantool).
- --dry-run runs the repair command in the dry-run mode (shows changes but doesn't apply them).
- --reload is a flag that enables reloading configuration on instances after the patch.

Repair commands

Topology summary

```
cartridge repair list-topology [flags]
```

Takes no arguments. Prints the current topology summary.

Remove instance

```
cartridge repair remove-instance UUID [flags]
```

Removes an instance with the specified UUID from cluster. If the specified instance isn't found, raises an error.

Set leader

```
cartridge repair set-leader REPLICASET-UUID INSTANCE-UUID [flags]
```

Sets the specified instance as the leader of the specified replica set. Raises an error if:

- a replica set or instance with the specified UUID doesn't exist;
- the specified instance doesn't belong to the specified replica set;
- the specified instance is disabled or expelled.

Set advertise URI

```
cartridge repair set-uri INSTANCE-UUID URI-TO [flags]
```

Rewrites the advertise URI for the specified instance. If the specified instance isn't found or is expelled, raises an error.

TGZ

cartridge pack tgz ./myapp creates a .tgz archive. It contains all files from the distribution directory (i.e. the application source code and rocks modules described in the application rockspec).

The result artifact name is <name>-<version>[-<suffix>].tar.gz.

RPM and DEB

cartridge pack rpm|deb ./myapp creates an RPM or DEB package.

The result artifact name is <name>-<version>[-<suffix>].{rpm,deb}.

Usage example

After package installation you need to specify configuration for instances to start.

For example, if your application is named myapp and you want to start two instances, put the myapp.yml file into the /etc/tarantool/conf.d directory.

```
myapp:
  cluster_cookie: secret-cookie

myapp.instance-1:
  http_port: 8081
  advertise_uri: localhost:3301

myapp.instance-2:
  http_port: 8082
  advertise_uri: localhost:3302
```

For more details about instances configuration see the documentation.

Now, start the configured instances:

```
systemctl start myapp@instance-1
systemctl start myapp@instance-2
```

If you use stateful failover, you need to start application stateboard.

(Remember that your application should contain stateboard.init.lua in its root.)

Add the myapp-stateboard section to /etc/tarantool/conf.d/myapp.yml:

```
myapp-stateboard:
  listen: localhost:3310
  password: passwd
```

Then, start the stateboard service:

```
systemctl start myapp-stateboard
```

Package details

The installed package name will be <name> no matter what the artifact name is.

It contains meta information: the package name (which is the application name), and the package version.

If you use an opensource version of Tarantool, the package has a tarantool dependency (version >= <major>.<minor> and < <major+1>, where <major>.<minor> is the version of Tarantool used for packing the application). You should enable the Tarantool repo to allow your package manager install this dependency correctly:

- for both RPM and DEB:

  ```
  curl -L https://tarantool.io/installer.sh | VER=${TARANTOOL_VERSION} bash
  ```

The package contents is as follows:

- the contents of the distribution directory, placed in the /usr/share/tarantool/<app-name> directory (for Tarantool Enterprise, this directory also contains tarantool and tarantoolctl binaries);
- unit files for running the application as a systemd service: /etc/systemd/system/<app-name>.service and /etc/systemd/system/<app-name>@.service;
- application stateboard unit file: /etc/systemd/system/<app-name>-stateboard.service (will be packed only if the application contains stateboard.init.lua in its root);
- the file /usr/lib/tmpfiles.d/<app-name>.conf that allows the instance to restart after server restart.

The following directories are created:

- /etc/tarantool/conf.d/ — directory for instances configuration;
- /var/lib/tarantool/ — directory to store instances snapshots;
- /var/run/tarantool/ — directory to store PID-files and console sockets.

See the documentation for details about deploying a Tarantool Cartridge application.

To start the instance-1 instance of the myapp service, say:

```
systemctl start myapp@instance-1
```

To start the application stateboard service, say:

```
systemctl start myapp-stateboard
```

This instance will look for its configuration across all sections of the YAML file(s) stored in /etc/tarantool/conf.d/*.

Use the options --unit-template, --instantiated-unit-template and --stateboard-unit-template to customize standard unit files.

You may need it first of all for DEB packages, if your build platform is different from the deployment platform. In this case, ExecStartPre may contain an incorrect path to mkdir. As a hotfix, we suggest customizing the unit files.

Example of an instantiated unit file:

```
[Unit]
Description=Tarantool Cartridge app {{ .Name }}@%i
After=network.target

[Service]
Type=simple
ExecStartPre=/bin/sh -c 'mkdir -p {{ .InstanceWorkDir }}'
ExecStart={{ .Tarantool }} {{ .AppEntrypointPath }}
Restart=on-failure
RestartSec=2
User=tarantool
Group=tarantool

Environment=TARANTOOL_APP_NAME={{ .Name }}
Environment=TARANTOOL_WORKDIR={{ .InstanceWorkDir }}
Environment=TARANTOOL_CFG={{ .ConfPath }}
Environment=TARANTOOL_PID_FILE={{ .InstancePidFile }}
Environment=TARANTOOL_CONSOLE_SOCK={{ .InstanceConsoleSock }}
Environment=TARANTOOL_INSTANCE_NAME=%i

LimitCORE=infinity
# Disable OOM killer
OOMScoreAdjust=-1000
# Increase fd limit for Vinyl
LimitNOFILE=65535

# Systemd waits until all xlogs are recovered
TimeoutStartSec=86400s
# Give a reasonable amount of time to close xlogs
TimeoutStopSec=10s

[Install]
WantedBy=multi-user.target
Alias={{ .Name }}.%i
```

Supported variables:

- Name — the application name;
- StateboardName — the application stateboard name (<app-name>-stateboard);
- DefaultWorkDir — default instance working directory (/var/lib/tarantool/<app-name>.default);
- InstanceWorkDir — application instance working directory (/var/lib/tarantool/<app-name>.<instance-name>);
- StateboardWorkDir — stateboard working directory (/var/lib/tarantool/<app-name>-stateboard);
- DefaultPidFile — default instance pid file (/var/run/tarantool/<app-name>.default.pid);
- InstancePidFile — application instance pid file (/var/run/tarantool/<app-name>.<instance-name>.pid);
- StateboardPidFile — stateboard pid file (/var/run/tarantool/<app-name>-stateboard.pid);
- DefaultConsoleSock — default instance console socket (/var/run/tarantool/<app-name>.default.control);
- InstanceConsoleSock — application instance console socket (/var/run/tarantool/<app-name>.<instance-name>.control);

- StateboardConsoleSock — stateboard console socket (/var/run/tarantool/<app-name>-stateboard.control);
- ConfPath — path to the application instances config (/etc/tarantool/conf.d);
- AppEntrypointPath — path to the application entrypoint (/usr/share/tarantool/<app-name>/init.lua);
- StateboardEntrypointPath — path to the stateboard entrypoint (/usr/share/tarantool/<app-name>/stateboard.init.lua);

Docker

cartridge pack docker ./myapp builds a Docker image where you can start one instance of the application.

Usage example

To start the instance-1 instance of the myapp application, say:

```
docker run -d \
        --name instance-1 \
        -e TARANTOOL_INSTANCE_NAME=instance-1 \
        -e TARANTOOL_ADVERTISE_URI=3302 \
        -e TARANTOOL_CLUSTER_COOKIE=secret \
        -e TARANTOOL_HTTP_PORT=8082 \
        -p 127.0.0.1:8082:8082 \
        myapp:1.0.0
```

By default, TARANTOOL_INSTANCE_NAME is set to default.

To check the instance logs, say:

```
docker logs instance-1
```

Runtime image tag

The result image is tagged as follows:

- <name>:<detected_version>[-<suffix>]: by default;
- <name>:<version>[-<suffix>]: if the --version parameter is specified;
- <tag>: if the --tag parameter is specified.

Build and runtime images

In fact, two images are created during the packing process: build image and runtime image.

First, the build image is used to perform application build. The build stages here are exactly the same as for other distribution types:

- Stage 1. Cleaning up the application directory
- Stage 2. Building the application (the build is always done ‘in Docker <Building in Docker_>‘_)
- Stage 3. Cleaning up the files before packaging

Second, the files are copied to the resulting (runtime) image, similarly to packing an application as an archive. This image is exactly the result of running cartridge pack docker).

Both images are based on centos:8.

All packages required for the default cartridge application build (git, gcc, make, cmake, unzip) are installed on the build image.

A proper version of Tarantool is provided on the runtime image:

- For opensource, Tarantool of the same version as the one used for local development is installed to the image.
- For Tarantool Enterprise, the bundle with Tarantool Enterprise binaries is copied to the image.

If your application requires some other applications for build or runtime, you can specify base layers for build and runtime images:

- build image: Dockerfile.build.cartridge (default) or --build-from;
- runtime image: Dockerfile.cartridge (default) or --from.

The Dockerfile of the base image should be started with the FROM centos:8 or FROM centos:7 line (except comments).

For example, if your application requires gcc-c++ for build and zip for runtime, customize the Dockerfiles as follows:

- Dockerfile.cartridge.build:

```
FROM centos:8
RUN yum install -y gcc-c++
# Note that git, gcc, make, cmake, unzip packages
# will be installed anyway
```

- Dockerfile.cartridge:

```
FROM centos:8
RUN yum install -y zip
```

Tarantool Enterprise SDK

If you use Tarantool Enterprise, you should explicitly specify the Tarantool SDK to be delivered on the runtime image.

If you want to use the SDK from your local machine, just pass the --sdk-local flag to the cartridge pack docker command.

Alternatively, you can specify a local path to another SDK using the --sdk-path option (or the environment variable TARANTOOL_SDK_PATH, which has lower priority).

Customizing the application build in Docker

You can pass --cache-from and --no-cache options of docker build command on building application in docker.

Using the runtime image

The application code is placed in the /usr/share/tarantool/<app-name> directory. An opensource version of Tarantool is installed to the image.

The run directory is /var/run/tarantool/<app-name>, the workdir is /var/lib/tarantool/<app-name>.

The runtime image also contains the file /usr/lib/tmpfiles.d/<app-name>.conf that allows the instance to restart after container restart.

It is the user's responsibility to set up a proper advertise URI (<host>:<port>) if the containers are deployed on different machines. The problem here is that an instance's advertise URI must be the same on all machines, because it will be used by all the other instances to connect to this one. For example, if you start an instance with an advertise URI set to localhost:3302, and then address it as <instance-host>:3302 from other instances, this won't work: the other instances will be recognizing it only as localhost:3302.

If you specify only a port, cartridge will use an auto-detected IP, so you need to configure Docker networks to set up inter-instance communication.

You can use Docker volumes to store instance snapshots and xlogs on the host machine. To start an image with a new application code, just stop the old container and start a new one using the new image.

Special files

You can put these files in your application root to control the application packaging process (see examples below):

- cartridge.pre-build: a script to be run before tarantoolctl rocks make. The main purpose of this script is to build some non-standard rocks modules (for example, from a submodule). Should be executable.
- cartridge.post-build: a script to be run after tarantoolctl rocks make. The main purpose of this script is to remove build artifacts from result package. Should be executable.

Example: cartridge.pre-build

```
#!/bin/sh

# The main purpose of this script is to build some non-standard rocks modules.
# It will be run before `tarantoolctl rocks make` on application build

tarantoolctl rocks make --chdir ./third_party/my-custom-rock-module
```

Example: cartridge.post-build

```
#!/bin/sh

# The main purpose of this script is to remove build artifacts from resulting package.
# It will be ran after `tarantoolctl rocks make` on application build.

rm -rf third_party
rm -rf node_modules
rm -rf doc
```

4.3.7 Tarantool Cartridge on Kubernetes

This guide covers the full life cycle of a Tarantool Cartridge app–from developing the app to operating it on Kubernetes.

Contents

Installation tools

The following tools are needed:

1. cartridge-cli is a utility for managing Cartridge applications. We need the version 2.3.0 or higher. Installation instructions are available here. If the installation is successful, the cartridge utility will be available in the system.

```
$ cartridge version
---
Tarantool Cartridge CLI v2.3.0 linux/amd64 commit: 06a5dad
```

2. kubectl is a Kubernetes cluster management tool. We need the version 1.16 or higher. Installation instructions can be found here.

```
$ kubectl version --client
---
Client Version: version.Info{Major:"1", Minor:"16", GitVersion:"v1.16.0", GitCommit:
↪"2bd9643cee5b3b3a5ecbd3af49d09018f0773c77", GitTreeState:"clean", BuildDate:"2019-09-18T14:36:53Z",
↪    GoVersion:"go1.12.9", Compiler:"gc", Platform:"linux/amd64"}
```

3. helm is a package manager for Kubernetes apps. We need the version 3.3.x. Installation instructions can be found here.

```
$ helm version
---
version.BuildInfo{Version:"v3.3.1", GitCommit:"249e5215cde0c3fa72e27eb7a30e8d55c9696144", GitTreeState:
↪"clean", GoVersion:"go1.14.7"}
```

4. minikube is a tool for creating a local Kubernetes cluster. We need the version 1.12 or higher. Installation instructions can be found here.

```
$ minikube version
---
minikube version: v1.12.3
commit: 2243b4b97c131e3244c5f014faedca0d846599f5-dirty
```

5. kind (optional) is another tool for creating a local cluster. It can be used instead of the minicube. Installation instructions can be found here.

```
$ kind version
---
kind v0.9.0 go1.15.2 linux/amd64
```

Creating an application

Let's create a Cartridge application named test-app using cartridge-cli:

```
$ cartridge create --name test-app
---
   • Create application test-app
   • Generate application files
   • Initialize application git repository
   • Application "test-app" created successfully
```

In the test-app directory, we get the app created from a template:

```
$ ls test-app
---
...

instances.yml
test-app-scm-1.rockspec
...
```

The app is fully functional and can respond to the HTTP GET request /hello.

Note: Check the cartridge version in test-app-scm-1.rockspec:

```
dependencies = {
    ...
    'cartridge == 2.3.0-1',
    ...
}
```

The version of Cartridge must be >= 2.3.0. Starting from this version, Cartridge waits for an instance to become available on its DNS address during the instance start. This is required for correct operations on Kubernetes. For versions below 2.3.0, an application must be customized independently. See the example of how to do this.

Building the application

Let's create a Docker image using cartridge-cli:

```
$ cartridge pack docker --tag vanyarock01/test-app:0.1.0-0-g68f6117
---
...
Running in 0ffbd57a0edf
Removing intermediate container 0ffbd57a0edf
 ---> aceef7a3be63
 ---> aceef7a3be63
Successfully built aceef7a3be63
Successfully tagged test-app:0.1.0-0-g68f6117
   • Created result image test-app:0.1.0-0-g68f6117
   • Application was successfully packed
```

Upload the image to the Docker registry:

```
$ docker push vanyarock01/test-app:0.1.0-0-g68f6117
---
The push refers to repository [docker.io/vanyarock01/test-app]
b327b35afe0a: Pushed
de30ed3f758d: Pushed
3c8808fbd85d: Pushed
291f6e44771a: Pushed
0.1.0-0-g275baa8: digest: sha256:5b3b92a615b34c7f132e72e2d61f692cf2091ca28be27bbbfed98106398d1c19 size: 1160
```

Note: You must be logged in via docker login and have access rights to the target registry.

Creating a Kubernetes cluster

If you have a ready-made cluster in the cloud, you can use it. If not, we suggest two ways of how to create a local cluster:

- using minikube
- using kind.

Using minikube

Create a Kubernetes cluster of version 1.16.4 with 4GB of RAM (recommended):

```
$ minikube start --kubernetes-version v1.16.4 --memory 4096
---
  minikube v1.12.3 on Ubuntu 18.10
  Automatically selected the docker driver. Other choices: kvm2, virtualbox
  Starting control plane node minikube in cluster minikube
  Creating docker container (CPUs=2, Memory=4096MB) ...
  Preparing Kubernetes v1.16.4 on Docker 19.03.8 ...
  Verifying Kubernetes components...
  Enabled addons: default-storageclass, storage-provisioner
  Done! kubectl is now configured to use "minikube"
```

Wait for the cluster state to be Ready:

```
$ kubectl get nodes
---
NAME       STATUS   ROLES    AGE   VERSION
minikube   Ready    master   21m   v1.16.4
```

Using kind

Create a Kubernetes cluster of version 1.16.4 by using the kind utility as an alternative to minikube:

```
$ kind create cluster --image kindest/node:v1.16.4
---
Creating cluster "kind" ...
 ✓ Ensuring node image (kindest/node:v1.16.4)
 ✓ Preparing nodes
 ✓ Writing configuration
 ✓ Starting control-plane
 ✓ Installing CNI
 ✓ Installing StorageClass
Set kubectl context to "kind-kind"
You can now use your cluster with:

kubectl cluster-info --context kind-kind

Not sure what to do next?   Check out https://kind.sigs.k8s.io/docs/user/quick-start/
```

Let's check the cluster status:

```
$ kubectl get nodes
---
NAME                 STATUS   ROLES    AGE   VERSION
kind-control-plane   Ready    master   48s   v1.16.4
```

Launch the application

To install the Tarantool Kubernetes operator and deploy the cluster, we will use the helm utility. Charts are published in our repository. Let's add it:

```
$ helm repo add tarantool https://tarantool.github.io/tarantool-operator
```

Two charts are available in the repository:

```
$ helm search repo tarantool
---
NAME                            CHART VERSION   APP VERSION DESCRIPTION
tarantool/tarantool-operator    0.0.8           1.16.0      kubernetes tarantool operator
tarantool/cartridge             0.0.8           1.0         A Helm chart for tarantool
```

The tarantool/tarantool-operator chart installs and configures the operator that manages Tarantool Cartridge clusters.

The tarantool/cartridge chart is a template for creating Tarantool Cartridge clusters. With the default settings, this chart deploys an example application consisting of 3 instances. The chart works only in conjunction with the Tarantool Kubernetes operator.

Note: Use the same version with both charts. If you set the tarantool-operator chart to version 0.0.8, set the cartridge chart to the same version 0.0.8.

Install tarantool-operator in the tarantool namespace:

```
$ helm install tarantool-operator tarantool/tarantool-operator --namespace tarantool --create-namespace --version␣
↪0.0.8
---
NAME: tarantool-operator
LAST DEPLOYED: Sun Sep 13 23:29:28 2020
NAMESPACE: tarantool
STATUS: deployed
REVISION: 1
TEST SUITE: None
```

Let's wait until a pod with the operator is ready to work:

```
$ kubectl get pods -n tarantool
---
NAME                            READY   STATUS    RESTARTS   AGE
tarantool-operator-xxx-yyy      0/1     Pending   0          3s
```

In the meantime, let's talk about what the Tarantool operator is and why it is needed.

Tarantool Kubernetes operator

This is a Kubernetes application that can manage Tarantool Cartridge resources.

What does this mean for us?

We don't need to know how to perform administrative actions such as joining a node or creating a replica set. The operator knows how to do this better, and if you set the value for its desired system configuration, it begins to bring the cluster to the desired state.

The Tarantool Kubernetes operator itself is an implementation of the Kubernetes Operator design pattern. It offers the automation of work with user resources using controllers that respond to various events and changes.

The following links can help you understand this pattern:

- Official description on kubernetes.io;
- Overview from the creators of the pattern (CoreOS);
- Post on Habr from Lamoda about the development of the operator.

In the meantime, our pod with tarantool-operator went into a Running state. The next step is to install the app using the tarantool/cartridge helm chart. To do this, prepare a description of the desired system.

Deploying a Tarantool Cartridge application

After you have deployed the cluster and installed the operator, you can move to the next step–launching the app.

We will deploy the app using the tarantool/cartridge chart. This is a template. Run it with the default settings and get our example application that has 3 instances. If you define your own settings, you can deploy any application of any topology using the Tarantool Cartridge.

Let's have a look at the settings in the values.yaml file. Comments provide a description of each parameter:

```yaml
# Environment name and cluster name
ClusterEnv: "dev"
ClusterName: "test-app"

# Docker image of the application
image:
  repository: "vanyarock01/test-app"
  tag: "0.1.0-0-g68f6117"
  pullPolicy: "IfNotPresent"

# The cluster topology includes a description of the number and
# characteristics of replicasets and is described in the RoleConfig section.

# For example, we want to create a cluster containing two types of replicasets:
# routers and storages:
RoleConfig:
  - RoleName: "routers" # Name of the replicaset type
    ReplicaCount: 1     # Number of replicas in the replicaset
    ReplicaSetCount: 1  # Number of replicasets for this role
    DiskSize: "1Gi"     # Persistent storage size
    CPUallocation: 0.1  # Part of vCPUs allocated for each container
    MemtxMemoryMB: 256  # Size of RAM allocated for each container
    RolesToAssign:      # Cartridge roles
      - "app.roles.custom"
      - "vshard-router"

  - RoleName: "storages"
    ReplicaCount: 2
    ReplicaSetCount: 1
    DiskSize: "1Gi"
    CPUallocation: 0.1
    MemtxMemoryMB: 256
    RolesToAssign:
      - "app.roles.custom"
      - "vshard-storage"
```

With this configuration we will get the following:

- A Tarantool Cartridge cluster called test-app.

- Two replica sets in the cluster: routers and storages.
- One Tarantool instance in the routers replica set.
- Two instances, master and replica, in the storages replica set.
- Each replica set performs the roles listed in the RolesToAssign parameter.

Install the app:

```
$ helm install -f values.yaml test-app tarantool/cartridge --namespace tarantool --version 0.0.8
---
NAME: test-app
LAST DEPLOYED: Mon Sep 14 10:46:50 2020
NAMESPACE: tarantool
STATUS: deployed
REVISION: 1
```

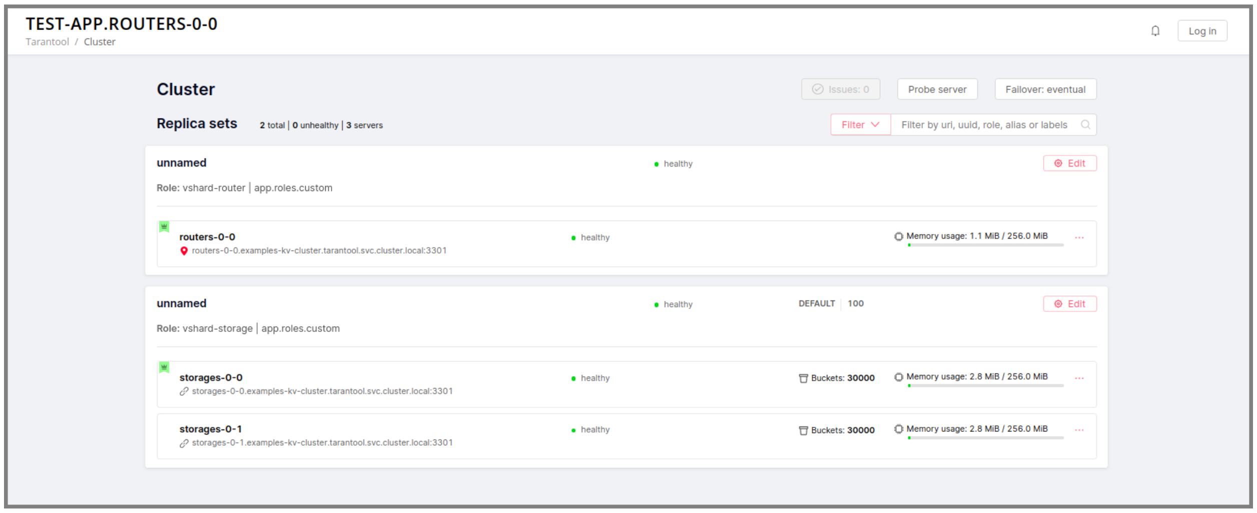
Let's wait for all the pods to launch:

```
$ kubectl -n tarantool get pods
NAME                         READY   STATUS    RESTARTS   AGE
routers-0-0                  0/1     Running   0          10s
storages-0-0                 1/1     Running   0          10s
...
tarantool-operator-xxx-yyy   1/1     Running   0          2m
```

To check the cluster, we forward ports from one of the pods and go to the Cartridge dashboard:

```
$ kubectl port-forward -n tarantool routers-0-0 8081:8081
```

Now the Tarantool Cartridge Web UI is available at http://localhost:8081.



TEST-APP.ROUTERS-0-0
Tarantool / Cluster

Cluster

Replica sets 2 total | 0 unhealthy | 3 servers

unnamed ● healthy
Role: vshard-router | app.roles.custom

routers-0-0 ● healthy Memory usage: 1.1 MiB / 256.0 MiB
routers-0-0.examples-kv-cluster.tarantool.svc.cluster.local:3301

unnamed ● healthy DEFAULT | 100
Role: vshard-storage | app.roles.custom

storages-0-0 ● healthy Buckets: 30000 Memory usage: 2.8 MiB / 256.0 MiB
storages-0-0.examples-kv-cluster.tarantool.svc.cluster.local:3301

storages-0-1 ● healthy Buckets: 30000 Memory usage: 2.8 MiB / 256.0 MiB
storages-0-1.examples-kv-cluster.tarantool.svc.cluster.local:3301

Cluster management

Adding a new replica

To increase the number of replicas in a replica set:

1. Change the configuration in the values.yaml file.

2. Update the app using the helm upgrade command.

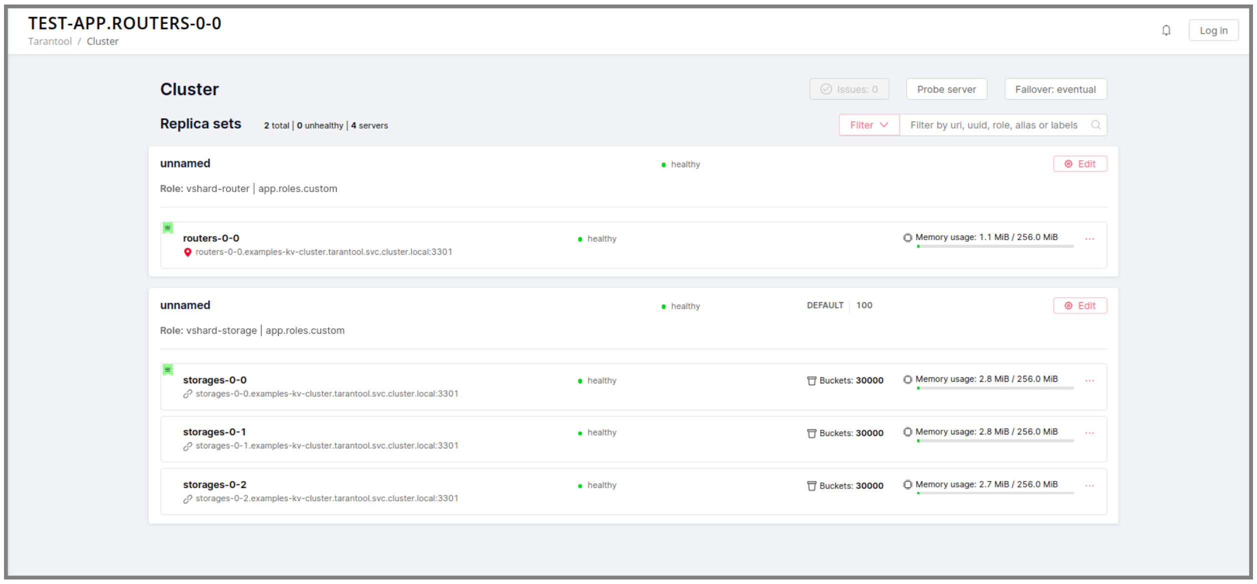
The ReplicaCount parameter is responsible for the number of instances in a replica set. Set it to 3 for the storages replica set:

```
- RoleName: "storages"
  ReplicaCount: 3
  ReplicaSetCount: 1
  DiskSize: "1Gi"
  CPUallocation: 0.10
  MemtxMemoryMB: 256
  RolesToAssign: "custom.vshard-storage"
```

Update the app:

```
$ helm upgrade -f values.yaml test-app tarantool/cartridge --namespace tarantool
---
Release "test-app" has been upgraded. Happy Helming!
NAME: test-app
LAST DEPLOYED: Tue Sep 15 10:35:55 2020
NAMESPACE: tarantool
STATUS: deployed
REVISION: 2
```

Let's wait until all the new pods go into the Running state and are displayed in the Cartridge Web UI.



Replica sets 2 total | 0 unhealthy | 4 servers

unnamed ● healthy
Role: vshard-router | app.roles.custom

routers-0-0 ● healthy Memory usage: 1.1 MiB / 256.0 MiB
routers-0-0.examples-kv-cluster.tarantool.svc.cluster.local:3301

unnamed ● healthy DEFAULT | 100
Role: vshard-storage | app.roles.custom

storages-0-0 ● healthy Buckets: 30000 Memory usage: 2.8 MiB / 256.0 MiB
storages-0-0.examples-kv-cluster.tarantool.svc.cluster.local:3301

storages-0-1 ● healthy Buckets: 30000 Memory usage: 2.8 MiB / 256.0 MiB
storages-0-1.examples-kv-cluster.tarantool.svc.cluster.local:3301

storages-0-2 ● healthy Buckets: 30000 Memory usage: 2.7 MiB / 256.0 MiB
storages-0-2.examples-kv-cluster.tarantool.svc.cluster.local:3301

The storages replica set has 3 instances: 1 master and 2 replicas.

Adding a shard (replica set)

The ReplicaSetCount parameter defines the number of replicas of the same type.

Let's increase the number of the routers replica sets to 2:

```
- RoleName: "routers"
  ReplicaCount: 1
  ReplicaSetCount: 2
```

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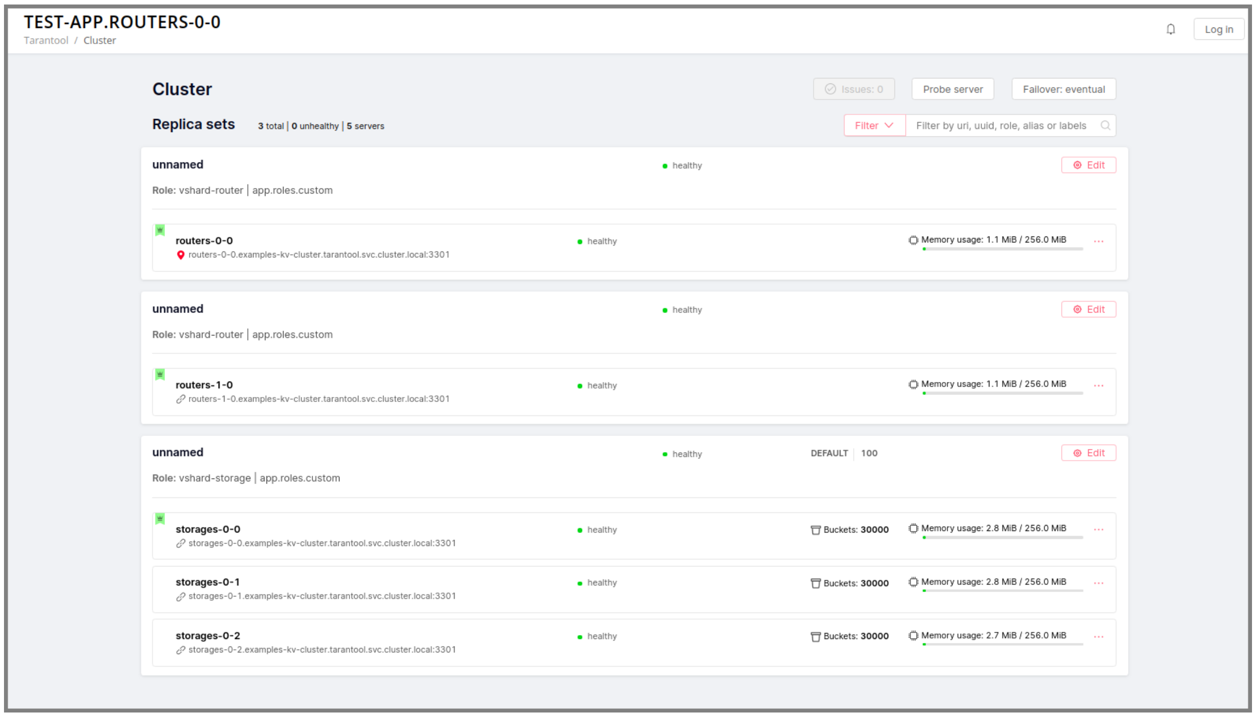
```
  DiskSize: "1Gi"
  CPUallocation: 0.10
  MemtxMemoryMB: 256
  RolesToAssign: "custom.vshard-router"
```

Update the app:

```
$ helm upgrade -f values.yaml test-app tarantool/cartridge --namespace tarantool
---
Release "test-app" has been upgraded. Happy Helming!
NAME: test-app
LAST DEPLOYED: Tue Sep 15 10:37:57 2020
NAMESPACE: tarantool
STATUS: deployed
REVISION: 3
```

Let's wait for the new pod to start:


TEST-APP.ROUTERS-0-0
Tarantool / Cluster

Cluster

Issues: 0 | Probe server | Failover: eventual

Replica sets — 3 total | 0 unhealthy | 5 servers

unnamed — healthy — Edit
Role: vshard-router | app.roles.custom
routers-0-0 — routers-0-0.examples-kv-cluster.tarantool.svc.cluster.local:3301 — healthy — Memory usage: 1.1 MiB / 256.0 MiB

unnamed — healthy — Edit
Role: vshard-router | app.roles.custom
routers-1-0 — routers-1-0.examples-kv-cluster.tarantool.svc.cluster.local:3301 — healthy — Memory usage: 1.1 MiB / 256.0 MiB

unnamed — healthy — DEFAULT | 100 — Edit
Role: vshard-storage | app.roles.custom
storages-0-0 — storages-0-0.examples-kv-cluster.tarantool.svc.cluster.local:3301 — healthy — Buckets: 30000 — Memory usage: 2.8 MiB / 256.0 MiB
storages-0-1 — storages-0-1.examples-kv-cluster.tarantool.svc.cluster.local:3301 — healthy — Buckets: 30000 — Memory usage: 2.8 MiB / 256.0 MiB
storages-0-2 — storages-0-2.examples-kv-cluster.tarantool.svc.cluster.local:3301 — healthy — Buckets: 30000 — Memory usage: 2.7 MiB / 256.0 MiB

Updating application version

Currently, the app logic contains one HTTP endpoint /hello that returns the string Hello world! in response to a GET request.

To check this out, let's forward the ports to the desired node:

```
$ kubectl port-forward -n tarantool routers-0-0 8081:8081
---
Forwarding from 127.0.0.1:8081 -> 8081
Forwarding from [::1]:8081 -> 8081
```

And then execute the request:

```
$ curl http://localhost:8081/hello
---
Hello world!
```

Let's add another endpoint that will return the string "Hello world, new version of the app!". To do this, add another httpd:route in the init function in the app/roles/custom.lua role:

```
local function init(opts) -- luacheck: no unused args
    ...
    -- new endpoint
    httpd:route({method = 'GET', path = '/v2/hello'}, function()
        return {body = 'Hello world, new version of the app!'}
    end)

    ...
end
```

Pack the new version of the app:

```
$ cartridge pack docker --tag vanyarock01/test-app:0.1.0-1-g4577716

---

...
Successfully tagged vanyarock01/test-app:0.1.0-1-g4577716
   • Created result image vanyarock01/test-app:0.1.0-1-g4577716
   • Application was successfully packed
```

Upload the new image version to the Docker registry:

```
$ docker push vanyarock01/test-app:0.1.0-1-g4577716
```

Update the values.yaml configuration file by specifying a new image.tag:

```
image:
  repository: "vanyarock01/test-app"
  tag: "0.1.0-1-g4577716"
  pullPolicy: "IfNotPresent"
```

Update the app on Kubernetes:

```
$ helm upgrade -f values.yaml test-app tarantool/cartridge --namespace tarantool

---

Release "test-app" has been upgraded. Happy Helming!
NAME: test-app
LAST DEPLOYED: Tue Sep 15 10:45:53 2020
NAMESPACE: tarantool
STATUS: deployed
REVISION: 4
```

Tarantool Kubernetes operator uses the OnDelete update policy. This means that the update has reached the cluster, but the pods will update the app image only after a restart:

```
$ kubectl delete pods -l tarantool.io/cluster-id=test-app -n tarantool
---
```

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```
pod "routers-0-0" deleted
pod "routers-1-0" deleted
pod "storages-0-0" deleted
pod "storages-0-1" deleted
pod "storages-0-2" deleted
```

Lets wait for the pods to start again and check the update:

```
$ kubectl port-forward -n tarantool routers-0-0 8081:8081
---
Forwarding from 127.0.0.1:8081 -> 8081
Forwarding from [::1]:8081 -> 8081
...
```

```
curl http://localhost:8081/v2/hello
---
Hello world, new version of the app!
```

Running multiple Tarantool Cartridge clusters in different namespaces

Tarantool Kubernetes operator can manage Tarantool Cartridge clusters only in its own namespace. Therefore, to deploy multiple Cartridge clusters in different namespaces you need to deploy an operator in each of them.

To install an operator in several namespaces, just specify the required namespace during installation:

```
$ helm install tarantool-operator tarantool/tarantool-operator --namespace NS_1 --create-namespace --version 0.0.
↪8

$ helm install tarantool-operator tarantool/tarantool-operator --namespace NS_2 --create-namespace --version 0.0.
↪8
```

These commands set the operator to the namespace NS_1 and the namespace NS_2. Then, in each of them, you can run a Tarantool Cartridge cluster.

```
$ helm install -f values.yaml cartridge tarantool/cartridge --namespace NS_1 --version 0.0.8

$ helm install -f values.yaml cartridge tarantool/cartridge --namespace NS_2 --version 0.0.8
```

Finally, we have two namespaces. Each has an operator and a Tarantool Cartridge cluster.

Deleting a cluster

To remove a cluster, execute the following command:

```
$ helm uninstall test-app --namespace tarantool
---
release "test-app" uninstalled
```

After a while, all the pods of our application will disappear. Among the pods in the tarantool namespace, only the Tarantool Kubernetes operator will remain.

```
$ kubectl get pods -n tarantool
---
NAME                             READY   STATUS    RESTARTS   AGE
tarantool-operator-xxx-yyy       1/1     Running   0          9m45s
```

If you need to remove the Tarantool Kubernetes operator, execute:

```
$ helm uninstall tarantool-operator --namespace tarantool
---
release "tarantool-operator" uninstalled
```

Note: helm uninstall does not remove persistent volumes. To remove them, you need to additionally perform the following:

```
$ kubectl delete pvc --all -n tarantool
---
persistentvolumeclaim "www-routers-0-0" deleted
persistentvolumeclaim "www-routers-1-0" deleted
persistentvolumeclaim "www-storages-0-0" deleted
```

Troubleshooting

When creating, updating, or scaling a cluster, errors may occur due to lack of physical resources.

Let’s examine possible error indications, root causes and solutions.

Insufficient CPU

After executing helm install / upgrade the pods remain in the Pending state.

It looks like this:

```
$ kubectl get pods -n tarantool
---
NAME                             READY   STATUS    RESTARTS   AGE
routers-0-0                    0/1     Pending   0          20m
routers-1-0                    0/1     Pending   0          20m
storages-0-0                   0/1     Pending   0          20m
tarantool-operator-xxx-yyy       1/1     Running   0          23m
```

Let’s take a look at the events of one of the pending pods:

```
$ kubectl -n tarantool describe pods routers-0-0
---
Events:
  Type     Reason             Age                    From                Message
  ----     ------             ----                   ----                -------
  Warning  FailedScheduling   34m                    default-scheduler   0/2 nodes are available: 2 Insufficient cpu.
  Warning  FailedScheduling   34m                    default-scheduler   0/2 nodes are available: 2 Insufficient cpu.
  Normal   NotTriggerScaleUp  3m33s (x175 over 34m)  cluster-autoscaler  pod didn't trigger scale-up (it wouldn
↪'t fit if a new node is added):
```

It is now clear that we don’t have enough CPU. You can reduce the allocated CPU size in the values.yaml configuration file–the CPUallocation parameter.

Insufficient disk space

After executing helm install/upgrade the pods remain in the ContainerCreating state. Let's take a look at the events:

```
$ kubectl -n tarantool describe pods routers-0-0
---
Events:
  Type     Reason                  Age                From                                         Message
  ----     ------                  ----               ----                                         -------
  Warning  FailedScheduling        7m44s              default-scheduler                            pod has unbound␣
↪immediate PersistentVolumeClaims
  Warning  FailedScheduling        7m44s              default-scheduler                            pod has unbound␣
↪immediate PersistentVolumeClaims
  Normal   Scheduled               7m42s              default-scheduler                            Successfully assigned␣
↪tarantool/routers-0-0 to kubernetes-cluster-3010-default-group-0
  Normal   SuccessfulAttachVolume  7m37s              attachdetach-controller                      AttachVolume.
↪Attach succeeded for volume "pvc-e0d3f30a-7dcc-4a67-a69d-4670dc77d556"
  Warning  FailedMount             67s (x9 over 7m5s)  kubelet, kubernetes-cluster-3010-default-group-0 ␣
↪MountVolume.MountDevice failed for volume "pvc-e0d3f30a-7dcc-4a67-a69d-4670dc77d556" : rpc error: code =␣
↪Internal desc = Unable to find Device path for volume
  Warning  FailedMount             66s (x3 over 5m38s)  kubelet, kubernetes-cluster-3010-default-group-0  Unable␣
↪to attach or mount volumes: unmounted volumes=[www], unattached volumes=[www default-token-jrz94]:␣
↪timed out waiting for the condition
```

Such events indicate that there is not enough disk space to create storages. You can change the size of the allocated memory using the DiskSize parameter in the values.yaml file for replica sets. The error can also be resolved by increasing the size of the physical cluster disk.

Customization

For most cases, the tarantool/cartridge helm chart is enough for you. However, if customization is required, you can continue to use the chart by making your own changes. You can also deployment.yaml and kubectl instead of helm.

Sidecar containers

What are they? With Kubernetes, it is possible to create several containers inside one pod that share common resources such as disk storage and network interfaces. Such containers are called sidecar.

Learn more about this architectural pattern here.

For implementation on Kubernetes, it is necessary to expand the container park in the description of the required resource. Let's try to add another service container with nginx to each pod containing a container with a Tarantool instance based on this article.

To do this, you will need to change the tarantool/cartridge chart. You can find it here. Add a new container with nginx to the ReplicasetTemplate which can be found in the templates/deployment.yaml file.

```
containers:
- name: "pim-storage"
  image: "{{ $.Values.image.repository }}:{{ $.Values.image.tag }}"
  ...
- name: "nginx-container"
  image: "nginx"
```

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```
  volumeMounts:
    - name: "www"
      mountPath: "/data"
```

Note: It is important to describe additional containers strictly after the pim-storage container. Otherwise, problems may occur when updating the version of the application.

By default, the Tarantool Kubernetes operator chooses the first one in the list as the application container.

Now, let's start the installation specifying the path to the directory with the customized chart:

```
$ helm install -f values.yaml test-app tarantool-operator/examples/kv/helm-chart/ --namespace tarantool
---
NAME: test-app
LAST DEPLOYED: Wed Sep 30 11:25:12 2020
NAMESPACE: tarantool
STATUS: deployed
REVISION: 1
```

If everything goes well, it will be visible in the pod list:

```
$ kubectl -n tarantool get pods
---
NAME                                READY   STATUS    RESTARTS   AGE
routers-0-0                       2/2     Running   0          113s
routers-1-0                       2/2     Running   0          113s
storages-0-0                      2/2     Running   0          113s
tarantool-operator-xxx-yyy            1/1     Running   0          30m
```

READY 2/2 means that 2 containers are ready inside the pod.

Installation in an internal network

Delivery of tools

We need to bring the tarantool-cartridge and tarantool-operator charts and the image of your application inside the internal network.

You can download the charts from the following links:

- tarantool-operator v0.0.8
- cartridge v0.0.8.

Next, you need to pack a Docker image with the tarantool-operator. First, let's pull the required version from the Docker Hub:

```
$ docker pull tarantool/tarantool-operator:0.0.8
---
0.0.8: Pulling from tarantool/tarantool-operator
3c72a8ed6814: Pull complete
e6ffc8cffd54: Pull complete
cb731cdf9a11: Pull complete
a42b002f4072: Pull complete
```

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```
Digest: sha256:e3b46c2a0231bd09a8cdc6c86eac2975211b2c597608bdd1e8510ee0054a9854
Status: Downloaded newer image for tarantool/tarantool-operator:0.0.8
docker.io/tarantool/tarantool-operator:0.0.8
```

And pack it into the archive:

```
$ docker save tarantool/tarantool-operator:0.0.8 | gzip > tarantool-operator-0.0.8.tar.gz
```

After delivering the archive with the container to the target location, you need to load the image to your Docker:

```
$ docker load < tarantool-operator-0.0.8.tar.gz
---
Loaded image: tarantool/tarantool-operator:0.0.8
```

All that remains is to push the image to the internal Docker registry. We will use an example Docker registry hosted on localhost:5000:

```
$ docker tag tarantool/tarantool-operator:0.0.8 localhost:5000/tarantool-operator:0.0.8

$ docker push localhost:5000/tarantool-operator:0.0.8
---
The push refers to repository [localhost:5000/tarantool-operator]
febd47bb69b9: Pushed
bacec9f8c1dd: Pushed
d1d164c2f681: Pushed
291f6e44771a: Pushed
0.0.8: digest: sha256:e3b46c2a0231bd09a8cdc6c86eac2975211b2c597608bdd1e8510ee0054a9854 size: 1155
```

Note: You can deliver the image with the application using the method described above.

Installing the Tarantool Kubernetes operator

Let's describe the custom operator values in the operator_values.yaml file:

```
image:
  # internal Docker repository
  repository: "localhost:5000/tarantool-operator"
  tag: "0.0.8"
  pullPolicy: "IfNotPresent"
```

And install the operator specifying the path to the archive with chart:

```
$ helm install tarantool-operator -f operator_values.yaml ./tarantool-operator-0.0.8.tgz --namespace tarantool --
↪create-namespace
---
NAME: tarantool-operator
LAST DEPLOYED: Tue Dec  1 14:53:47 2020
NAMESPACE: tarantool
STATUS: deployed
REVISION: 1
TEST SUITE: None
```

Check the installation:

```
$ kubectl -n tarantool get pods
---
NAME                               READY   STATUS    RESTARTS   AGE
tarantool-operator-xxx-yyy         1/1     Running   0          7s
```

Installing the Tarantool Cartridge app

We have pushed the app image to the local Docker registry beforehand. What remains is to customize the values.yaml file by specifying the available repository:

```
...
image:
  repository: "localhost:5000/test-app"
  tag: "0.1.0-0-g68f6117"
  pullPolicy: "IfNotPresent"
...
```

The complete configuration of the values.yaml can be found in the instructions for installing the Tarantool Cartridge application described in the guide earlier.

It remains to unpack the Cartridge chart:

```
$ tar -xzf tarantool-operator-cartridge-0.0.8.tar.gz
```

And run the installation by specifying the path to the chart:

```
$ helm install -f values.yaml test-app tarantool-operator-cartridge-0.0.8/examples/kv/helm-chart/ --namespace
↪tarantool
---
NAME: test-app
LAST DEPLOYED: Tue Dec  1 15:52:41 2020
NAMESPACE: tarantool
STATUS: deployed
REVISION: 1
```

Let’s take a look at the pods to make sure the installation is successful:

```
$ kubectl -n tarantool get pods
---
NAME                               READY   STATUS    RESTARTS   AGE
routers-0-0                        1/1     Running   0          8m30s
storages-0-0                       1/1     Running   0          8m30s
storages-1-0                       1/1     Running   0          8m30s
tarantool-operator-xxx-yyy         1/1     Running   0          67m
```

4.3.8 Changelog

All notable changes to this project will be documented in this file.

The format is based on Keep a Changelog and this project adheres to Semantic Versioning.

[Unreleased]

Added

- New GraphQL API: {cluster {suggestions {force_apply {uuid reasons}}}} to heal the cluster in case of config errors like Configuration checksum mismatch, Configuration is prepared and locked, and sometimes OperationError.
- Show an issue when ConfiguringRoles state stucks for more than 5s.

Fixed

- Properly handle etcd index updates while polling stateful failover updates. The problem affected long-running clusters and resulted in flooding logs with the "Etcd cluster id mismatch" warnings.
- Allow specifying server zone in join_server API.

[2.4.0] - 2020-12-29

Added

Zones and zone distances:

- Add support of replica weights and zones via a clusterwide config new section zone_distances and a server parameter zone.

Fencing:

- Implement a fencing feature. It protects a replicaset from the presence of multiple leaders when the network is partitioned and forces the leader to become read-only.
- New failover parameter failover_timout specifies the time (in seconds) used by membership to mark suspect members as dead which triggers failover.
- Fencing parameters fencing_enabled, fencing_pause, fencing_timeout are available for customization via Lua and GraphQL API, and in WebUI too.

Issues and suggestions:

- New GraphQL API: {cluster {suggestions {refine_uri {}}}} to heal the cluster after relocation of servers advertise_uri.
- New Lua API cartridge.config_force_reapply() and similar GraphQL mutation cluster { config_force_reapply() } to heal several operational errors:
  - "Prepare2pcError: Two-phase commit is locked";
  - "SaveConfigError: …/config.prepare: Directory not empty";
  - "Configuration is prepared and locked on …" (an issue);
  - "Configuration checksum mismatch on …" (an issue).

  It'll unlock two-phase commit (remove config.prepare lock), upload the active config from the current instance and reconfigure all roles.

Hot-reload:

- New feature for hot reloading roles code without restarting an instance – cartridge.reload_roles. The feature is experimental and should be enabled explicitly: cartridge.cfg({roles_reload_allowed = true}).

Miscellanous:

- New cartridge.cfg option swim_broadcast to manage instances auto-discovery on start. Default: true.
- New argparse options support for tarantool 2.5+: replication_synchro_quorum, replication_synchro_timeout, memtx_use_mvcc_engine.

Changed

- Default value of failover_timeout increased from 3 to 20 seconds (important change).
- RPC functions now consider suspect members as healthy to be in agreement with failover (important change).

Fixed

- Don't stuck in ConnectingFullmesh state when instance is restarted with a different advertise_uri. Also keep "Server details" dialog in WebUI operable in this case.
- Allow applying config when instance is in OperationError. It doesn't cause loss of quorum anymore.
- Stop vshard fibers when the corresponding role is disabled.
- Make console.listen error more clear when console_sock exceeds UNIX_PATH_MAX limit.
- Fix upstream.idle issue tolerance to avoid unnecessary warnings "Replication: long idle (1 > 1)".
- Allow removing spaces from DDL schema for the sake of drop migrations.
- Make DDL schema validation stricter. Forbid redundant keys in schema top-level and make spaces mandatory.

Enhanced is WebUI

- Update server details modal, add support for server zones.
- Properly display errors on WebUI pages "Users" and "Code".
- Indicate config checksum mismatch in issues list.
- Indicate the change of arvertise_uri in issues list.
- Show an issue if the clusterwide config is locked on an instance.
- Refresh interval and stat refresh period variables can be customized via frontend-core's set_variable feature or at runtime.

[2.3.0] - 2020-08-26

Added

- When failover mode is stateful, all manual leader promotions will be consistent: every instance before becoming writable performs wait_lsn operation to sync with previous one. If consistency couldn't be reached due to replication failure, a user could either revert it (promote previous leader), or force promotion to be inconsistent.
- Early logger initialization (for Tarantool > 2.5.0-100, which supports it).

- Add probe_uri_timeout argparse option responsible for retrying "Can't ping myself" error on startup.
- New test helper: cartridge.test-helpers.etcd.
- Support on_push and on_push_ctx options for cartridge.rpc_call().
- Changing users password invalidates HTTP cookie.
- Support GraphQL default variables.

Fixed

- Eventual failover may miss an event while roles are being reconfigured.
- Compatibility with pipe logging, see tarantool/tarantool#5220.
- Non-informative assertion when instance is bootstrapped with a distinct advertise_uri.
- Indexing nil value in get_topology() query.
- Initialization race of vshard storage which results in OperationError.
- Lack of vshard router attempts to reconnect to the replicas.
- Make GraphQL syntax errors more clear.
- Better errors.pcall() performance, errors rock updated to v2.1.4.

Enhanced is WebUI

- Show instance names in issues list.
- Show app name in window title.
- Add the "Force leader promotion" button in the stateful failover mode.
- Indicate consistent switchover problems with a yellow leader flag.

[2.2.0] - 2020-06-23

Added

- When running under systemd use <APP_NAME>.<INSTANCE_NAME> as default syslog identity.
- Support etcd as state provider for stateful failover.

Changed

- Improve rocks detection for feedback daemon. Besides cartridge version it now parses manifest file from the .rocks/ directory and collects rocks versions.
- Make uuid parameters optional for test helpers. Make servers option accept number of servers in replicaset.

Enhanced in WebUI

- Prettier errors displaying.
- Enhance replicaset filtering by role / status.
- Error stacktrace received from the backend is shown in notifications.

[2.1.2] - 2020-04-24

Fixed

- Avoid trimming console_sock if it's name is too long.
- Fix file descriptors leak during box recovery.
- Support console_sock option in stateboard as well as notify socket and other box options similar to regular cartridge instances.

[2.1.1] - 2020-04-20

Fixed

- Frontend core update: fix route mapping

[2.1.0] - 2020-04-16

Added

- Implement stateful failover mode. You can read more in "Failover architecture" documentation topic.
- Respect box.cfg options wal_dir, memtx_dir, vinyl_dir. They can be either absolute or relative - in the later case it's calculated relative to cartridge.workdir.
- New option in cartridge.cfg({upgrade_schema=...}) to automatically upgrade schema to modern tarantool version (only for leader). It also has been added for argparse.
- Extend GraphQL issues API with various topics: replication, failover, memory, clock. Make thresholds configurable via argparse.

Changed

- Make GraphQL validation stricter: scalar values can't have sub-selections; composite types must have sub-selections; omitting non-nullable arguments in variable list is forbidden. Your code may be affected if it doesn't conform GraphQL specification.
- GraphQL query auth_params returns "fullname" (if it was specified) instead of "username".
- Update errors dependency to 2.1.3.
- Update ddl dependency to 1.1.0.

Deprecated

Lua API:

- cartridge.admin_get_failover -> cartridge.failover_get_params
- cartridge.admin_enable/disable_failover -> cartridge.failover_set_params

GraphQL API:

- query {cluster {failover} } -> query {cluster {failover_params {...} } }
- mutation {cluster {failover()} } -> mutation {cluster {failover_params() {...} } }

Fixed

- Properly handle nested input object in GraphQL:

  ```
  mutation($uuid: String!) {
    cluster { edit_topology(servers: [{uuid: $uuid ...}]) {} }
  }
  ```

- Show WebUI notification on successful config upload.
- Repair GraphQL queries add_user, issues on uninitialized instance.

Enhanced in WebUI

- Show "You are here" marker.
- Show application and instance names in app title.
- Indicate replication and failover issues.
- Fix bug with multiple menu items selected.
- Refactor pages filtering, forbid opening blacklisted pages.
- Enable JS chunks caching.

[2.0.2] - 2020-03-17

Added

- Expose membership options in argparse module (edit them with environment variables and command-line arguments).
- New internal module to handle .tar files.

Lua API:

- cartridge.cfg({webui_blacklist = {'/admin/code', ...}}): blacklist certain WebUI pages.
- cartridge.get_schema() referencing older _G.cartridge_get_schema.
- cartridge.set_schema() referencing older _G.cartridge_set_schema.

GraphQL API:

- Make use of GraphQL error extensions: provide additional information about class_name and stack of original error.
- cluster{ issues{ level message ... }}: obtain more details on replication status
- cluster{ self {...} }: new fields app_name, instance_name.
- servers{ boxinfo { cartridge {...} }}: new fields version, state, error.

Test helpers:

- Allow specifying all_rw replicaset flag in luatest helpers.
- Add cluster({env = ...}) option for specifying clusterwide environment variables.

Changed

- Remove redundant topology availability checks from two-phase commit.
- Prevent instance state transition from ConnectingFullmesh to OperationError if replication fails to connect or to sync. Since now such fails result in staying in ConnectingFullmesh state until it succeeds.
- Specifying pool.connect() options user, password, reconnect_after are deprecated and ignored, they never worked as intended and will never do. Option connect_timeout is deprecated, but for backward compatibility treated as wait_connected.

Fixed

- Fix DDL failure if spaces field is null in input schema.
- Check content of cluster_cookie for absence of special characters so it doesn't break the authorization. Allowed symbols are [a-zA-Z0-9_.~-].
- Drop remote-control connections after full-featured box.cfg becomes available to prevent clients from using limited functionality for too long. During instance recovery remote-control won't accept any connections: clients wait for box.cfg to finish recovery.
- Update errors rock dependency to 2.1.2: eliminate duplicate stack trace from error.str field.
- Apply custom_proc_title setting without waiting for box.cfg.
- Make GraphQL compatible with req:read_cached() call in httpd hooks.
- Avoid "attempt to index nil value" error when using rpc on an uninitialized instance.

Enhanced in WebUI

- Add an ability to hide certain WebUI pages.
- Validate YAML in code editor WebUI.
- Fix showing errors in Code editor page.
- Remember last open file in Code editor page. Open first file when local storage is empty.
- Expand file tree in Code editor page by default.
- Show Cartridge version in server info dialog.
- Server alias is clickable in replicaset list.

- Show networking errors in splash panel instead of notifications.
- Accept float values for vshard-storage weight.

[2.0.1] - 2020-01-15

Added

- Expose TARANTOOL_DEMO_URI environment variable in GraphQL query cluster{ self{demo_uri} } for demo purposes.

Fixed

- Notifications in schema editor WebUI.
- Fix GraphQL servers query compatibility with old cartridge versions.
- Two-phase commit backward compatibility with v1.2.0.

[2.0.0] - 2019-12-27

Added

- Use for frontend part single point of configuration HTTP handlers. As example: you can add your own client HTTP middleware for auth.
- Built-in DDL schema management. Schema is a part of clusterwide configuration. It's applied to every instance in cluster.
- DDL schema editor and code editor pages in WebUI.
- Instances now have internal state machine which helps to manage cluster operation and protect from invalid state transitions.
- WebUI checkbox to specify all_rw replicaset property.
- GraphQL API for clusterwide configuration management.
- Measure clock difference across instances and provide clock_delta in GraphQL servers query and in admin.get_servers() Lua API.
- New option in rpc_call(..., {uri=...}) to perform a call on a particular uri.

Changed

- cartridge.rpc_get_candidates() doesn't return error "No remotes with role available" anymore, empty table is returned instead. (incompatible change)
- Base advertise port in luatest helpers changed from 33000 to 13300, which is outside ip_local_port_range. Using port from local range usually caused tests failing with an error "address already in use". (incompatible change, but affects tests only)
- Whole new way to bootstrap instances. Instead of polling membership for getting clusterwide config the instance now start Remote Control Server (with limited iproto protocol functionality) on the same port. Two-phase commit is then executed over net.box connection. (major change, but still compatible)

- Failover isn't triggered on suspect instance state anymore
- Functions admin.get_servers, get_replicasets and similar GraphQL queries now return an error if the instance handling the request is in state InitError or BootError.
- Clusterwide configuration is now represented with a file tree. All sections that were tables are saved to separate .yml files. Compatibility with the old-style configuration is preserved. Accessing unmarshalled sections with get_readonly/deepcopy methods is provided without .yml extension as earlier. (major change, but still compatible)
- After an old leader restarts it'll try to sync with an active one before taking the leadership again so that failover doesn't switch too early before leader finishes recovery. If replication setup fails the instance enters the OperationError state, which can be avoided by explicitly specifying replication_connect_quorum = 1 (or 0). (major change)
- Option {prefer_local = false} in rpc_call makes it always use netbox connection, even to connect self. It never tries to perform call locally.
- Update vshard dependency to 0.1.14.

Removed

- Function cartridge.bootstrap is removed. Use admin_edit_topology interad. (incompatible change)
- Misspelled role callback validate is now removed completely. Keep using validate_config.

Fixed

- Arrange proper failover triggering: don't miss events, don't trigger if nothing changed. Fix races in calling apply_config between failover and two-phase commit.
- Race condition when creating working directory.
- Hide users page in WebUI when auth backend implements no user management functions. Enable auth switcher is displayed on main cluster page in this case.
- Displaying boolean values in server details.
- Add deduplication for WebUI notifications: no more spam.
- Automatically choose default vshard group in create and edit replicaset modals.
- Enhance WebUI modals scrolling.

[1.2.0] - 2019-10-21

Added

- 'Auto' placeholder to weight input in the Replicaset forms.
- 'Select all' and 'Deselect all' buttons to roles field in Replicaset add and edit forms.
- Refresh replicaset list in UI after topology edit actions: bootstrap, join, expel, probe, replicaset edit.
- New Lua API cartridge.http_authorize_request() suitable for checking HTTP request headers.
- New Lua API cartridge.http_render_response() for generating HTTP response with proper Set-Cookie headers.

- New Lua API cartridge.http_get_username() to check authorization of active HTTP session.
- New Lua API cartridge.rpc_get_candidates() to get list of instances suitable for performing a remote call.
- Network error notification in UI.
- Allow specifying vshard storage group in test helpers.

Changed

- Get UI components from Tarantool UI-Kit
- When recovering from snapshot, instances are started read-only. It is still possible to override it by argparse (command line arguments or environment variables)

Fixed

- Editing topology with failover_priority argument.
- Now cartridge.rpc.get_candidates() returns value as specified in doc. Also it accepts new option healthy_only to filter instances which have membership status healthy.
- Replicaset weight tooltip in replicasets list
- Total buckets count in buckets tooltip
- Validation error in user edit form
- Leader flag in server details modal
- Human-readable error for invalid GrqphQL queries: Field "x" is not defined on type "String"
- User management error "attempt to index nil value" when one of users has empty e-mail value
- Catch rpc_call errors when they are performed locally

[1.1.0] - 2019-09-24

Added

- New Lua API admin_edit_topology has been added to unite multiple others: admin_edit_replicaset, admin_edit_server, admin_join_server, admin_expel_server. It's suitable for editing multiple servers/replicasets at once. It can be used for bootstrapping cluster from scratch, joining a server to an existing replicaset, creating new replicaset with one or more servers, editing uri/labels of servers, disabling or expelling servers.
- Similar API is implemented in a GraphQL mutation cluster{edit_topology()}.
- New GraphQL mutation cluster { edit_vshard_options } is suitable for fine-tuning vshard options: rebalancer_max_receiving, collect_lua_garbage, sync_timeout, collect_bucket_garbage_interval, rebalancer_disbalance_threshold.

Changed

- Both bootstrapping from scratch and patching topology in clusterwide config automatically probe servers, which aren't added to membership yet (earlier it influenced join_server mutation only). This is a prerequisite for multijoin api implementation.
- WebUI users page is hidden if auth_backend doesn't provide list_users callback.

Deprecated

Lua API:

- cartridge.admin_edit_replicaset()
- cartridge.admin_edit_server()
- cartridge.admin_join_server()
- cartridge.admin_expel_server()

GraphQL API:

- mutation{ edit_replicaset() }
- mutation{ edit_server() }
- mutation{ join_server() }
- mutation{ expel_server() }

Fixed

- Protect users_acl and auth sections when downloading clusterwide config. Also forbid uploading them.

[1.0.0] - 2019-08-29

Added

- New parameter topology.replicasets[].all_rw in clusterwide config for configuring all instances in the replicaset as read_only = false. It can be managed with both GraphQL and Lua API edit_replicaset.
- Remote Control server - a replacement for the box.cfg({listen}), with limited functionality, independent on box.cfg. The server is only to be used internally for bootstrapping new instances.
- New module argparse for gathering configuration options from command-line arguments, environment variables, and configuration files. It is used internally and overrides cluster.cfg and box.cfg options.
- Auth parameter cookie_max_age is now configurable with GraphQL API. Also now it's stored in clusterwide config, so changing it on a single server will affect all others in cluster.
- Detect that we run under systemd and switch to syslog logging from stderr. This allows to filter log messages by severity with journalctl
- Redesign WebUI

Changed

- The project renamed to cartridge. Use require('cartridge') instead of require('cluster'). All submodules are renamed too. (incompatible change)
- Submodule cluster.test_helpers renamed to cartridge.test-helpers for consistency. (incompatible change)
- Modifying auth params with GraphQL before the cluster was bootstrapped is now forbidden and returns an error.
- Introducing a new auth parameter cookie_renew_age. When cluster handles an HTTP request with the cookie, whose age in older then specified, it refreshes the cookie. It may be useful to set cookie_max_age to a small value (for example 10 minutes), so the user will be logged out after cookie_max_age seconds of inactivity. Otherwise, if he's active, the cookie will be updated every cookie_renew_age seconds and the session will not be interrupted.
- Changed configuration options for cluster.cfg(): roles now is a mandatory table, workdir is optional now (defaults to ".")
- Parameter advertise_uri is optional now, default value is derived as follows. advertise_uri is a compound of <HOST> and <PORT>. When <HOST> isn't specified, it's detected as the only non-local IP address. If it can't be determined or there is more than one IP address available it defaults to "localhost". When <PORT> isn't specified, it's derived from numeric suffix _<N> of TARANTOOL_INSTANCE_NAME: <PORT> = 3300+<N>. Otherwise default <PORT> = 3301 is used.
- Parameter http_port is derived from instance name too. If it can't be derived it defaults to 8081. New parameter http_enabled = false is used to disable it (by default it's enabled).
- Removed user cluster, which was used internally for orchestration over netbox. Tarantool built-in user admin is used instead now. It can also be used for HTTP authentication to access WebUI. Cluster cookie is used as a password in both cases. (incompatible change)

Removed

Two-layer table structure in API, which was deprecated earlier, is now removed completely:

- cartridge.service_registry.*
- cartridge.confapplier.*
- cartridge.admin.*

Instead you can use top-level functions:

- cartridge.config_get_readonly
- cartridge.config_get_deepcopy
- cartridge.config_patch_clusterwide
- cartridge.service_get
- cartridge.admin_get_servers
- cartridge.admin_get_replicasets
- cartridge.admin_probe_server
- cartridge.admin_join_server
- cartridge.admin_edit_server

- cartridge.admin_expel_server
- cartridge.admin_enable_servers
- cartridge.admin_disable_servers
- cartridge.admin_edit_replicaset
- cartridge.admin_get_failover
- cartridge.admin_enable_failover
- cartridge.admin_disable_failover

[0.10.0] - 2019-08-01

Added

- Cluster can now operate without vshard roles (if you don't need sharding). Deprecation warning about implicit vshard roles isn't issued any more, they aren't registered unless explicitly specified either in cluster.cfg({roles=...}) or in dependencies to one of user-defined roles.
- New role flag hidden = true. Hidden roles aren't listed in cluster.admin.get_replicasets().roles and therefore in WebUI. Hidden roles are supposed to be a dependency for another role, yet they still can be enabled with edit_replicaset function (both Lua and GraphQL).
- New role flag: permanent = true. Permanent roles are always enabled. Also they are hidden implicitly.
- New functions in cluster test_helpers - Cluster:upload_config(config) and Cluster:download_config()

Fixed

- cluster.call_rpc used to return 'Role unavailable' error as a first argument instead of nil, err. It can appear when role is specified in clusterwide config, but wasn't initialized properly. There are two reasons for that: race condition, or prior error in either role init or apply_config methods.

[0.9.2] - 2019-07-12

Fixed

- Update frontend-core dependency which used to litter package.loaded with tons of JS code

[0.9.1] - 2019-07-10

Added

- Support for vshard groups in WebUI

Fixed

- Uniform handling vshard group 'default' when multiple groups aren't configured
- Requesting multiple vshard groups info before the cluster was bootstrapped

[0.9.0] - 2019-07-02

Added

- User management page in WebUI
- Configuring multiple isolated vshard groups in a single cluster
- Support for joining multiple instances in a single call to config_patch_clusterwide
- Integration tests helpers

Changed

- GraphQL API known_roles format now includes roles dependencies
- cluster.rpc_call option remote_only renamed to prefer_local with the opposite meaning

Fixed

- Don't display renamed or removed roles in webui
- Uploading config without a section removes it from clusterwide config

[0.8.0] - 2019-05-20

Added

- Specifying role dependencies
- Set read-only option for slave nodes
- Labels for servers

Changed

- Admin http endpoint changed from /graphql to /admin/api
- Graphql output now contains null values for empty objects
- Deprecate implicity of vshard roles `'cluster.roles.vshard-storage'`, `'cluster.roles.vshard-router'`. Now they should be specified explicitly in cluster.cfg({roles = ...})
- cluster.service_get(`'vshard-router'`) now returns cluster.roles.vshard-router module instead of vshard. router (incompatible change)
- cluster.service_get(`'vshard-storage'`) now returns cluster.roles.vshard-storage module instead of vshard.storage` (incompatible change)
- cluster.admin.bootstrap_vshard now can be called on any instance

Fixed

- Operating vshard-storage roles before vshard was bootstrapped

[0.7.0] - 2019-04-05

Added

- Failover priority configuration using WebUI
- Remote calls across cluster instances using cluster.rpc module
- Displaying box.cfg and box.info in WebUI
- Authorization for HTTP API and WebUI
- Configuration download/upload via WebUI
- Lua API documentation, which you can read with tarantoolctl rocks doc cluster command.

Changed

- Instance restart now triggers config validation before roles initialization
- Update WebUI design
- Lua API changed (old functions still work, but issue warnings): - cluster.confapplier.* -> cluster.config_* - cluster.service_registry.* -> cluster.service_*

[0.6.3] - 2019-02-08

Fixed

- Cluster used to call 'validate()' role method instead of documented 'validate_config()', so it was added. The undocumented 'validate()' still may be used for the sake of compatibility, but issues a warning that it was deprecated.

[0.6.2] - 2019-02-07

Fixed

- Minor internal corner cases

[0.6.1] - 2019-02-05

Fixed

- UI/UX: Replace "bootstrap vshard" button with a noticable panel
- UI/UX: Replace failover panel with a small button

[0.6.0] - 2019-01-30

Fixed

- Ability to disable vshard-storage role when zero-weight rebalancing finishes

- Active master indication during failover
- Other minor improvements

Changed

- New frontend core
- Dependencies update
- Call to join_server automatically does probe_server

Added

- Servers filtering by roles, uri, alias in WebUI

[0.5.1] - 2018-12-12

Fixed

- WebUI errors

[0.5.0] - 2018-12-11

Fixed

- Graphql mutations order

Changed

- Callbacks in user-defined roles are called with is_master parameter, indicating state of the instance
- Combine cluster.init and cluster.register_role api calls in single cluster.cfg
- Eliminate raising exceptions
- Absorb http server in cluster.cfg

Added

- Support of vshard replicaset weight parameter
- join_server() timeout parameter to make call synchronous

[0.4.0] - 2018-11-27

Fixed/Improved

- Uncaught exception in WebUI
- Indicate when backend is unavailable

- Sort servers in replicaset, put master first
- Cluster mutations are now synchronous, except joining new servers

Added

- Lua API for temporarily disabling servers
- Lua API for implementing user-defined roles

[0.3] - 2018-10-30

Changed

- Config structure incompatible with v0.2

Added

- Explicit vshard master configuration
- Automatic failover (switchable)
- Unit tests

[0.2] - 2018-10-01

Changed

- Allow vshard bootstrapping from ui
- Several stability improvements

[0.1] - 2018-09-25

Added

- Basic functionality
- Integration tests
- Luarock-based packaging
- Gitlab CI integration

4.4 Application server

Here we introduce the basics of working with Tarantool as a Lua application server.

This chapter contains the following sections:

4.4.1 Launching an application

Using Tarantool as an application server, you can write your own applications. Tarantool's native language for writing applications is Lua, so a typical application would be a file that contains your Lua script. But you can also write applications in C or C++.

Note: If you're new to Lua, we recommend going over the interactive Tarantool tutorial before proceeding with this chapter. To launch the tutorial, say tutorial() in Tarantool console:

```
tarantool> tutorial()
---
- |
 Tutorial -- Screen #1 -- Hello, Moon
 ====================================

 Welcome to the Tarantool tutorial.
 It will introduce you to Tarantool's Lua application server
 and database server, which is what's running what you're seeing.
 This is INTERACTIVE -- you're expected to enter requests
 based on the suggestions or examples in the screen's text.
 <...>
```

Let's create and launch our first Lua application for Tarantool. Here's a simplest Lua application, the good old "Hello, world!":

```
#!/usr/bin/env tarantool
print('Hello, world!')
```

We save it in a file. Let it be myapp.lua in the current directory.

Now let's discuss how we can launch our application with Tarantool.

Launching in Docker

If we run Tarantool in a Docker container, the following command will start Tarantool without any application:

```
$ # create a temporary container and run it in interactive mode
$ docker run --rm -t -i tarantool/tarantool:1
```

To run Tarantool with our application, we can say:

```
$ # create a temporary container and
$ # launch Tarantool with our application
$ docker run --rm -t -i \
            -v `pwd`/myapp.lua:/opt/tarantool/myapp.lua \
            -v /data/dir/on/host:/var/lib/tarantool \
            tarantool/tarantool:1 tarantool /opt/tarantool/myapp.lua
```

Here two resources on the host get mounted in the container:

- our application file (myapp.lua) and
- Tarantool data directory (/data/dir/on/host).

By convention, the directory for Tarantool application code inside a container is /opt/tarantool, and the directory for data is /var/lib/tarantool.

Launching a binary program

If we run Tarantool from a package or from a source build, we can launch our application:

- in the script mode,
- as a server application, or
- as a daemon service.

The simplest way is to pass the filename to Tarantool at start:

```
$ tarantool myapp.lua
Hello, world!
$
```

Tarantool starts, executes our script in the script mode and exits.

Now let's turn this script into a server application. We use box.cfg from Tarantool's built-in Lua module to:

- launch the database (a database has a persistent on-disk state, which needs to be restored after we start an application) and
- configure Tarantool as a server that accepts requests over a TCP port.

We also add some simple database logic, using space.create() and create_index() to create a space with a primary index. We use the function box.once() to make sure that our logic will be executed only once when the database is initialized for the first time, so we don't try to create an existing space or index on each invocation of the script:

```
#!/usr/bin/env tarantool
-- Configure database
box.cfg {
   listen = 3301
}
box.once("bootstrap", function()
   box.schema.space.create('tweedledum')
   box.space.tweedledum:create_index('primary',
       { type = 'TREE', parts = {1, 'unsigned'}})
end)
```

Now we launch our application in the same manner as before:

```
$ tarantool myapp.lua
Hello, world!
2017-08-11 16:07:14.250 [41436] main/101/myapp.lua C> version 2.1.0-429-g4e5231702
2017-08-11 16:07:14.250 [41436] main/101/myapp.lua C> log level 5
2017-08-11 16:07:14.251 [41436] main/101/myapp.lua I> mapping 1073741824 bytes for tuple arena...
2017-08-11 16:07:14.255 [41436] main/101/myapp.lua I> recovery start
2017-08-11 16:07:14.255 [41436] main/101/myapp.lua I> recovering from `./00000000000000000000.snap'
2017-08-11 16:07:14.271 [41436] main/101/myapp.lua I> recover from `./00000000000000000000.xlog'
2017-08-11 16:07:14.271 [41436] main/101/myapp.lua I> done `./00000000000000000000.xlog'
2017-08-11 16:07:14.272 [41436] main/102/hot_standby I> recover from `./00000000000000000000.xlog'
2017-08-11 16:07:14.274 [41436] iproto/102/iproto I> binary: started
2017-08-11 16:07:14.275 [41436] iproto/102/iproto I> binary: bound to [::]:3301
2017-08-11 16:07:14.275 [41436] main/101/myapp.lua I> done `./00000000000000000000.xlog'
2017-08-11 16:07:14.278 [41436] main/101/myapp.lua I> ready to accept requests
```

This time, Tarantool executes our script and keeps working as a server, accepting TCP requests on port 3301. We can see Tarantool in the current session's process list:

```
$ ps | grep "tarantool"
  PID TTY           TIME CMD
41608 ttys001       0:00.47 tarantool myapp.lua <running>
```

But the Tarantool instance will stop if we close the current terminal window. To detach Tarantool and our application from the terminal window, we can launch it in the daemon mode. To do so, we add some parameters to box.cfg{}:

- background = true that actually tells Tarantool to work as a daemon service,
- log = 'dir-name' that tells the Tarantool daemon where to store its log file (other log settings are available in Tarantool log module), and
- pid_file = 'file-name' that tells the Tarantool daemon where to store its pid file.

For example:

```
box.cfg {
   listen = 3301,
   background = true,
   log = '1.log',
   pid_file = '1.pid'
}
```

We launch our application in the same manner as before:

```
$ tarantool myapp.lua
Hello, world!
$
```

Tarantool executes our script, gets detached from the current shell session (you won't see it with ps | grep "tarantool") and continues working in the background as a daemon attached to the global session (with SID = 0):

```
$ ps -ef | grep "tarantool"
  PID SID     TIME  CMD
42178   0  0:00.72 tarantool myapp.lua <running>
```

Now that we have discussed how to create and launch a Lua application for Tarantool, let's dive deeper into programming practices.

4.4.2 Creating an application

Further we walk you through key programming practices that will give you a good start in writing Lua applications for Tarantool. For an adventure, this is a story of implementing… a real microservice based on Tarantool! We implement a backend for a simplified version of Pokémon Go, a location-based augmented reality game released in mid-2016. In this game, players use a mobile device's GPS capability to locate, capture, battle and train virtual monsters called "pokémon", who appear on the screen as if they were in the same real-world location as the player.

To stay within the walk-through format, let's narrow the original gameplay as follows. We have a map with pokémon spawn locations. Next, we have multiple players who can send catch-a-pokémon requests to the server (which runs our Tarantool microservice). The server replies whether the pokémon is caught or not, increases the player's pokémon counter if yes, and triggers the respawn-a-pokémon method that spawns a new pokémon at the same location in a while.

We leave client-side applications outside the scope of this story. Yet we promise a mini-demo in the end to simulate real users and give us some fun. :-)

* * *

First, what would be the best way to deliver our microservice?

Modules, rocks and applications

To make our game logic available to other developers and Lua applications, let's put it into a Lua module.

A module (called "rock" in Lua) is an optional library which enhances Tarantool functionality. So, we can install our logic as a module in Tarantool and use it from any Tarantool application or module. Like applications, modules in Tarantool can be written in Lua (rocks), C or C++.

Modules are good for two things:

- easier code management (reuse, packaging, versioning), and
- hot code reload without restarting the Tarantool instance.

Technically, a module is a file with source code that exports its functions in an API. For example, here is a Lua module named mymodule.lua that exports one function named myfun:

```
local exports = {}
exports.myfun = function(input_string)
   print('Hello', input_string)
end
return exports
```

To launch the function myfun() – from another module, from a Lua application, or from Tarantool itself, – we need to save this module as a file, then load this module with the require() directive and call the exported function.

For example, here's a Lua application that uses myfun() function from mymodule.lua module:

```
-- loading the module
local mymodule = require('mymodule')

-- calling myfun() from within test() function
local test = function()
  mymodule.myfun()
end
```

A thing to remember here is that the require() directive takes load paths to Lua modules from the package. path variable. This is a semicolon-separated string, where a question mark is used to interpolate the module name. By default, this variable contains system-wide Lua paths and the working directory. But if we put our modules inside a specific folder (e.g. scripts/), we need to add this folder to package.path before any calls to require():

```
package.path = 'scripts/?.lua;' .. package.path
```

For our microservice, a simple and convenient solution would be to put all methods in a Lua module (say pokemon.lua) and to write a Lua application (say game.lua) that initializes the gaming environment and starts the game loop.

* * *

Now let's get down to implementation details. In our game, we need three entities:

- map, which is an array of pokémons with coordinates of respawn locations; in this version of the game, let a location be a rectangle identified with two points, upper-left and lower-right;
- player, which has an ID, a name, and coordinates of the player's location point;
- pokémon, which has the same fields as the player, plus a status (active/inactive, that is present on the map or not) and a catch probability (well, let's give our pokémons a chance to escape :-))

We'll store these entities as tuples in Tarantool spaces. But to deliver our backend application as a microservice, the good practice would be to send/receive our data in the universal JSON format, thus using Tarantool as a document storage.

Avro schemas

To store JSON data as tuples, we will apply a savvy practice which reduces data footprint and ensures all stored documents are valid. We will use Tarantool module avro-schema which checks the schema of a JSON document and converts it to a Tarantool tuple. The tuple will contain only field values, and thus take a lot less space than the original document. In avro-schema terms, converting JSON documents to tuples is "flattening", and restoring the original documents is "unflattening".

First you need to install the module with tarantoolctl rocks install avro-schema.

Further usage is quite straightforward:

(1) For each entity, we need to define a schema in Apache Avro schema syntax, where we list the entity's fields with their names and Avro data types.

(2) At initialization, we call avro-schema.create() that creates objects in memory for all schema entities, and compile() that generates flatten/unflatten methods for each entity.

(3) Further on, we just call flatten/unflatten methods for a respective entity on receiving/sending the entity's data.

Here's what our schema definitions for the player and pokémon entities look like:

```
local schema = {
    player = {
        type="record",
        name="player_schema",
        fields={
            {name="id", type="long"},
            {name="name", type="string"},
            {
                name="location",
                type= {
                    type="record",
                    name="player_location",
                    fields={
                        {name="x", type="double"},
                        {name="y", type="double"}
                    }
                }
            }
        }
    },
    pokemon = {
        type="record",
        name="pokemon_schema",
        fields={
```

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```
            {name="id", type="long"},
            {name="status", type="string"},
            {name="name", type="string"},
            {name="chance", type="double"},
            {
                name="location",
                type= {
                    type="record",
                    name="pokemon_location",
                    fields={
                        {name="x", type="double"},
                        {name="y", type="double"}
                    }
                }
            }
        }
    }
}
```

And here's how we create and compile our entities at initialization:

```
-- load avro-schema module with require()
local avro = require('avro_schema')

-- create models
local ok_m, pokemon = avro.create(schema.pokemon)
local ok_p, player = avro.create(schema.player)
if ok_m and ok_p then
    -- compile models
    local ok_cm, compiled_pokemon = avro.compile(pokemon)
    local ok_cp, compiled_player = avro.compile(player)
    if ok_cm and ok_cp then
        -- start the game
        <...>
    else
        log.error('Schema compilation failed')
    end
else
    log.info('Schema creation failed')
end
return false
```

As for the map entity, it would be an overkill to introduce a schema for it, because we have only one map in the game, it has very few fields, and – which is most important – we use the map only inside our logic, never exposing it to external users.

* * *

Next, we need methods to implement the game logic. To simulate object-oriented programming in our Lua code, let's store all Lua functions and shared variables in a single local variable (let's name it as game). This will allow us to address functions or variables from within our module as self.func_name or self.var_name. Like this:

```
local game = {
    -- a local variable
```

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```
  num_players = 0,

  -- a method that prints a local variable
  hello = function(self)
    print('Hello! Your player number is ' .. self.num_players .. '.')
  end,

  -- a method that calls another method and returns a local variable
  sign_in = function(self)
    self.num_players = self.num_players + 1
    self:hello()
    return self.num_players
  end
}
```

In OOP terms, we can now regard local variables inside game as object fields, and local functions as object methods.

Note: In this manual, Lua examples use local variables. Use global variables with caution, since the module's users may be unaware of them.

To enable/disable the use of undeclared global variables in your Lua code, use Tarantool's strict module.

So, our game module will have the following methods:

- catch() to calculate whether the pokémon was caught (besides the coordinates of both the player and pokémon, this method will apply a probability factor, so not every pokémon within the player's reach will be caught);
- respawn() to add missing pokémons to the map, say, every 60 seconds (we assume that a frightened pokémon runs away, so we remove a pokémon from the map on any catch attempt and add it back to the map in a while);
- notify() to log information about caught pokémons (like "Player 1 caught pokémon A");
- start() to initialize the game (it will create database spaces, create and compile avro schemas, and launch respawn()).

Besides, it would be convenient to have methods for working with Tarantool storage. For example:

- add_pokemon() to add a pokémon to the database, and
- map() to populate the map with all pokémons stored in Tarantool.

We'll need these two methods primarily when initializing our game, but we can also call them later, for example to test our code.

Bootstrapping a database

Let's discuss game initialization. In start() method, we need to populate Tarantool spaces with pokémon data. Why not keep all game data in memory? Why use a database? The answer is: persistence. Without a database, we risk losing data on power outage, for example. But if we store our data in an in-memory database, Tarantool takes care to persist it on disk whenever it's changed. This gives us one more benefit: quick startup in case of failure. Tarantool has a smart algorithm that quickly loads all data from disk into memory on startup, so the warm-up takes little time.

We'll be using functions from Tarantool built-in box module:

- box.schema.create_space('pokemons') to create a space named pokemon for storing information about pokémons (we don't create a similar space for players, because we intend to only send/receive player information via API calls, so we needn't store it);
- box.space.pokemons:create_index('primary', {type = 'hash', parts = {1, 'unsigned'}}) to create a primary HASH index by pokémon ID;
- box.space.pokemons:create_index('status', {type = 'tree', parts = {2, 'str'}}) to create a secondary TREE index by pokémon status.

Notice the parts = argument in the index specification. The pokémon ID is the first field in a Tarantool tuple since it's the first member of the respective Avro type. So does the pokémon status. The actual JSON document may have ID or status fields at any position of the JSON map.

The implementation of start() method looks like this:

```
-- create game object
start = function(self)
    -- create spaces and indexes
    box.once('init', function()
        box.schema.create_space('pokemons')
        box.space.pokemons:create_index(
            "primary", {type = 'hash', parts = {1, 'unsigned'}}
        )
        box.space.pokemons:create_index(
            "status", {type = "tree", parts = {2, 'str'}}
        )
    end)

    -- create models
    local ok_m, pokemon = avro.create(schema.pokemon)
    local ok_p, player = avro.create(schema.player)
    if ok_m and ok_p then
        -- compile models
        local ok_cm, compiled_pokemon = avro.compile(pokemon)
        local ok_cp, compiled_player = avro.compile(player)
        if ok_cm and ok_cp then
            -- start the game
            <...>
        else
            log.error('Schema compilation failed')
        end
    else
        log.info('Schema creation failed')
    end
    return false
end
```

GIS

Now let's discuss catch(), which is the main method in our gaming logic.

Here we receive the player's coordinates and the target pokémon's ID number, and we need to answer whether the player has actually caught the pokémon or not (remember that each pokémon has a chance to escape).

First thing, we validate the received player data against its Avro schema. And we check whether such a pokémon exists in our database and is displayed on the map (the pokémon must have the active status):

```
catch = function(self, pokemon_id, player)
    -- check player data
    local ok, tuple = self.player_model.flatten(player)
    if not ok then
        return false
    end
    -- get pokemon data
    local p_tuple = box.space.pokemons:get(pokemon_id)
    if p_tuple == nil then
        return false
    end
    local ok, pokemon = self.pokemon_model.unflatten(p_tuple)
    if not ok then
        return false
    end
    if pokemon.status ~= self.state.ACTIVE then
        return false
    end
    -- more catch logic to follow
    <...>
end
```

Next, we calculate the answer: caught or not.

To work with geographical coordinates, we use Tarantool gis module.

To keep things simple, we don't load any specific map, assuming that we deal with a world map. And we do not validate incoming coordinates, assuming again that all received locations are within the planet Earth.

We use two geo-specific variables:

- wgs84, which stands for the latest revision of the World Geodetic System standard, WGS84. Basically, it comprises a standard coordinate system for the Earth and represents the Earth as an ellipsoid.
- nationalmap, which stands for the US National Atlas Equal Area. This is a projected coordinates system based on WGS84. It gives us a zero base for location projection and allows positioning our players and pokémons in meters.

Both these systems are listed in the EPSG Geodetic Parameter Registry, where each system has a unique number. In our code, we assign these listing numbers to respective variables:

```
wgs84 = 4326,
nationalmap = 2163,
```

For our game logic, we need one more variable, catch_distance, which defines how close a player must get to a pokémon before trying to catch it. Let's set the distance to 100 meters.

```
catch_distance = 100,
```

Now we're ready to calculate the answer. We need to project the current location of both player (p_pos) and pokémon (m_pos) on the map, check whether the player is close enough to the pokémon (using catch_distance), and calculate whether the player has caught the pokémon (here we generate some random value and let the pokémon escape if the random value happens to be less than 100 minus pokémon's chance value):

```
-- project locations
local m_pos = gis.Point(
    {pokemon.location.x, pokemon.location.y}, self.wgs84
```

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```
):transform(self.nationalmap)
local p_pos = gis.Point(
    {player.location.x, player.location.y}, self.wgs84
):transform(self.nationalmap)

-- check catch distance condition
if p_pos:distance(m_pos) > self.catch_distance then
    return false
end
-- try to catch pokemon
local caught = math.random(100) >= 100 - pokemon.chance
if caught then
    -- update and notify on success
    box.space.pokemons:update(
        pokemon_id, {{'=', self.STATUS, self.state.CAUGHT}}
    )
    self:notify(player, pokemon)
end
return caught
```

Index iterators

By our gameplay, all caught pokémons are returned back to the map. We do this for all pokémons on the map every 60 seconds using respawn() method. We iterate through pokémons by status using Tarantool index iterator function index:pairs and reset the statuses of all "caught" pokémons back to "active" using box.space.pokemons:update().

```
respawn = function(self)
    fiber.name('Respawn fiber')
    for _, tuple in box.space.pokemons.index.status:pairs(
           self.state.CAUGHT) do
        box.space.pokemons:update(
            tuple[self.ID],
            {{'=', self.STATUS, self.state.ACTIVE}}
        )
    end
 end
```

For readability, we introduce named fields:

ID = 1, STATUS = 2,

The complete implementation of start() now looks like this:

```
-- create game object
start = function(self)
    -- create spaces and indexes
    box.once('init', function()
       box.schema.create_space('pokemons')
       box.space.pokemons:create_index(
           "primary", {type = 'hash', parts = {1, 'unsigned'}}
       )
       box.space.pokemons:create_index(
           "status", {type = "tree", parts = {2, 'str'}}
       )
```

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```
    end)

    -- create models
    local ok_m, pokemon = avro.create(schema.pokemon)
    local ok_p, player = avro.create(schema.player)
    if ok_m and ok_p then
        -- compile models
        local ok_cm, compiled_pokemon = avro.compile(pokemon)
        local ok_cp, compiled_player = avro.compile(player)
        if ok_cm and ok_cp then
            -- start the game
            self.pokemon_model = compiled_pokemon
            self.player_model = compiled_player
            self.respawn()
            log.info('Started')
            return true
         else
            log.error('Schema compilation failed')
         end
    else
        log.info('Schema creation failed')
    end
    return false
end
```

Fibers

But wait! If we launch it as shown above – self.respawn() – the function will be executed only once, just like all the other methods. But we need to execute respawn() every 60 seconds. Creating a fiber is the Tarantool way of making application logic work in the background at all times.

A fiber exists for executing instruction sequences but it is not a thread. The key difference is that threads use preemptive multitasking, while fibers use cooperative multitasking. This gives fibers the following two advantages over threads:

- Better controllability. Threads often depend on the kernel's thread scheduler to preempt a busy thread and resume another thread, so preemption may occur unpredictably. Fibers yield themselves to run another fiber while executing, so yields are controlled by application logic.
- Higher performance. Threads require more resources to preempt as they need to address the system kernel. Fibers are lighter and faster as they don't need to address the kernel to yield.

Yet fibers have some limitations as compared with threads, the main limitation being no multi-core mode. All fibers in an application belong to a single thread, so they all use the same CPU core as the parent thread. Meanwhile, this limitation is not really serious for Tarantool applications, because a typical bottleneck for Tarantool is the HDD, not the CPU.

A fiber has all the features of a Lua coroutine and all programming concepts that apply for Lua coroutines will apply for fibers as well. However, Tarantool has made some enhancements for fibers and has used fibers internally. So, although use of coroutines is possible and supported, use of fibers is recommended.

Well, performance or controllability are of little importance in our case. We'll launch respawn() in a fiber to make it work in the background all the time. To do so, we'll need to amend respawn():

```
respawn = function(self)
    -- let's give our fiber a name;
```

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```
    -- this will produce neat output in fiber.info()
    fiber.name('Respawn fiber')
    while true do
        for _, tuple in box.space.pokemons.index.status:pairs(
                self.state.CAUGHT) do
            box.space.pokemons:update(
                tuple[self.ID],
                {{'=', self.STATUS, self.state.ACTIVE}}
            )
        end
        fiber.sleep(self.respawn_time)
    end
end
```

and call it as a fiber in start():

```
start = function(self)
    -- create spaces and indexes
        <...>
    -- create models
        <...>
    -- compile models
        <...>
    -- start the game
       self.pokemon_model = compiled_pokemon
       self.player_model = compiled_player
       fiber.create(self.respawn, self)
       log.info('Started')
    -- errors if schema creation or compilation fails
       <...>
end
```

Logging

One more helpful function that we used in start() was log.info() from Tarantool log module. We also need this function in notify() to add a record to the log file on every successful catch:

```
-- event notification
notify = function(self, player, pokemon)
    log.info("Player '%s' caught '%s'", player.name, pokemon.name)
end
```

We use default Tarantool log settings, so we'll see the log output in console when we launch our application in script mode.

* * *

Great! We've discussed all programming practices used in our Lua module (see pokemon.lua).

Now let's prepare the test environment. As planned, we write a Lua application (see game.lua) to initialize Tarantool's database module, initialize our game, call the game loop and simulate a couple of player requests.

To launch our microservice, we put both pokemon.lua module and game.lua application in the current directory, install all external modules, and launch the Tarantool instance running our game.lua application (this example is for Ubuntu):

```
$ ls
game.lua  pokemon.lua
$ sudo apt-get install tarantool-gis
$ sudo apt-get install tarantool-avro-schema
$ tarantool game.lua
```

Tarantool starts and initializes the database. Then Tarantool executes the demo logic from game.lua: adds a pokémon named Pikachu (its chance to be caught is very high, 99.1), displays the current map (it contains one active pokémon, Pikachu) and processes catch requests from two players. Player1 is located just near the lonely Pikachu pokémon and Player2 is located far away from it. As expected, the catch results in this output are "true" for Player1 and "false" for Player2. Finally, Tarantool displays the current map which is empty, because Pikachu is caught and temporarily inactive:

```
$ tarantool game.lua
2017-01-09 20:19:24.605 [6282] main/101/game.lua C> version 1.7.3-43-gf5fa1e1
2017-01-09 20:19:24.605 [6282] main/101/game.lua C> log level 5
2017-01-09 20:19:24.605 [6282] main/101/game.lua I> mapping 1073741824 bytes for tuple arena...
2017-01-09 20:19:24.609 [6282] main/101/game.lua I> initializing an empty data directory
2017-01-09 20:19:24.634 [6282] snapshot/101/main I> saving snapshot `./00000000000000000000.snap.inprogress'
2017-01-09 20:19:24.635 [6282] snapshot/101/main I> done
2017-01-09 20:19:24.641 [6282] main/101/game.lua I> ready to accept requests
2017-01-09 20:19:24.786 [6282] main/101/game.lua I> Started
---
- {'id': 1, 'status': 'active', 'location': {'y': 2, 'x': 1}, 'name': 'Pikachu', 'chance': 99.1}
...

2017-01-09 20:19:24.789 [6282] main/101/game.lua I> Player 'Player1' caught 'Pikachu'
true
false
--- []
...

2017-01-09 20:19:24.789 [6282] main C> entering the event loop
```

nginx

In the real life, this microservice would work over HTTP. Let's add nginx web server to our environment and make a similar demo. But how do we make Tarantool methods callable via REST API? We use nginx with Tarantool nginx upstream module and create one more Lua script (app.lua) that exports three of our game methods – add_pokemon(), map() and catch() – as REST endpoints of the nginx upstream module:

```
local game = require('pokemon')
box.cfg{listen=3301}
game:start()

-- add, map and catch functions exposed to REST API
function add(request, pokemon)
    return {
        result=game:add_pokemon(pokemon)
    }
end

function map(request)
    return {
        map=game:map()
```

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```
    }
end

function catch(request, pid, player)
    local id = tonumber(pid)
    if id == nil then
        return {result=false}
    end
    return {
        result=game:catch(id, player)
    }
end
```

An easy way to configure and launch nginx would be to create a Docker container based on a Docker image with nginx and the upstream module already installed (see http/Dockerfile). We take a standard nginx.conf, where we define an upstream with our Tarantool backend running (this is another Docker container, see details below):

```
upstream tnt {
      server pserver:3301 max_fails=1 fail_timeout=60s;
      keepalive 250000;
}
```

and add some Tarantool-specific parameters (see descriptions in the upstream module's README file):

```
server {
  server_name tnt_test;

  listen 80 default deferred reuseport so_keepalive=on backlog=65535;

  location = / {
      root /usr/local/nginx/html;
  }

  location /api {
    # answers check infinity timeout
    tnt_read_timeout 60m;
    if ( $request_method = GET ) {
       tnt_method "map";
    }
    tnt_http_rest_methods get;
    tnt_http_methods all;
    tnt_multireturn_skip_count 2;
    tnt_pure_result on;
    tnt_pass_http_request on parse_args;
    tnt_pass tnt;
  }
}
```

Likewise, we put Tarantool server and all our game logic in a second Docker container based on the official Tarantool 1.9 image (see src/Dockerfile) and set the container's default command to tarantool app.lua. This is the backend.

Non-blocking IO

To test the REST API, we create a new script (client.lua), which is similar to our game.lua application, but makes HTTP POST and GET requests rather than calling Lua functions:

```lua
local http = require('curl').http()
local json = require('json')
local URI = os.getenv('SERVER_URI')
local fiber = require('fiber')

local player1 = {
    name="Player1",
    id=1,
    location = {
        x=1.0001,
        y=2.0003
    }
}
local player2 = {
    name="Player2",
    id=2,
    location = {
        x=30.123,
        y=40.456
    }
}

local pokemon = {
    name="Pikachu",
    chance=99.1,
    id=1,
    status="active",
    location = {
        x=1,
        y=2
    }
}

function request(method, body, id)
    local resp = http:request(
        method, URI, body
    )
    if id ~= nil then
        print(string.format('Player %d result: %s',
            id, resp.body))
    else
        print(resp.body)
    end
end

local players = {}
function catch(player)
    fiber.sleep(math.random(5))
    print('Catch pokemon by player ' .. tostring(player.id))
    request(
        'POST', '{"method": "catch",
        "params": [1, '..json.encode(player)..']}',
        tostring(player.id)
```

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```
    )
    table.insert(players, player.id)
end

print('Create pokemon')
request('POST', '{"method": "add",
    "params": ['..json.encode(pokemon)..']}')
request('GET', '')

fiber.create(catch, player1)
fiber.create(catch, player2)

-- wait for players
while #players ~= 2 do
    fiber.sleep(0.001)
end

request('GET', '')
os.exit()
```

When you run this script, you'll notice that both players have equal chances to make the first attempt at catching the pokémon. In a classical Lua script, a networked call blocks the script until it's finished, so the first catch attempt can only be done by the player who entered the game first. In Tarantool, both players play concurrently, since all modules are integrated with Tarantool cooperative multitasking and use non-blocking I/O.

Indeed, when Player1 makes its first REST call, the script doesn't block. The fiber running catch() function on behalf of Player1 issues a non-blocking call to the operating system and yields control to the next fiber, which happens to be the fiber of Player2. Player2's fiber does the same. When the network response is received, Player1's fiber is activated by Tarantool cooperative scheduler, and resumes its work. All Tarantool modules use non-blocking I/O and are integrated with Tarantool cooperative scheduler. For module developers, Tarantool provides an API.

For our HTTP test, we create a third container based on the official Tarantool 1.9 image (see client/Dockerfile) and set the container's default command to tarantool client.lua.

* * *

To run this test locally, download our pokemon project from GitHub and say:

```
$ docker-compose build
$ docker-compose up
```

Docker Compose builds and runs all the three containers: pserver (Tarantool backend), phttp (nginx) and pclient (demo client). You can see log messages from all these containers in the console, pclient saying that it made an HTTP request to create a pokémon, made two catch requests, requested the map (empty since the pokémon is caught and temporarily inactive) and exited:

```
pclient_1  | Create pokemon
<...>
pclient_1  | {"result":true}
pclient_1  | {"map":[{"id":1,"status":"active","location":{"y":2,"x":1},"name":"Pikachu","chance":99.100000}]}
pclient_1  | Catch pokemon by player 2
pclient_1  | Catch pokemon by player 1
pclient_1  | Player 1 result: {"result":true}
```

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```
pclient_1  | Player 2 result: {"result":false}
pclient_1  | {"map":[]}
pokemon_pclient_1 exited with code 0
```

Congratulations! Here's the end point of our walk-through. As further reading, see more about installing and contributing a module.

See also reference on Tarantool modules and C API, and don't miss our Lua cookbook recipes.

4.4.3 Installing a module

Modules in Lua and C that come from Tarantool developers and community contributors are available in the following locations:

- Tarantool modules repository (see below)
- Tarantool deb/rpm repositories (see below)

Installing a module from a repository

See README in tarantool/rocks repository for detailed instructions.

Installing a module from deb/rpm

Follow these steps:

1. Install Tarantool as recommended on the download page.
2. Install the module you need. Look up the module's name on Tarantool rocks page and put the prefix "tarantool-" before the module name to avoid ambiguity:

   ```
   $ # for Ubuntu/Debian:
   $ sudo apt-get install tarantool-<module-name>

   $ # for RHEL/CentOS/Amazon:
   $ sudo yum install tarantool-<module-name>
   ```

   For example, to install the module shard on Ubuntu, say:

   ```
   $ sudo apt-get install tarantool-shard
   ```

Once these steps are complete, you can:

- load any module with

  ```
  tarantool> name = require('module-name')
  ```

  for example:

  ```
  tarantool> shard = require('shard')
  ```

- search locally for installed modules using package.path (Lua) or package.cpath (C):

```
tarantool> package.path
---
- ./?.lua;./?/init.lua; /usr/local/share/tarantool/?.lua;/usr/local/share/
tarantool/?/init.lua;/usr/share/tarantool/?.lua;/usr/share/tarantool/?/ini
t.lua;/usr/local/share/lua/5.1/?.lua;/usr/local/share/lua/5.1/?/init.lua;/
usr/share/lua/5.1/?.lua;/usr/share/lua/5.1/?/init.lua;
...

tarantool> package.cpath
---
- ./?.so;/usr/local/lib/x86_64-linux-gnu/tarantool/?.so;/usr/lib/x86_64-li
nux-gnu/tarantool/?.so;/usr/local/lib/tarantool/?.so;/usr/local/lib/x86_64
-linux-gnu/lua/5.1/?.so;/usr/lib/x86_64-linux-gnu/lua/5.1/?.so;/usr/local/
lib/lua/5.1/?.so;
...
```

Note: Question-marks stand for the module name that was specified earlier when saying require('module-name').

4.4.4 Contributing a module

We have already discussed how to create a simple module in Lua for local usage. Now let's discuss how to create a more advanced Tarantool module and then get it published on Tarantool rocks page and included in official Tarantool images for Docker.

To help our contributors, we have created modulekit, a set of templates for creating Tarantool modules in Lua and C.

Note: As a prerequisite for using modulekit, install tarantool-dev package first. For example, in Ubuntu say:

```
$ sudo apt-get install tarantool-dev
```

Contributing a module in Lua

See README in "luakit" branch of tarantool/modulekit repository for detailed instructions and examples.

Contributing a module in C

In some cases, you may want to create a Tarantool module in C rather than in Lua. For example, to work with specific hardware or low-level system interfaces.

See README in "ckit" branch of tarantool/modulekit repository for detailed instructions and examples.

Note: You can also create modules with C++, provided that the code does not throw exceptions.

4.4.5 Reloading a module

You can reload any Tarantool application or module with zero downtime.

Reloading a module in Lua

Here's an example that illustrates the most typical case – "update and reload".

Note: In this example, we use recommended administration practices based on instance files and tarantoolctl utility.

1. Update the application file.

   For example, a module in /usr/share/tarantool/app.lua:

```
local function start()
  -- initial version
  box.once("myapp:v1.0", function()
    box.schema.space.create("somedata")
    box.space.somedata:create_index("primary")
    ...
  end)

  -- migration code from 1.0 to 1.1
  box.once("myapp:v1.1", function()
    box.space.somedata.index.primary:alter(...)
    ...
  end)

  -- migration code from 1.1 to 1.2
  box.once("myapp:v1.2", function()
    box.space.somedata.index.primary:alter(...)
    box.space.somedata:insert(...)
    ...
  end)
end

-- start some background fibers if you need

local function stop()
  -- stop all background fibers and clean up resources
end

local function api_for_call(xxx)
  -- do some business
end

return {
  start = start,
  stop = stop,
  api_for_call = api_for_call
}
```

2. Update the instance file.

   For example, /etc/tarantool/instances.enabled/my_app.lua:

```
#!/usr/bin/env tarantool
--
-- hot code reload example
--

box.cfg({listen = 3302})

-- ATTENTION: unload it all properly!
local app = package.loaded['app']
if app ~= nil then
  -- stop the old application version
  app.stop()
  -- unload the application
  package.loaded['app'] = nil
  -- unload all dependencies
  package.loaded['somedep'] = nil
end

-- load the application
log.info('require app')
app = require('app')

-- start the application
app.start({some app options controlled by sysadmins})
```

The important thing here is to properly unload the application and its dependencies.

3. Manually reload the application file.

   For example, using tarantoolctl:

```
$ tarantoolctl eval my_app /etc/tarantool/instances.enabled/my_app.lua
```

Reloading a module in C

After you have compiled a new version of a C module (*.so shared library), call box.schema.func.reload('module-name') from your Lua script to reload the module.

Starting in Tarantool version 2.3, reload() will create a temporary file to store the module if any of its functions is still running. The directory for this file is what is specified in the TMPDIR environment variable, or it is /tmp if the TMPDIR environment variable is blank.

4.4.6 Developing with an IDE

You can use IntelliJ IDEA as an IDE to develop and debug Lua applications for Tarantool.

1. Download and install the IDE from the official web-site.

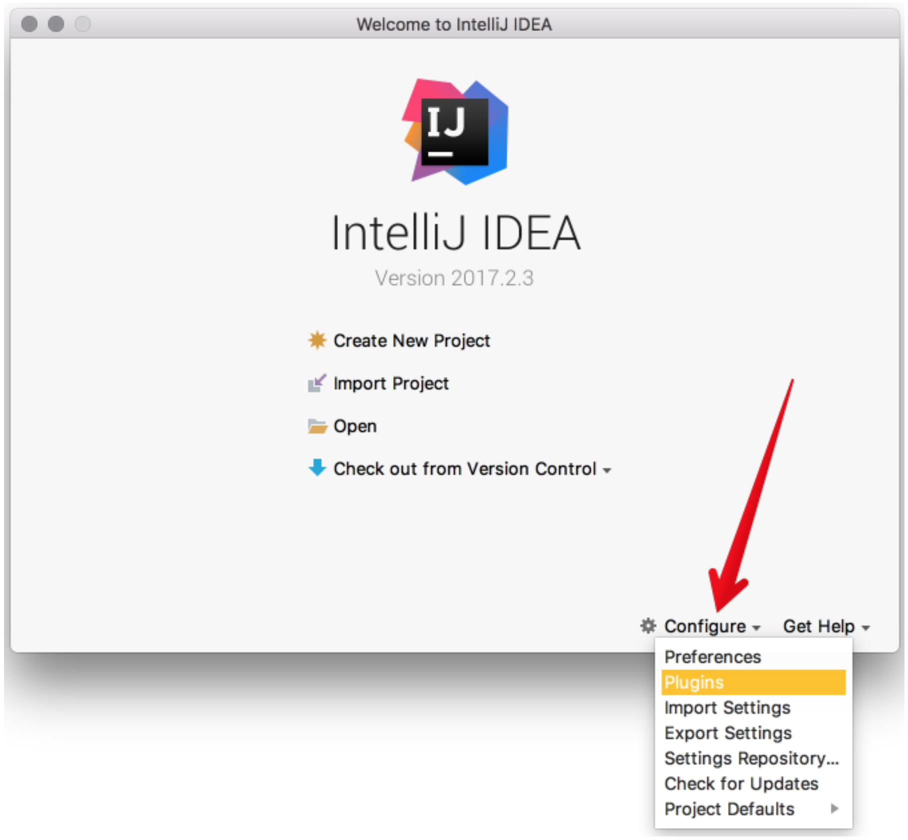
   JetBrains provides specialized editions for particular languages: IntelliJ IDEA (Java), PHPStorm (PHP), PyCharm (Python), RubyMine (Ruby), CLion (C/C++), WebStorm (Web) and others. So, download a version that suits your primary programming language.

   Tarantool integration is supported for all editions.

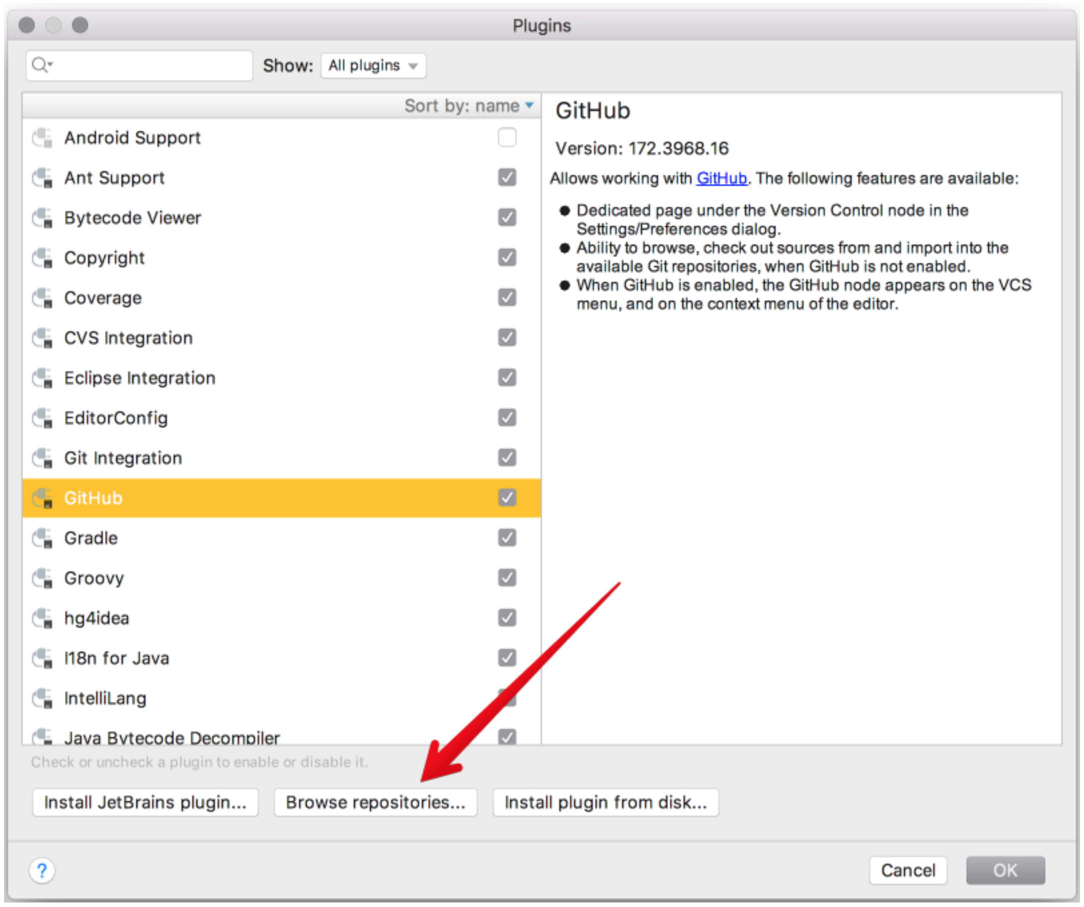
2. Configure the IDE:

   a. Start IntelliJ IDEA.

b. Click Configure button and select Plugins.



c. Click Browse repositories.



GitHub

Version: 172.3968.16

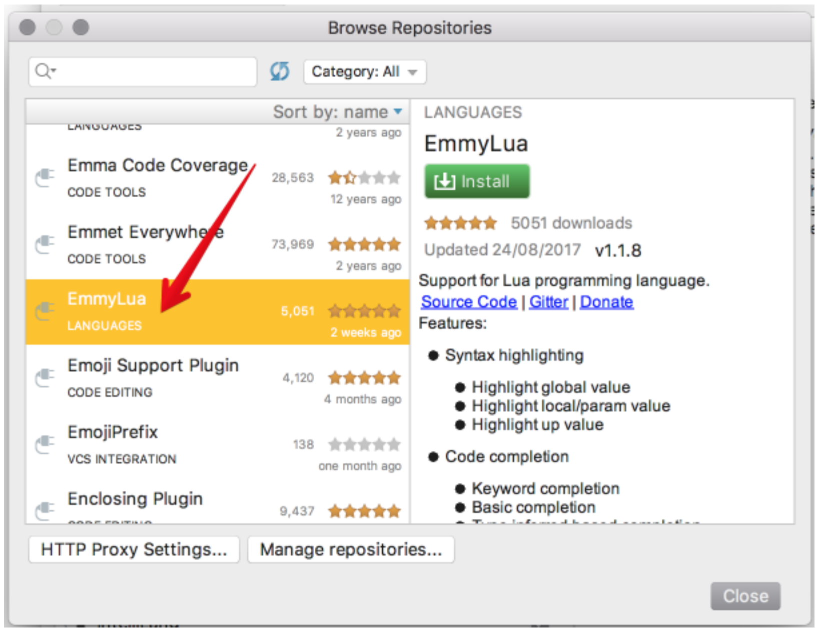
Allows working with GitHub. The following features are available:

- Dedicated page under the Version Control node in the Settings/Preferences dialog.
- Ability to browse, check out sources from and import into the available Git repositories, when GitHub is not enabled.
- When GitHub is enabled, the GitHub node appears on the VCS menu, and on the context menu of the editor.

Check or uncheck a plugin to enable or disable it.

d. Install EmmyLua plugin.

Note: Please don't be confused with Lua plugin, which is less powerful than EmmyLua.



LANGUAGES

EmmyLua

Install

5051 downloads

Updated 24/08/2017 v1.1.8

Support for Lua programming language.

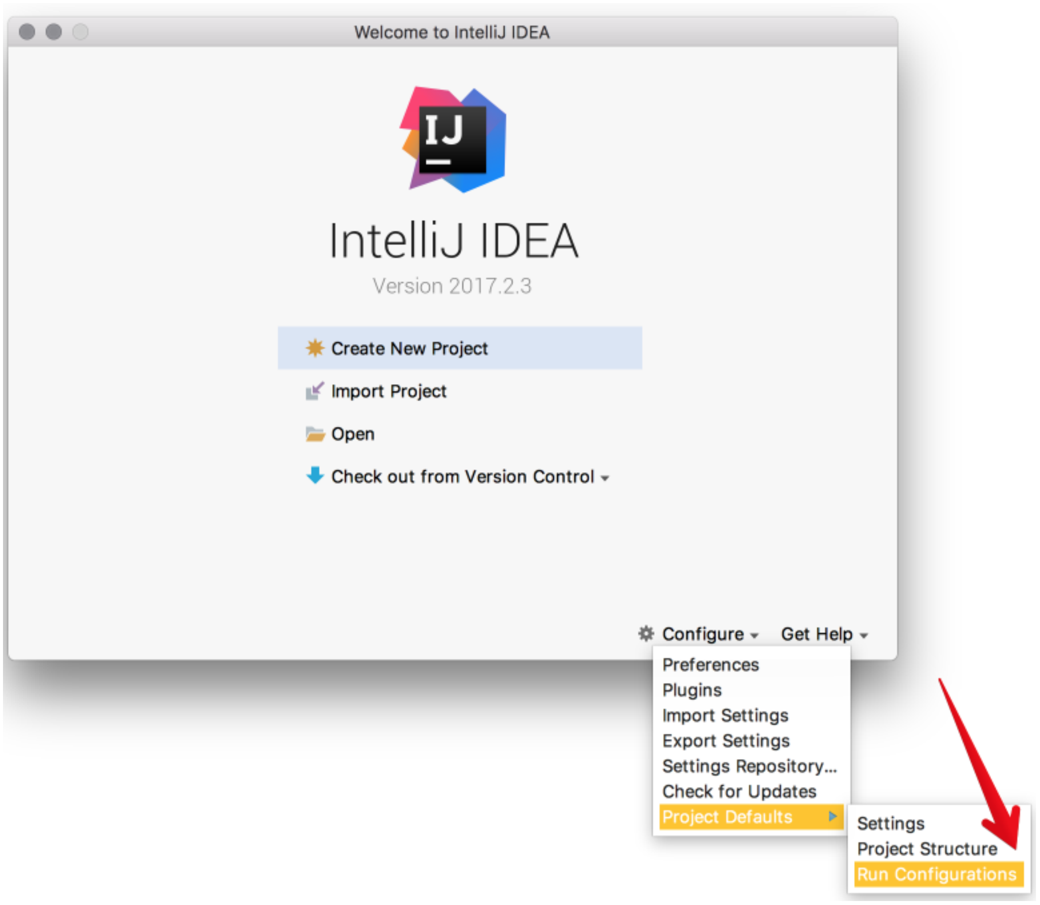
Source Code | Gitter | Donate

Features:

- Syntax highlighting
  - Highlight global value
  - Highlight local/param value
  - Highlight up value
- Code completion
  - Keyword completion
  - Basic completion

e. Restart IntelliJ IDEA.

f. Click Configure, select Project Defaults and then Run Configurations.

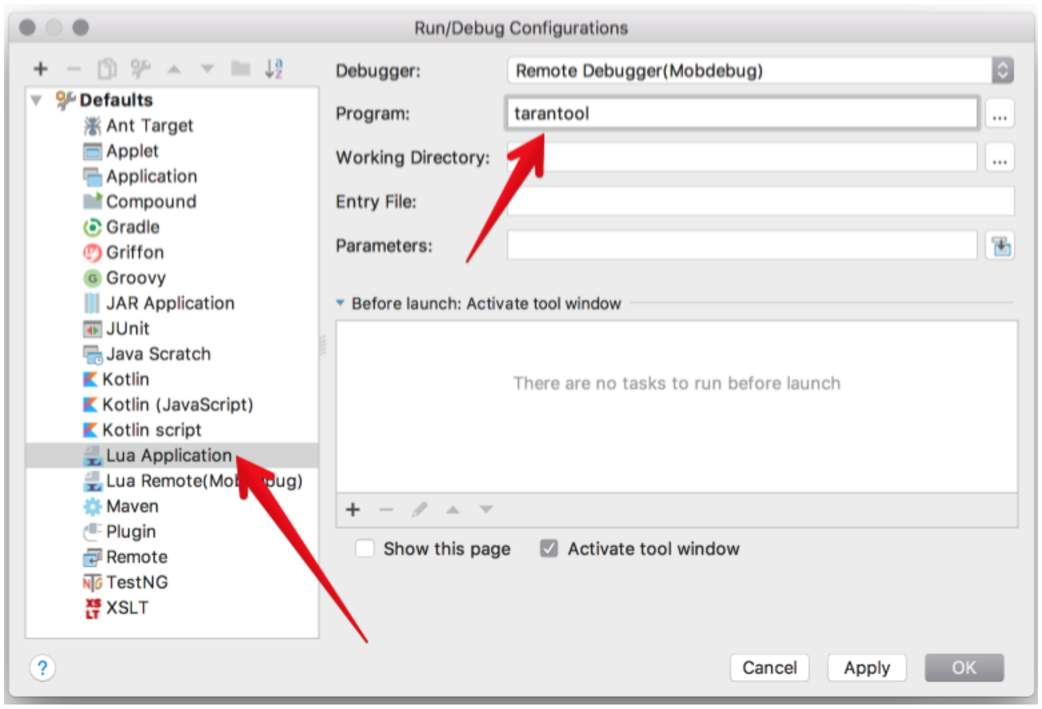


g. Find Lua Application in the sidebar at the left.

h. In Program, type a path to an installed tarantool binary.

By default, this is tarantool or /usr/bin/tarantool on most platforms.

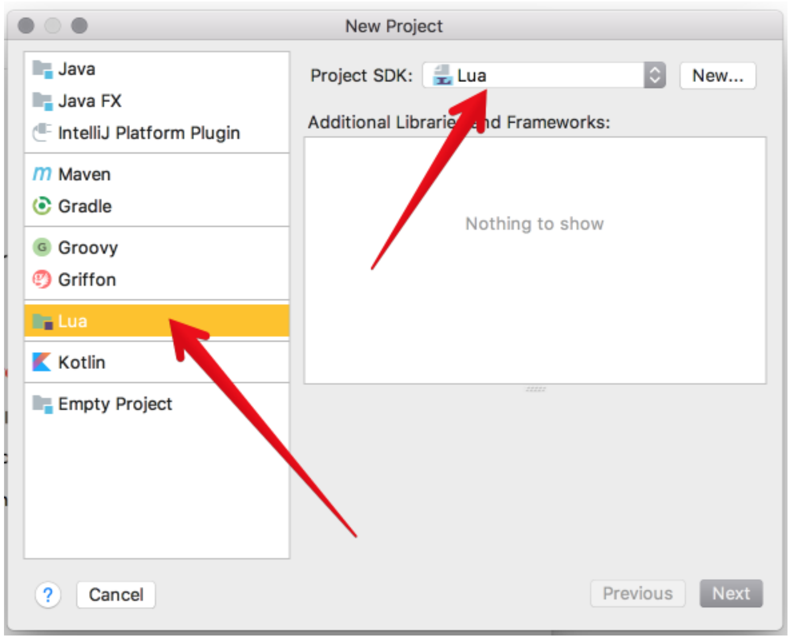
If you installed tarantool from sources to a custom directory, please specify the proper path here.



Debugger: Remote Debugger(Mobdebug)
Program: tarantool
Working Directory:
Entry File:
Parameters:

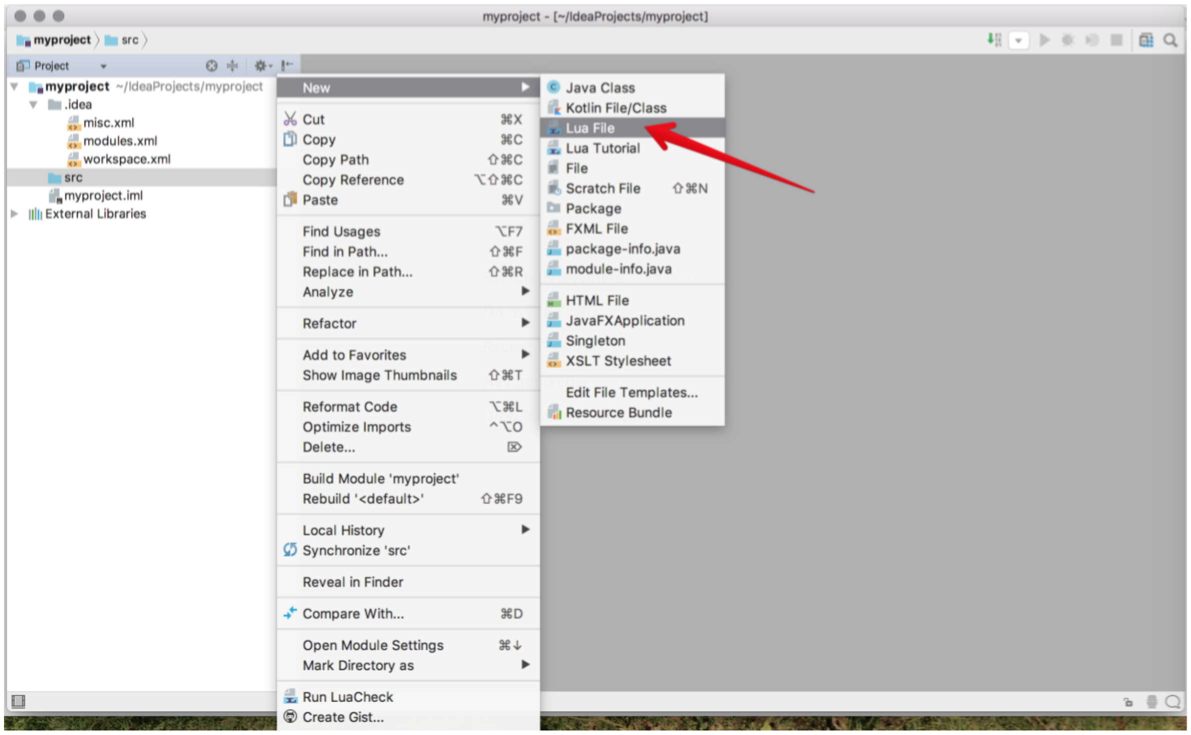
Now IntelliJ IDEA is ready to use with Tarantool.

3. Create a new Lua project.

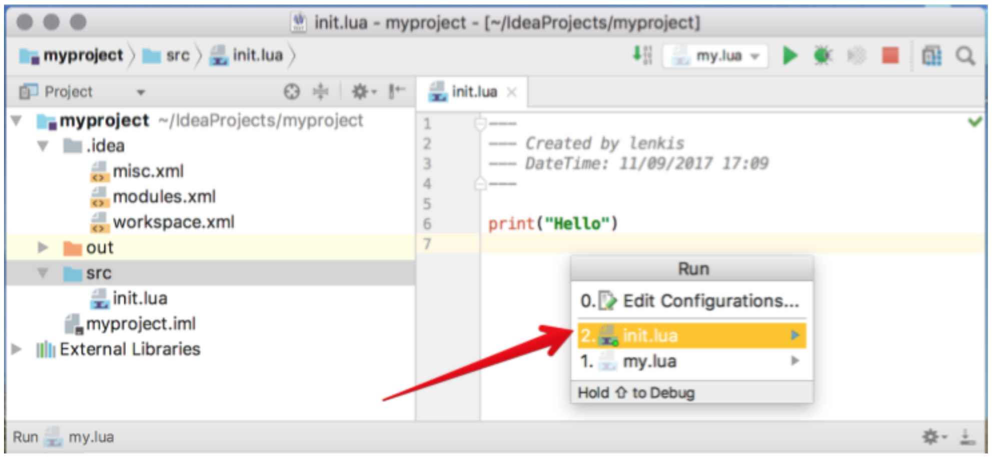


Project SDK: Lua

4. Add a new Lua file, for example init.lua.



5. Write your code, save the file.
6. To run you application, click Run -> Run in the main menu and select your source file in the list.

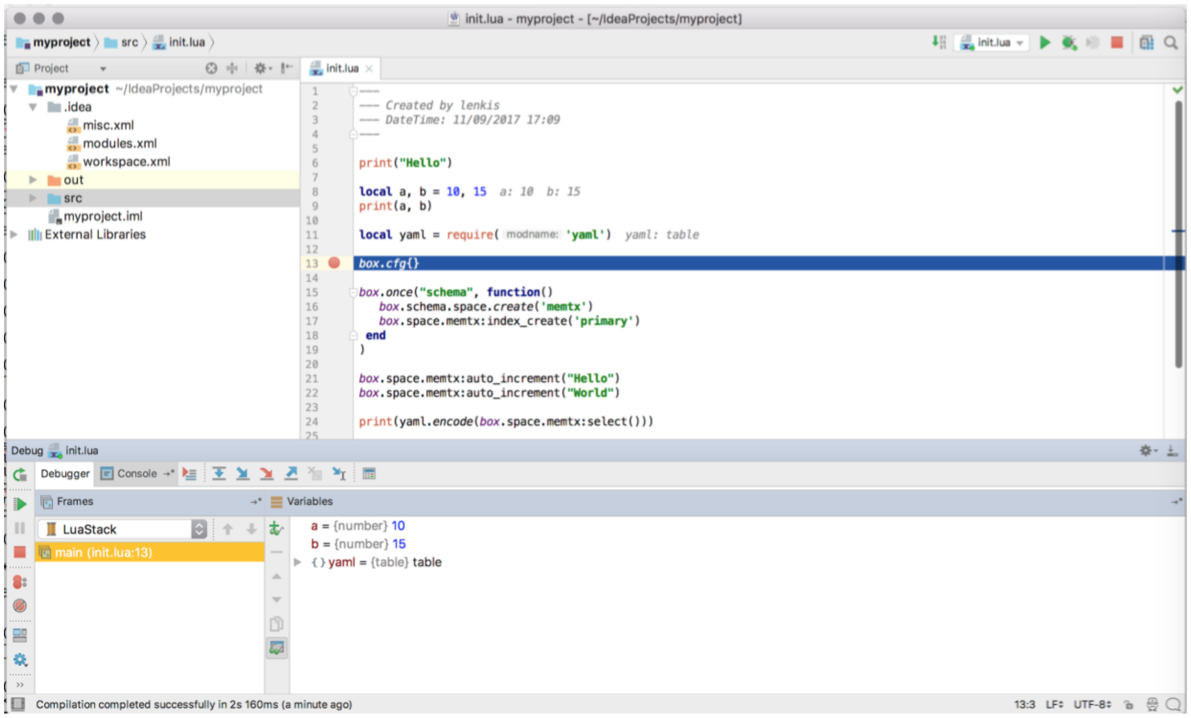

init.lua - myproject - [~/IdeaProjects/myproject]
Run
0. Edit Configurations...
2. init.lua
1. my.lua
Hold ⇧ to Debug

```
--
-- Created by lenkis
-- DateTime: 11/09/2017 17:09
--

print("Hello")
```

Or click Run -> Debug to start debugging.

Note: To use Lua debugger, please upgrade Tarantool to version 1.7.5-29-gbb6170e4b or later.



init.lua - myproject - [~/IdeaProjects/myproject]

```
---
--- Created by lenkis
--- DateTime: 11/09/2017 17:09
---

print("Hello")

local a, b = 10, 15  a: 10  b: 15
print(a, b)

local yaml = require( modname: 'yaml')  yaml: table

box.cfg{}

box.once("schema", function()
    box.schema.space.create('memtx')
    box.space.memtx:index_create('primary')
 end
)

box.space.memtx:auto_increment("Hello")
box.space.memtx:auto_increment("World")

print(yaml.encode(box.space.memtx:select()))
```

```
main (init.lua:13)

a = {number} 10
b = {number} 15
{} yaml = {table} table
```

Compilation completed successfully in 2s 160ms (a minute ago)

4.4.7 Cookbook recipes

Here are contributions of Lua programs for some frequent or tricky situations.

You can execute any of these programs by copying the code into a .lua file, and then entering chmod +x ./program-name.lua and ./program-name.lua on the terminal.

The first line is a "hashbang":

```
#!/usr/bin/env tarantool
```

This runs Tarantool Lua application server, which should be on the execution path.

This section contains the following recipes:

- count_array.lua
- count_array_with_nils.lua
- count_array_with_nulls.lua
- count_map.lua
- swap.lua
- class.lua
- garbage.lua
- fiber_producer_and_consumer.lua
- socket_tcpconnect.lua
- socket_tcp_echo.lua
- getaddrinfo.lua
- socket_udp_echo.lua
- http_get.lua
- http_send.lua
- http_server.lua
- http_generate_html.lua
- select_all.go

Use freely.

hello_world.lua

The standard example of a simple program.

```
#!/usr/bin/env tarantool

print('Hello, World!')
```

console_start.lua

Use box.once() to initialize a database (creating spaces) if this is the first time the server has been run. Then use console.start() to start interactive mode.

```
#!/usr/bin/env tarantool

-- Configure database
box.cfg {
    listen = 3313
}

box.once("bootstrap", function()
    box.schema.space.create('tweedledum')
    box.space.tweedledum:create_index('primary',
        { type = 'TREE', parts = {1, 'unsigned'}})
```

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```
end)

require('console').start()
```

fio_read.lua

Use the fio module to open, read, and close a file.

```
#!/usr/bin/env tarantool

local fio = require('fio')
local errno = require('errno')
local f = fio.open('/tmp/xxxx.txt', {'O_RDONLY' })
if not f then
    error("Failed to open file: "..errno.strerror())
end
local data = f:read(4096)
f:close()
print(data)
```

fio_write.lua

Use the fio module to open, write, and close a file.

```
#!/usr/bin/env tarantool

local fio = require('fio')
local errno = require('errno')
local f = fio.open('/tmp/xxxx.txt', {'O_CREAT', 'O_WRONLY', 'O_APPEND'},
    tonumber('0666', 8))
if not f then
    error("Failed to open file: "..errno.strerror())
end
f:write("Hello\n");
f:close()
```

ffi_printf.lua

Use the LuaJIT ffi library to call a C built-in function: printf(). (For help understanding ffi, see the FFI tutorial.)

```
#!/usr/bin/env tarantool

local ffi = require('ffi')
ffi.cdef[[
    int printf(const char *format, ...);
]]

ffi.C.printf("Hello, %s\n", os.getenv("USER"));
```

ffi_gettimeofday.lua

Use the LuaJIT ffi library to call a C function: gettimeofday(). This delivers time with millisecond precision, unlike the time function in Tarantool's clock module.

```
#!/usr/bin/env tarantool

local ffi = require('ffi')
ffi.cdef[[
    typedef long time_t;
    typedef struct timeval {
    time_t tv_sec;
    time_t tv_usec;
} timeval;
    int gettimeofday(struct timeval *t, void *tzp);
]]

local timeval_buf = ffi.new("timeval")
local now = function()
    ffi.C.gettimeofday(timeval_buf, nil)
    return tonumber(timeval_buf.tv_sec * 1000 + (timeval_buf.tv_usec / 1000))
end
```

ffi_zlib.lua

Use the LuaJIT ffi library to call a C library function. (For help understanding ffi, see the FFI tutorial.)

```
#!/usr/bin/env tarantool

local ffi = require("ffi")
ffi.cdef[[
    unsigned long compressBound(unsigned long sourceLen);
    int compress2(uint8_t *dest, unsigned long *destLen,
    const uint8_t *source, unsigned long sourceLen, int level);
    int uncompress(uint8_t *dest, unsigned long *destLen,
    const uint8_t *source, unsigned long sourceLen);
]]
local zlib = ffi.load(ffi.os == "Windows" and "zlib1" or "z")

-- Lua wrapper for compress2()
local function compress(txt)
    local n = zlib.compressBound(#txt)
    local buf = ffi.new("uint8_t[?]", n)
    local buflen = ffi.new("unsigned long[1]", n)
    local res = zlib.compress2(buf, buflen, txt, #txt, 9)
    assert(res == 0)
    return ffi.string(buf, buflen[0])
end

-- Lua wrapper for uncompress
local function uncompress(comp, n)
    local buf = ffi.new("uint8_t[?]", n)
    local buflen = ffi.new("unsigned long[1]", n)
    local res = zlib.uncompress(buf, buflen, comp, #comp)
    assert(res == 0)
    return ffi.string(buf, buflen[0])
```

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```
end

-- Simple test code.
local txt = string.rep("abcd", 1000)
print("Uncompressed size: ", #txt)
local c = compress(txt)
print("Compressed size: ", #c)
local txt2 = uncompress(c, #txt)
assert(txt2 == txt)
```

ffi_meta.lua

Use the LuaJIT ffi library to access a C object via a metamethod (a method which is defined with a metatable).

```
#!/usr/bin/env tarantool

local ffi = require("ffi")
ffi.cdef[[
typedef struct { double x, y; } point_t;
]]

local point
local mt = {
  __add = function(a, b) return point(a.x+b.x, a.y+b.y) end,
  __len = function(a) return math.sqrt(a.x*a.x + a.y*a.y) end,
  __index = {
    area = function(a) return a.x*a.x + a.y*a.y end,
  },
}
point = ffi.metatype("point_t", mt)

local a = point(3, 4)
print(a.x, a.y)  --> 3  4
print(#a)        --> 5
print(a:area())  --> 25
local b = a + point(0.5, 8)
print(#b)        --> 12.5
```

ffi_varbinary_insert.lua

Use the LuaJIT ffi library to insert a tuple which has a VARBINARY field.

Note that it is allowed only inside a memtx transaction: when box_insert() does not yield.

Lua does not have direct support for VARBINARY, so using C is one way to put in data which in MessagePack is stored as bin (MP_BIN). If the tuple is retrieved later, field “b” will have type = ‘cdata’.

```
#!/usr/bin/env tarantool

-- box.cfg{} should be here

s = box.schema.space.create('withdata')
s:format({{"b", "varbinary"}})
```

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```
s:create_index('pk', {parts = {1, "varbinary"}})

buffer = require('buffer')
ffi = require('ffi')

function varbinary_insert(space, bytes)
    local tmpbuf = buffer.ibuf()
    local p = tmpbuf:alloc(3 + #bytes)
    p[0] = 0x91 -- MsgPack code for "array-1"
    p[1] = 0xC4 -- MsgPack code for "bin-8" so up to 256 bytes
    p[2] = #bytes
    for i, c in pairs(bytes) do p[i + 3 - 1] = c end
    ffi.cdef[[int box_insert(uint32_t space_id,
                             const char *tuple,
                             const char *tuple_end,
                             box_tuple_t **result);]]
    ffi.C.box_insert(space.id, tmpbuf.rpos, tmpbuf.wpos, nil)
    tmpbuf:recycle()
end

varbinary_insert(s, {0xDE, 0xAD, 0xBE, 0xAF})
varbinary_insert(s, {0xFE, 0xED, 0xFA, 0xCE})

-- if successful, Tarantool enters the event loop now
```

print_arrays.lua

Create Lua tables, and print them. Notice that for the 'array' table the iterator function is ipairs(), while for the 'map' table the iterator function is pairs(). (ipairs() is faster than pairs(), but pairs() is recommended for map-like tables or mixed tables.) The display will look like: "1 Apple | 2 Orange | 3 Grapefruit | 4 Banana | k3 v3 | k1 v1 | k2 v2".

```
#!/usr/bin/env tarantool

array = { 'Apple', 'Orange', 'Grapefruit', 'Banana'}
for k, v in ipairs(array) do print(k, v) end

map = { k1 = 'v1', k2 = 'v2', k3 = 'v3' }
for k, v in pairs(map) do print(k, v) end
```

count_array.lua

Use the '#' operator to get the number of items in an array-like Lua table. This operation has O(log(N)) complexity.

```
#!/usr/bin/env tarantool

array = { 1, 2, 3}
print(#array)
```

count_array_with_nils.lua

Missing elements in arrays, which Lua treats as “nil”s, cause the simple “#” operator to deliver improper results. The “print(#t)” instruction will print “4”; the “print(counter)” instruction will print “3”; the “print(max)” instruction will print “10”. Other table functions, such as table.sort(), will also misbehave when “nils” are present.

```
#!/usr/bin/env tarantool

local t = {}
t[1] = 1
t[4] = 4
t[10] = 10
print(#t)
local counter = 0
for k,v in pairs(t) do counter = counter + 1 end
print(counter)
local max = 0
for k,v in pairs(t) do if k > max then max = k end end
print(max)
```

count_array_with_nulls.lua

Use explicit NULL values to avoid the problems caused by Lua’s nil == missing value behavior. Although json.NULL == nil is true, all the print instructions in this program will print the correct value: 10.

```
#!/usr/bin/env tarantool

local json = require('json')
local t = {}
t[1] = 1; t[2] = json.NULL; t[3]= json.NULL;
t[4] = 4; t[5] = json.NULL; t[6]= json.NULL;
t[6] = 4; t[7] = json.NULL; t[8]= json.NULL;
t[9] = json.NULL
t[10] = 10
print(#t)
local counter = 0
for k,v in pairs(t) do counter = counter + 1 end
print(counter)
local max = 0
for k,v in pairs(t) do if k > max then max = k end end
print(max)
```

count_map.lua

Get the number of elements in a map-like table.

```
#!/usr/bin/env tarantool

local map = { a = 10, b = 15, c = 20 }
local size = 0
for _ in pairs(map) do size = size + 1; end
print(size)
```

swap.lua

Use a Lua peculiarity to swap two variables without needing a third variable.

```
#!/usr/bin/env tarantool

local x = 1
local y = 2
x, y = y, x
print(x, y)
```

class.lua

Create a class, create a metatable for the class, create an instance of the class. Another illustration is at http://lua-users.org/wiki/LuaClassesWithMetatable.

```
#!/usr/bin/env tarantool

-- define class objects
local myclass_somemethod = function(self)
    print('test 1', self.data)
end

local myclass_someothermethod = function(self)
    print('test 2', self.data)
end

local myclass_tostring = function(self)
    return 'MyClass <'..self.data..'>'
end

local myclass_mt = {
    __tostring = myclass_tostring;
    __index = {
        somemethod = myclass_somemethod;
        someothermethod = myclass_someothermethod;
    }
}

-- create a new object of myclass
local object = setmetatable({ data = 'data'}, myclass_mt)
print(object:somemethod())
print(object.data)
```

garbage.lua

Activate the Lua garbage collector with the collectgarbage function.

```
#!/usr/bin/env tarantool

collectgarbage('collect')
```

fiber_producer_and_consumer.lua

Start one fiber for producer and one fiber for consumer. Use fiber.channel() to exchange data and synchronize. One can tweak the channel size (ch_size in the program code) to control the number of simultaneous tasks waiting for processing.

```
#!/usr/bin/env tarantool

local fiber = require('fiber')
local function consumer_loop(ch, i)
    -- initialize consumer synchronously or raise an error()
    fiber.sleep(0) -- allow fiber.create() to continue
    while true do
        local data = ch:get()
        if data == nil then
            break
        end
        print('consumed', i, data)
        fiber.sleep(math.random()) -- simulate some work
    end
end

local function producer_loop(ch, i)
    -- initialize consumer synchronously or raise an error()
    fiber.sleep(0) -- allow fiber.create() to continue
    while true do
        local data = math.random()
        ch:put(data)
        print('produced', i, data)
    end
end

local function start()
    local consumer_n = 5
    local producer_n = 3

    -- Create a channel
    local ch_size = math.max(consumer_n, producer_n)
    local ch = fiber.channel(ch_size)

    -- Start consumers
    for i=1, consumer_n,1 do
        fiber.create(consumer_loop, ch, i)
    end

    -- Start producers
    for i=1, producer_n,1 do
        fiber.create(producer_loop, ch, i)
    end
end

start()
print('started')
```

socket_tcpconnect.lua

Use socket.tcp_connect() to connect to a remote host via TCP. Display the connection details and the result of a GET request.

```lua
#!/usr/bin/env tarantool

local s = require('socket').tcp_connect('google.com', 80)
print(s:peer().host)
print(s:peer().family)
print(s:peer().type)
print(s:peer().protocol)
print(s:peer().port)
print(s:write("GET / HTTP/1.0\r\n\r\n"))
print(s:read('\r\n'))
print(s:read('\r\n'))
```

socket_tcp_echo.lua

Use socket.tcp_connect() to set up a simple TCP server, by creating a function that handles requests and echos them, and passing the function to socket.tcp_server(). This program has been used to test with 100,000 clients, with each client getting a separate fiber.

```lua
#!/usr/bin/env tarantool

local function handler(s, peer)
    s:write("Welcome to test server, " .. peer.host .."\n")
    while true do
        local line = s:read('\n')
        if line == nil then
            break -- error or eof
        end
        if not s:write("pong: "..line) then
            break -- error or eof
        end
    end
end

local server, addr = require('socket').tcp_server('localhost', 3311, handler)
```

getaddrinfo.lua

Use socket.getaddrinfo() to perform non-blocking DNS resolution, getting both the AF_INET6 and AF_INET information for 'google.com'. This technique is not always necessary for tcp connections because socket.tcp_connect() performs socket.getaddrinfo under the hood, before trying to connect to the first available address.

```lua
#!/usr/bin/env tarantool

local s = require('socket').getaddrinfo('google.com', 'http', { type = 'SOCK_STREAM' })
print('host=',s[1].host)
print('family=',s[1].family)
print('type=',s[1].type)
print('protocol=',s[1].protocol)
```

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```
print('port=',s[1].port)
print('host=',s[2].host)
print('family=',s[2].family)
print('type=',s[2].type)
print('protocol=',s[2].protocol)
print('port=',s[2].port)
```

socket_udp_echo.lua

Tarantool does not currently have a udp_server function, therefore socket_udp_echo.lua is more complicated than socket_tcp_echo.lua. It can be implemented with sockets and fibers.

```
#!/usr/bin/env tarantool

local socket = require('socket')
local errno = require('errno')
local fiber = require('fiber')

local function udp_server_loop(s, handler)
    fiber.name("udp_server")
    while true do
        -- try to read a datagram first
        local msg, peer = s:recvfrom()
        if msg == "" then
            -- socket was closed via s:close()
            break
        elseif msg ~= nil then
            -- got a new datagram
            handler(s, peer, msg)
        else
            if s:errno() == errno.EAGAIN or s:errno() == errno.EINTR then
                -- socket is not ready
                s:readable() -- yield, epoll will wake us when new data arrives
            else
                -- socket error
                local msg = s:error()
                s:close() -- save resources and don't wait GC
                error("Socket error: " .. msg)
            end
        end
    end
end

local function udp_server(host, port, handler)
    local s = socket('AF_INET', 'SOCK_DGRAM', 0)
    if not s then
        return nil -- check errno:strerror()
    end
    if not s:bind(host, port) then
        local e = s:errno() -- save errno
        s:close()
        errno(e) -- restore errno
        return nil -- check errno:strerror()
    end
```

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```
    fiber.create(udp_server_loop, s, handler) -- start a new background fiber
    return s
end
```

A function for a client that connects to this server could look something like this . . .

```
local function handler(s, peer, msg)
    -- You don't have to wait until socket is ready to send UDP
    -- s:writable()
    s:sendto(peer.host, peer.port, "Pong: " .. msg)
end

local server = udp_server('127.0.0.1', 3548, handler)
if not server then
    error('Failed to bind: ' .. errno.strerror())
end

print('Started')

require('console').start()
```

http_get.lua

Use the http module to get data via HTTP.

```
#!/usr/bin/env tarantool

local http_client = require('http.client')
local json = require('json')
local r = http_client.get('https://api.frankfurter.app/latest?to=USD%2CRUB')
if r.status ~= 200 then
    print('Failed to get currency ', r.reason)
    return
end
local data = json.decode(r.body)
print(data.base, 'rate of', data.date, 'is', data.rates.RUB, 'RUB or', data.rates.USD, 'USD')
```

http_send.lua

Use the http module to send data via HTTP.

```
#!/usr/bin/env tarantool

local http_client = require('http.client')
local json = require('json')
local data = json.encode({ Key = 'Value'})
local headers = { Token = 'xxxx', ['X-Secret-Value'] = '42' }
local r = http_client.post('http://localhost:8081', data, { headers = headers})
if r.status == 200 then
    print 'Success'
end
```

http_server.lua

Use the http rock (which must first be installed) to turn Tarantool into a web server.

```
#!/usr/bin/env tarantool

local function handler(self)
    return self:render{ json = { ['Your-IP-Is'] = self:peer().host } }
end

local server = require('http.server').new(nil, 8080) -- listen *:8080
local router = require('http.router').new({charset = "utf8"})
server:set_router(router)
router:route({ path = '/' }, handler)
server:start()
-- connect to localhost:8080 and see json
```

http_generate_html.lua

Use the http rock (which must first be installed) to generate HTML pages from templates. The http rock has a fairly simple template engine which allows execution of regular Lua code inside text blocks (like PHP). Therefore there is no need to learn new languages in order to write templates.

```
#!/usr/bin/env tarantool

local function handler(self)
local fruits = { 'Apple', 'Orange', 'Grapefruit', 'Banana'}
    return self:render{ fruits = fruits }
end

local server = require('http.server').new(nil, 8080) -- nil means '*'
local router = require('http.router').new({charset = "utf8"})
server:set_router(router)
router:route({ path = '/', file = 'index.html.lua' }, handler)
server:start()
```

An "HTML" file for this server, including Lua, could look like this (it would produce "1 Apple | 2 Orange | 3 Grapefruit | 4 Banana").

```
<html>
<body>
    <table border="1">
        % for i,v in pairs(fruits) do
        <tr>
            <td><%= i %></td>
            <td><%= v %></td>
        </tr>
        % end
    </table>
</body>
</html>
```

select_all.go

In Go, there is no one-liner to select all tuples from a Tarantool space. Yet you can use a script like this one. Call it on the instance you want to connect to.

```
package main

import (
	"fmt"
	"log"

	"github.com/tarantool/go-tarantool"
)

/*
box.cfg{listen = 3301}
box.schema.user.passwd('pass')

s = box.schema.space.create('tester')
s:format({
    {name = 'id', type = 'unsigned'},
    {name = 'band_name', type = 'string'},
    {name = 'year', type = 'unsigned'}
})
s:create_index('primary', { type = 'hash', parts = {'id'} })
s:create_index('scanner', { type = 'tree', parts = {'id', 'band_name'} })

s:insert{1, 'Roxette', 1986}
s:insert{2, 'Scorpions', 2015}
s:insert{3, 'Ace of Base', 1993}
*/

func main() {
	conn, err := tarantool.Connect("127.0.0.1:3301", tarantool.Opts{
		User: "admin",
		Pass: "pass",
	})

	if err != nil {
		log.Fatalf("Connection refused")
	}
	defer conn.Close()

	spaceName := "tester"
	indexName := "scanner"
	idFn := conn.Schema.Spaces[spaceName].Fields["id"].Id
	bandNameFn := conn.Schema.Spaces[spaceName].Fields["band_name"].Id

	var tuplesPerRequest uint32 = 2
	cursor := []interface{}{}

	for {
		resp, err := conn.Select(spaceName, indexName, 0, tuplesPerRequest, tarantool.IterGt, cursor)
		if err != nil {
			log.Fatalf("Failed to select: %s", err)
		}

		if resp.Code != tarantool.OkCode {
```

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```
                log.Fatalf("Select failed: %s", resp.Error)
        }

        if len(resp.Data) == 0 {
                break
        }

        fmt.Println("Iteration")

        tuples := resp.Tuples()
        for _, tuple := range tuples {
                fmt.Printf("\t%v\n", tuple)
        }

        lastTuple := tuples[len(tuples)-1]
        cursor = []interface{}{lastTuple[idFn], lastTuple[bandNameFn]}
    }
}
```

4.5 Administration

Tarantool is designed to have multiple running instances on the same host.

Here we show how to administer Tarantool instances using any of the following utilities:

- systemd native utilities, or
- tarantoolctl, a utility shipped and installed as part of Tarantool distribution.

Note:

- Unlike the rest of this manual, here we use system-wide paths.
- Console examples here are for Fedora.

This chapter includes the following sections:

4.5.1 Instance configuration

For each Tarantool instance, you need two files:

- [Optional] An application file with instance-specific logic. Put this file into the /usr/share/tarantool/ directory.

  For example, /usr/share/tarantool/my_app.lua (here we implement it as a Lua module that bootstraps the database and exports start() function for API calls):

```
local function start()
    box.schema.space.create("somedata")
    box.space.somedata:create_index("primary")
    <...>
end
```

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```
return {
  start = start;
}
```

- An instance file with instance-specific initialization logic and parameters. Put this file, or a symlink to it, into the instance directory (see instance_dir parameter in tarantoolctl configuration file).

  For example, /etc/tarantool/instances.enabled/my_app.lua (here we load my_app.lua module and make a call to start() function from that module):

```
#!/usr/bin/env tarantool

box.cfg {
    listen = 3301;
}

-- load my_app module and call start() function
-- with some app options controlled by sysadmins
local m = require('my_app').start({...})
```

Instance file

After this short introduction, you may wonder what an instance file is, what it is for, and how tarantoolctl uses it. After all, Tarantool is an application server, so why not start the application stored in /usr/share/tarantool directly?

A typical Tarantool application is not a script, but a daemon running in background mode and processing requests, usually sent to it over a TCP/IP socket. This daemon needs to be started automatically when the operating system starts, and managed with the operating system standard tools for service management – such as systemd or init.d. To serve this very purpose, we created instance files.

You can have more than one instance file. For example, a single application in /usr/share/tarantool can run in multiple instances, each of them having its own instance file. Or you can have multiple applications in /usr/share/tarantool – again, each of them having its own instance file.

An instance file is typically created by a system administrator. An application file is often provided by a developer, in a Lua rock or an rpm/deb package.

An instance file is designed to not differ in any way from a Lua application. It must, however, configure the database, i.e. contain a call to box.cfg{} somewhere in it, because it's the only way to turn a Tarantool script into a background process, and tarantoolctl is a tool to manage background processes. Other than that, an instance file may contain arbitrary Lua code, and, in theory, even include the entire application business logic in it. We, however, do not recommend this, since it clutters the instance file and leads to unnecessary copy-paste when you need to run multiple instances of an application.

tarantoolctl configuration file

While instance files contain instance configuration, the tarantoolctl configuration file contains the configuration that tarantoolctl uses to override instance configuration. In other words, it contains system-wide configuration defaults. If tarantoolctl fails to find this file with the method described in section Starting/stopping an instance, it uses default settings.

Most of the parameters are similar to those used by box.cfg{}. Here are the default settings (possibly installed in /etc/default/tarantool or /etc/sysconfig/tarantool as part of Tarantool distribution – see OS-specific default paths in Notes for operating systems):

```
default_cfg = {
    pid_file   = "/var/run/tarantool",
    wal_dir    = "/var/lib/tarantool",
    memtx_dir  = "/var/lib/tarantool",
    vinyl_dir  = "/var/lib/tarantool",
    log        = "/var/log/tarantool",
    username   = "tarantool",
    language   = "Lua",
}
instance_dir = "/etc/tarantool/instances.enabled"
```

where:

- pid_file
  Directory for the pid file and control-socket file; tarantoolctl will add "/instance_name" to the directory name.
- wal_dir
  Directory for write-ahead .xlog files; tarantoolctl will add "/instance_name" to the directory name.
- memtx_dir
  Directory for snapshot .snap files; tarantoolctl will add "/instance_name" to the directory name.
- vinyl_dir
  Directory for vinyl files; tarantoolctl will add "/instance_name" to the directory name.
- log
  The place where the application log will go; tarantoolctl will add "/instance_name.log" to the name.
- username
  The user that runs the Tarantool instance. This is the operating-system user name rather than the Tarantool-client user name. Tarantool will change its effective user to this user after becoming a daemon.
- language
  The interactive console language. Can be either Lua or SQL.
- instance_dir
  The directory where all instance files for this host are stored. Put instance files in this directory, or create symbolic links.

  The default instance directory depends on Tarantool's WITH_SYSVINIT build option: when ON, it is /etc/tarantool/instances.enabled, otherwise (OFF or not set) it is /etc/tarantool/instances.available. The latter case is typical for Tarantool builds for Linux distros with systemd.

  To check the build options, say tarantool --version.

As a full-featured example, you can take example.lua script that ships with Tarantool and defines all configuration options.

4.5.2 Starting/stopping an instance

While a Lua application is executed by Tarantool, an instance file is executed by tarantoolctl which is a Tarantool script.

Here is what tarantoolctl does when you issue the command:

```
$ tarantoolctl start <instance_name>
```

1. Read and parse the command line arguments. The last argument, in our case, contains an instance name.
2. Read and parse its own configuration file. This file contains tarantoolctl defaults, like the path to the directory where instances should be searched for.

   When tarantool is invoked by root, it looks for a configuration file in /etc/default/tarantool. When tarantool is invoked by a local (non-root) user, it looks for a configuration file first in the current directory ($PWD/.tarantoolctl), and then in the current user's home directory ($HOME/.config/tarantool/tarantool). If no configuration file is found there, or in the /usr/local/etc/default/tarantool file, then tarantoolctl falls back to built-in defaults.
3. Look up the instance file in the instance directory, for example /etc/tarantool/instances.enabled. To build the instance file path, tarantoolctl takes the instance name, prepends the instance directory and appends ".lua" extension to the instance file.
4. Override box.cfg{} function to pre-process its parameters and ensure that instance paths are pointing to the paths defined in the tarantoolctl configuration file. For example, if the configuration file specifies that instance work directory must be in /var/tarantool, then the new implementation of box.cfg{} ensures that work_dir parameter in box.cfg{} is set to /var/tarantool/<instance_name>, regardless of what the path is set to in the instance file itself.
5. Create a so-called "instance control file". This is a Unix socket with Lua console attached to it. This file is used later by tarantoolctl to query the instance state, send commands to the instance and so on.
6. Set the TARANTOOLCTL environment variable to 'true'. This allows the user to know that the instance was started by tarantoolctl.
7. Finally, use Lua dofile command to execute the instance file.

If you start an instance using systemd tools, like this (the instance name is my_app):

```
$ systemctl start tarantool@my_app
$ ps axuf|grep my_app
taranto+  5350  1.3  0.3 1448872 7736 ?        Ssl  20:05   0:28 tarantool my_app.lua <running>
```

... this actually calls tarantoolctl like in case of tarantoolctl start my_app.

To check the instance file for syntax errors prior to starting my_app instance, say:

```
$ tarantoolctl check my_app
```

To enable my_app instance for auto-load during system startup, say:

```
$ systemctl enable tarantool@my_app
```

To stop a running my_app instance, say:

```
$ tarantoolctl stop my_app
$ # - OR -
$ systemctl stop tarantool@my_app
```

To restart (i.e. stop and start) a running my_app instance, say:

```
$ tarantoolctl restart my_app
$ # - OR -
$ systemctl restart tarantool@my_app
```

Running Tarantool locally

Sometimes you may need to run a Tarantool instance locally, e.g. for test purposes. Let's configure a local instance, then start and monitor it with tarantoolctl.

First, we create a sandbox directory on the user's path:

```
$ mkdir ~/tarantool_test
```

... and set default tarantoolctl configuration in $HOME/.config/tarantool/tarantool. Let the file contents be:

```
default_cfg = {
    pid_file  = "/home/user/tarantool_test/my_app.pid",
    wal_dir   = "/home/user/tarantool_test",
    snap_dir  = "/home/user/tarantool_test",
    vinyl_dir = "/home/user/tarantool_test",
    log       = "/home/user/tarantool_test/log",
}
instance_dir = "/home/user/tarantool_test"
```

Note:

- Specify a full path to the user's home directory instead of "~/".
- Omit username parameter. tarantoolctl normally doesn't have permissions to switch current user when invoked by a local user. The instance will be running under 'admin'.

Next, we create the instance file ~/tarantool_test/my_app.lua. Let the file contents be:

```
box.cfg{listen = 3301}
box.schema.user.passwd('Gx5!')
box.schema.user.grant('guest','read,write,execute','universe')
fiber = require('fiber')
box.schema.space.create('tester')
box.space.tester:create_index('primary',{})
i = 0
while 0 == 0 do
    fiber.sleep(5)
    i = i + 1
    print('insert ' .. i)
    box.space.tester:insert{i, 'my_app tuple'}
end
```

Let's verify our instance file by starting it without tarantoolctl first:

```
$ cd ~/tarantool_test
$ tarantool my_app.lua
2017-04-06 10:42:15.762 [54085] main/101/my_app.lua C> version 1.7.3-489-gd86e36d5b
2017-04-06 10:42:15.763 [54085] main/101/my_app.lua C> log level 5
2017-04-06 10:42:15.764 [54085] main/101/my_app.lua I> mapping 268435456 bytes for tuple arena...
2017-04-06 10:42:15.774 [54085] iproto/101/main I> binary: bound to [::]:3301
2017-04-06 10:42:15.774 [54085] main/101/my_app.lua I> initializing an empty data directory
2017-04-06 10:42:15.789 [54085] snapshot/101/main I> saving snapshot `./00000000000000000000.snap.inprogress'
2017-04-06 10:42:15.790 [54085] snapshot/101/main I> done
2017-04-06 10:42:15.791 [54085] main/101/my_app.lua I> vinyl checkpoint done
2017-04-06 10:42:15.791 [54085] main/101/my_app.lua I> ready to accept requests
```

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```
insert 1
insert 2
insert 3
<...>
```

Now we tell tarantoolctl to start the Tarantool instance:

```
$ tarantoolctl start my_app
```

Expect to see messages indicating that the instance has started. Then:

```
$ ls -l ~/tarantool_test/my_app
```

Expect to see the .snap file and the .xlog file. Then:

```
$ less ~/tarantool_test/log/my_app.log
```

Expect to see the contents of my_app's log, including error messages, if any. Then:

```
$ tarantoolctl enter my_app
tarantool> box.cfg{}
tarantool> console = require('console')
tarantool> console.connect('localhost:3301')
tarantool> box.space.tester:select({0}, {iterator = 'GE'})
```

Expect to see several tuples that my_app has created.

Stop now. A polite way to stop my_app is with tarantoolctl, thus we say:

```
$ tarantoolctl stop my_app
```

Finally, we make a cleanup.

```
$ rm -R tarantool_test
```

4.5.3 Logs

Tarantool logs important events to a file, e.g. /var/log/tarantool/my_app.log. To build the log file path, tarantoolctl takes the instance name, prepends the instance directory and appends ".log" extension.

Let's write something to the log file:

```
$ tarantoolctl enter my_app
/bin/tarantoolctl: connected to unix/:/var/run/tarantool/my_app.control
unix/:/var/run/tarantool/my_app.control> require('log').info("Hello for the manual readers")
---
...
```

Then check the logs:

```
$ tail /var/log/tarantool/my_app.log
2017-04-04 15:54:04.977 [29255] main/101/tarantoolctl C> version 1.7.3-382-g68ef3f6a9
2017-04-04 15:54:04.977 [29255] main/101/tarantoolctl C> log level 5
2017-04-04 15:54:04.978 [29255] main/101/tarantoolctl I> mapping 134217728 bytes for tuple arena...
2017-04-04 15:54:04.985 [29255] iproto/101/main I> binary: bound to [::1]:3301
```

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```
2017-04-04 15:54:04.986 [29255] main/101/tarantoolctl I> recovery start
2017-04-04 15:54:04.986 [29255] main/101/tarantoolctl I> recovering from `/var/lib/tarantool/my_app/
↪00000000000000000000.snap'
2017-04-04 15:54:04.988 [29255] main/101/tarantoolctl I> ready to accept requests
2017-04-04 15:54:04.988 [29255] main/101/tarantoolctl I> set 'checkpoint_interval' configuration option to 3600
2017-04-04 15:54:04.988 [29255] main/101/my_app I> Run console at unix/:/var/run/tarantool/my_app.control
2017-04-04 15:54:04.989 [29255] main/106/console/unix/:/var/ I> started
2017-04-04 15:54:04.989 [29255] main C> entering the event loop
2017-04-04 15:54:47.147 [29255] main/107/console/unix/: I> Hello for the manual readers
```

When logging to a file, the system administrator must ensure logs are rotated timely and do not take up all the available disk space. With tarantoolctl, log rotation is pre-configured to use logrotate program, which you must have installed.

File /etc/logrotate.d/tarantool is part of the standard Tarantool distribution, and you can modify it to change the default behavior. This is what this file is usually like:

```
/var/log/tarantool/*.log {
    daily
    size 512k
    missingok
    rotate 10
    compress
    delaycompress
    create 0640 tarantool adm
    postrotate
        /usr/bin/tarantoolctl logrotate `basename ${1%%.*}`
    endscript
}
```

If you use a different log rotation program, you can invoke tarantoolctl logrotate command to request instances to reopen their log files after they were moved by the program of your choice.

Tarantool can write its logs to a log file, syslog or a program specified in the configuration file (see log parameter).

By default, logs are written to a file as defined in tarantoolctl defaults. tarantoolctl automatically detects if an instance is using syslog or an external program for logging, and does not override the log destination in this case. In such configurations, log rotation is usually handled by the external program used for logging. So, tarantoolctl logrotate command works only if logging-into-file is enabled in the instance file.

4.5.4 Security

Tarantool allows for two types of connections:

- With console.listen() function from console module, you can set up a port which can be used to open an administrative console to the server. This is for administrators to connect to a running instance and make requests. tarantoolctl invokes console.listen() to create a control socket for each started instance.
- With box.cfg{listen=…} parameter from box module, you can set up a binary port for connections which read and write to the database or invoke stored procedures.

When you connect to an admin console:

- The client-server protocol is plain text.
- No password is necessary.

- The user is automatically 'admin'.
- Each command is fed directly to the built-in Lua interpreter.

Therefore you must set up ports for the admin console very cautiously. If it is a TCP port, it should only be opened for a specific IP. Ideally, it should not be a TCP port at all, it should be a Unix domain socket, so that access to the server machine is required. Thus a typical port setup for admin console is:

```
console.listen('/var/lib/tarantool/socket_name.sock')
```

and a typical connection URI is:

```
/var/lib/tarantool/socket_name.sock
```

if the listener has the privilege to write on /var/lib/tarantool and the connector has the privilege to read on /var/lib/tarantool. Alternatively, to connect to an admin console of an instance started with tarantoolctl, use tarantoolctl enter.

To find out whether a TCP port is a port for admin console, use telnet. For example:

```
$ telnet 0 3303
Trying 0.0.0.0...
Connected to 0.
Escape character is '^]'.
Tarantool 2.1.0 (Lua console)
type 'help' for interactive help
```

In this example, the response does not include the word "binary" and does include the words "Lua console". Therefore it is clear that this is a successful connection to a port for admin console, and you can now enter admin requests on this terminal.

When you connect to a binary port:

- The client-server protocol is binary.
- The user is automatically 'guest'.
- To change the user, it's necessary to authenticate.

For ease of use, tarantoolctl connect command automatically detects the type of connection during handshake and uses EVAL binary protocol command when it's necessary to execute Lua commands over a binary connection. To execute EVAL, the authenticated user must have global "EXECUTE" privilege.

Therefore, when ssh access to the machine is not available, creating a Tarantool user with global "EXECUTE" privilege and non-empty password can be used to provide a system administrator remote access to an instance.

4.5.5 Server introspection

Using Tarantool as a client

Tarantool enters the interactive mode if:

- you start Tarantool without an instance file, or
- the instance file contains console.start().

Tarantool displays a prompt (e.g. "tarantool>") and you can enter requests. When used this way, Tarantool can be a client for a remote server. See basic examples in Getting started.

The interactive mode is used by tarantoolctl to implement "enter" and "connect" commands.

Executing code on an instance

You can attach to an instance's admin console and execute some Lua code using tarantoolctl:

```
$ # for local instances:
$ tarantoolctl enter my_app
/bin/tarantoolctl: Found my_app.lua in /etc/tarantool/instances.available
/bin/tarantoolctl: Connecting to /var/run/tarantool/my_app.control
/bin/tarantoolctl: connected to unix/:/var/run/tarantool/my_app.control
unix/:/var/run/tarantool/my_app.control> 1 + 1
---
- 2
...
unix/:/var/run/tarantool/my_app.control>

$ # for local and remote instances:
$ tarantoolctl connect username:password@127.0.0.1:3306
```

You can also use tarantoolctl to execute Lua code on an instance without attaching to its admin console. For example:

```
$ # executing commands directly from the command line
$ <command> | tarantoolctl eval my_app
<...>

$ # - OR -

$ # executing commands from a script file
$ tarantoolctl eval my_app script.lua
<...>
```

Note: Alternatively, you can use the console module or the net.box module from a Tarantool server. Also, you can write your client programs with any of the connectors. However, most of the examples in this manual illustrate usage with either tarantoolctl connect or using the Tarantool server as a client.

Health checks

To check the instance status, say:

```
$ tarantoolctl status my_app
my_app is running (pid: /var/run/tarantool/my_app.pid)

$ # - OR -

$ systemctl status tarantool@my_app
tarantool@my_app.service - Tarantool Database Server
Loaded: loaded (/etc/systemd/system/tarantool@.service; disabled; vendor preset: disabled)
Active: active (running)
Docs: man:tarantool(1)
Process: 5346 ExecStart=/usr/bin/tarantoolctl start %I (code=exited, status=0/SUCCESS)
Main PID: 5350 (tarantool)
Tasks: 11 (limit: 512)
CGroup: /system.slice/system-tarantool.slice/tarantool@my_app.service
+ 5350 tarantool my_app.lua <running>
```

To check the boot log, on systems with systemd, say:

```
$ journalctl -u tarantool@my_app -n 5
-- Logs begin at Fri 2016-01-08 12:21:53 MSK, end at Thu 2016-01-21 21:17:47 MSK. --
Jan 21 21:17:47 localhost.localdomain systemd[1]: Stopped Tarantool Database Server.
Jan 21 21:17:47 localhost.localdomain systemd[1]: Starting Tarantool Database Server...
Jan 21 21:17:47 localhost.localdomain tarantoolctl[5969]: /usr/bin/tarantoolctl: Found my_app.lua in /etc/
↪tarantool/instances.available
Jan 21 21:17:47 localhost.localdomain tarantoolctl[5969]: /usr/bin/tarantoolctl: Starting instance...
Jan 21 21:17:47 localhost.localdomain systemd[1]: Started Tarantool Database Server
```

For more details, use the reports provided by functions in the following submodules:

- box.cfg submodule (check and specify all configuration parameters for the Tarantool server)
- box.slab submodule (monitor the total use and fragmentation of memory allocated for storing data in Tarantool)
- box.info submodule (introspect Tarantool server variables, primarily those related to replication)
- box.stat submodule (introspect Tarantool request and network statistics)

You can also try prometheus, a plugin that makes it easy to collect metrics (e.g. memory usage or number of requests) from Tarantool applications and databases and expose them via the Prometheus protocol.

Example

A very popular administrator request is box.slab.info(), which displays detailed memory usage statistics for a Tarantool instance.

```
tarantool> box.slab.info()
---
- items_size: 228128
  items_used_ratio: 1.8%
  quota_size: 1073741824
  quota_used_ratio: 0.8%
  arena_used_ratio: 43.2%
  items_used: 4208
  quota_used: 8388608
  arena_size: 2325176
  arena_used: 1003632
...
```

Tarantool takes memory from the operating system, for example when a user does many insertions. You can see how much it has taken by saying (on Linux):

```
ps -eo args,%mem | grep "tarantool"
```

Tarantool almost never releases this memory, even if the user deletes everything that was inserted, or reduces fragmentation by calling the Lua garbage collector via the collectgarbage function.

Ordinarily this does not affect performance. But, to force Tarantool to release memory, you can call box.snapshot, stop the server instance, and restart it.

Profiling performance issues

Tarantool can at times work slower than usual. There can be multiple reasons, such as disk issues, CPU-intensive Lua scripts or misconfiguration. Tarantool's log may lack details in such cases, so the only indications that something goes wrong are log entries like this: W> too long DELETE: 8.546 sec. Here are tools and techniques that can help you collect Tarantool's performance profile, which is helpful in troubleshooting slowdowns.

Note: Most of these tools – except fiber.info() – are intended for generic GNU/Linux distributions, but not FreeBSD or Mac OS.

fiber.info()

The simplest profiling method is to take advantage of Tarantool's built-in functionality. fiber.info() returns information about all running fibers with their corresponding C stack traces. You can use this data to see how many fibers are running and which C functions are executed more often than others.

First, enter your instance's interactive administrator console:

```
$ tarantoolctl enter NAME
```

Once there, load the fiber module:

```
tarantool> fiber = require('fiber')
```

After that you can get the required information with fiber.info().

At this point, your console output should look something like this:

```
tarantool> fiber = require('fiber')
---
...
tarantool> fiber.info()
---
- 360:
    csw: 2098165
    backtrace:
    - '#0 0x4d1b77 in wal_write(journal*, journal_entry*)+487'
    - '#1 0x4bbf68 in txn_commit(txn*)+152'
    - '#2 0x4bd5d8 in process_rw(request*, space*, tuple**)+136'
    - '#3 0x4bed48 in box_process1+104'
    - '#4 0x4d72f8 in lbox_replace+120'
    - '#5 0x50f317 in lj_BC_FUNCC+52'
    fid: 360
    memory:
      total: 61744
      used: 480
    name: main
  129:
    csw: 113
    backtrace: []
    fid: 129
    memory:
      total: 57648
      used: 0
    name: 'console/unix/:'
...
```

We highly recommend to assign meaningful names to fibers you create so that you can find them in the fiber.info() list. In the example below, we create a fiber named myworker:

```
tarantool> fiber = require('fiber')
---
...
tarantool> f = fiber.create(function() while true do fiber.sleep(0.5) end end)
---
...
tarantool> f:name('myworker') <!-- assigning the name to a fiber
---
...
tarantool> fiber.info()
---
- 102:
    csw: 14
    backtrace:
    - '#0 0x501a1a in fiber_yield_timeout+90'
    - '#1 0x4f2008 in lbox_fiber_sleep+72'
    - '#2 0x5112a7 in lj_BC_FUNCC+52'
    fid: 102
    memory:
      total: 57656
      used: 0
    name: myworker <!-- newly created background fiber
  101:
    csw: 284
    backtrace: []
    fid: 101
    memory:
      total: 57656
      used: 0
    name: interactive
...
```

You can kill any fiber with fiber.kill(fid):

```
tarantool> fiber.kill(102)
---
...
tarantool> fiber.info()
---
- 101:
    csw: 324
    backtrace: []
    fid: 101
    memory:
      total: 57656
      used: 0
    name: interactive
...
```

To get a table of all alive fibers you can use fiber.top().

If you want to dynamically obtain information with fiber.info(), the shell script below may come in handy. It connects to a Tarantool instance specified by NAME every 0.5 seconds, grabs the fiber.info() output and writes it to the fiber-info.txt file:

```
$ rm -f fiber.info.txt
$ watch -n 0.5 "echo 'require(\"fiber\").info()' | tarantoolctl enter NAME | tee -a fiber-info.txt"
```

If you can't understand which fiber causes performance issues, collect the metrics of the fiber.info() output for 10-15 seconds using the script above and contact the Tarantool team at support@tarantool.org.

Poor man's profilers

pstack <pid>

To use this tool, first install it with a package manager that comes with your Linux distribution. This command prints an execution stack trace of a running process specified by the PID. You might want to run this command several times in a row to pinpoint the bottleneck that causes the slowdown.

Once installed, say:

```
$ pstack $(pidof tarantool INSTANCENAME.lua)
```

Next, say:

```
$ echo $(pidof tarantool INSTANCENAME.lua)
```

to show the PID of the Tarantool instance that runs the INSTANCENAME.lua file.

You should get similar output:

```
Thread 19 (Thread 0x7f09d1bff700 (LWP 24173)):
#0 0x00007f0a1a5423f2 in ?? () from /lib64/libgomp.so.1
#1 0x00007f0a1a53fdc0 in ?? () from /lib64/libgomp.so.1
#2 0x00007f0a1ad5adc5 in start_thread () from /lib64/libpthread.so.0
#3 0x00007f0a1a050ced in clone () from /lib64/libc.so.6
Thread 18 (Thread 0x7f09d13fe700 (LWP 24174)):
#0 0x00007f0a1a5423f2 in ?? () from /lib64/libgomp.so.1
#1 0x00007f0a1a53fdc0 in ?? () from /lib64/libgomp.so.1
#2 0x00007f0a1ad5adc5 in start_thread () from /lib64/libpthread.so.0
#3 0x00007f0a1a050ced in clone () from /lib64/libc.so.6
<...>
Thread 2 (Thread 0x7f09c8bfe700 (LWP 24191)):
#0 0x00007f0a1ad5e6d5 in pthread_cond_wait@@GLIBC_2.3.2 () from /lib64/libpthread.so.0
#1 0x000000000045d901 in wal_writer_pop(wal_writer*) ()
#2 0x000000000045db01 in wal_writer_f(__va_list_tag*) ()
#3 0x0000000000429abc in fiber_cxx_invoke(int (*)(__va_list_tag*), __va_list_tag*) ()
#4 0x00000000004b52a0 in fiber_loop ()
#5 0x00000000006099cf in coro_init ()
Thread 1 (Thread 0x7f0a1c47fd80 (LWP 24172)):
#0 0x00007f0a1a0512c3 in epoll_wait () from /lib64/libc.so.6
#1 0x00000000006051c8 in epoll_poll ()
#2 0x0000000000607533 in ev_run ()
#3 0x0000000000428e13 in main ()
```

gdb -ex "bt" -p <pid>

As with pstack, the GNU debugger (also known as gdb) needs to be installed before you can start using it. Your Linux package manager can help you with that.

Once the debugger is installed, say:

```
$ gdb -ex "set pagination 0" -ex "thread apply all bt" --batch -p $(pidof tarantool INSTANCENAME.lua)
```

Next, say:

```
$ echo $(pidof tarantool INSTANCENAME.lua)
```

to show the PID of the Tarantool instance that runs the INSTANCENAME.lua file.

After using the debugger, your console output should look like this:

```
[Thread debugging using libthread_db enabled]
Using host libthread_db library "/lib/x86_64-linux-gnu/libthread_db.so.1".

[CUT]

Thread 1 (Thread 0x7f72289ba940 (LWP 20535)):
#0 _int_malloc (av=av@entry=0x7f7226e0eb20 <main_arena>, bytes=bytes@entry=504) at malloc.c:3697
#1 0x00007f7226acf21a in __libc_calloc (n=<optimized out>, elem_size=<optimized out>) at malloc.c:3234
#2 0x00000000004631f8 in vy_merge_iterator_reserve (capacity=3, itr=0x7f72264af9e0) at /usr/src/tarantool/
↪src/box/vinyl.c:7629
#3 vy_merge_iterator_add (itr=itr@entry=0x7f72264af9e0, is_mutable=is_mutable@entry=true, belong_
↪range=belong_range@entry=false) at /usr/src/tarantool/src/box/vinyl.c:7660
#4 0x00000000004703df in vy_read_iterator_add_mem (itr=0x7f72264af990) at /usr/src/tarantool/src/box/
↪vinyl.c:8387
#5 vy_read_iterator_use_range (itr=0x7f72264af990) at /usr/src/tarantool/src/box/vinyl.c:8453
#6 0x000000000047657d in vy_read_iterator_start (itr=<optimized out>) at /usr/src/tarantool/src/box/vinyl.
↪c:8501
#7 0x00000000004766b5 in vy_read_iterator_next (itr=itr@entry=0x7f72264af990,␣
↪result=result@entry=0x7f72264afad8) at /usr/src/tarantool/src/box/vinyl.c:8592
#8 0x000000000047689d in vy_index_get (tx=tx@entry=0x7f7226468158, index=index@entry=0x2563860, key=
↪<optimized out>, part_count=<optimized out>, result=result@entry=0x7f72264afad8) at /usr/src/tarantool/
↪src/box/vinyl.c:5705
#9 0x0000000000477601 in vy_replace_impl (request=<optimized out>, request=<optimized out>,␣
↪stmt=0x7f72265a7150, space=0x2567ea0, tx=0x7f7226468158) at /usr/src/tarantool/src/box/vinyl.c:5920
#10 vy_replace (tx=0x7f7226468158, stmt=stmt@entry=0x7f72265a7150, space=0x2567ea0, request=<optimized␣
↪out>) at /usr/src/tarantool/src/box/vinyl.c:6608
#11 0x00000000004615a9 in VinylSpace::executeReplace (this=<optimized out>, txn=<optimized out>, space=
↪<optimized out>, request=<optimized out>) at /usr/src/tarantool/src/box/vinyl_space.cc:108
#12 0x00000000004bd723 in process_rw (request=request@entry=0x7f72265a70f8,␣
↪space=space@entry=0x2567ea0, result=result@entry=0x7f72264afbc8) at /usr/src/tarantool/src/box/box.cc:182
#13 0x00000000004bed48 in box_process1 (request=0x7f72265a70f8, result=result@entry=0x7f72264afbc8) at /
↪usr/src/tarantool/src/box/box.cc:700
#14 0x00000000004bf389 in box_replace (space_id=space_id@entry=513, tuple=<optimized out>, tuple_end=
↪<optimized out>, result=result@entry=0x7f72264afbc8) at /usr/src/tarantool/src/box/box.cc:754
#15 0x00000000004d72f8 in lbox_replace (L=0x413c5780) at /usr/src/tarantool/src/box/lua/index.c:72
#16 0x000000000050f317 in lj_BC_FUNCC ()
#17 0x00000000004d37c7 in execute_lua_call (L=0x413c5780) at /usr/src/tarantool/src/box/lua/call.c:282
#18 0x000000000050f317 in lj_BC_FUNCC ()
#19 0x0000000000529c7b in lua_cpcall ()
#20 0x00000000004f6aa3 in luaT_cpcall (L=L@entry=0x413c5780, func=func@entry=0x4d36d0 <execute_lua_
↪call>, ud=ud@entry=0x7f72264afde0) at /usr/src/tarantool/src/lua/utils.c:962
#21 0x00000000004d3fe7 in box_process_lua (handler=0x4d36d0 <execute_lua_call>,␣
↪out=out@entry=0x7f7213020600, request=request@entry=0x413c5780) at /usr/src/tarantool/src/box/lua/call.
↪c:382
#22 box_lua_call (request=request@entry=0x7f72130401d8, out=out@entry=0x7f7213020600) at /usr/src/
↪tarantool/src/box/lua/call.c:405
#23 0x00000000004c0f27 in box_process_call (request=request@entry=0x7f72130401d8,␣
↪out=out@entry=0x7f7213020600) at /usr/src/tarantool/src/box/box.cc:1074
#24 0x000000000041326c in tx_process_misc (m=0x7f7213040170) at /usr/src/tarantool/src/box/iproto.cc:942
#25 0x0000000000504554 in cmsg_deliver (msg=0x7f7213040170) at /usr/src/tarantool/src/cbus.c:302
#26 0x0000000000504c2e in fiber_pool_f (ap=<error reading variable: value has been optimized out>) at /usr/
↪src/tarantool/src/fiber_pool.c:64
```

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```
#27 0x000000000041122c in fiber_cxx_invoke(fiber_func, typedef __va_list_tag __va_list_tag *) (f=
↪<optimized out>, ap=<optimized out>) at /usr/src/tarantool/src/fiber.h:645
#28 0x00000000005011a0 in fiber_loop (data=<optimized out>) at /usr/src/tarantool/src/fiber.c:641
#29 0x0000000000688fbf in coro_init () at /usr/src/tarantool/third_party/coro/coro.c:110
```

Run the debugger in a loop a few times to collect enough samples for making conclusions about why Tarantool demonstrates suboptimal performance. Use the following script:

```
$ rm -f stack-trace.txt
$ watch -n 0.5 "gdb -ex 'set pagination 0' -ex 'thread apply all bt' --batch -p $(pidof tarantool␣
↪INSTANCENAME.lua) | tee -a stack-trace.txt"
```

Structurally and functionally, this script is very similar to the one used with fiber.info() above.

If you have any difficulties troubleshooting, let the script run for 10-15 seconds and then send the resulting stack-trace.txt file to the Tarantool team at support@tarantool.org.

Warning: Use the poor man's profilers with caution: each time they attach to a running process, this stops the process execution for about a second, which may leave a serious footprint in high-load services.

gperftools

To use the CPU profiler from the Google Performance Tools suite with Tarantool, first take care of the prerequisites:

- For Debian/Ubuntu, run:

```
$ apt-get install libgoogle-perftools4
```

- For RHEL/CentOS/Fedora, run:

```
$ yum install gperftools-libs
```

Once you do this, install Lua bindings:

```
$ tarantoolctl rocks install gperftools
```

Now you're ready to go. Enter your instance's interactive administrator console:

```
$ tarantoolctl enter NAME
```

To start profiling, say:

```
tarantool> cpuprof = require('gperftools.cpu')
tarantool> cpuprof.start('/home/<username>/tarantool-on-production.prof')
```

It takes at least a couple of minutes for the profiler to gather performance metrics. After that, save the results to disk (you can do that as many times as you need):

```
tarantool> cpuprof.flush()
```

To stop profiling, say:

```
tarantool> cpuprof.stop()
```

You can now analyze the output with the pprof utility that comes with the gperftools package:

```
$ pprof --text /usr/bin/tarantool /home/<username>/tarantool-on-production.prof
```

Note: On Debian/Ubuntu, the pprof utility is called google-pprof.

Your output should look similar to this:

```
Total: 598 samples
      83  13.9%  13.9%       83  13.9% epoll_wait
      54   9.0%  22.9%      102  17.1%
vy_mem_tree_insert.constprop.35
      32   5.4%  28.3%       34   5.7% __write_nocancel
      28   4.7%  32.9%       42   7.0% vy_mem_iterator_start_from
      26   4.3%  37.3%       26   4.3% _IO_str_seekoff
      21   3.5%  40.8%       21   3.5% tuple_compare_field
      19   3.2%  44.0%       19   3.2%
::TupleCompareWithKey::compare
      19   3.2%  47.2%       38   6.4% tuple_compare_slowpath
      12   2.0%  49.2%       23   3.8% __libc_calloc
       9   1.5%  50.7%        9   1.5%
::TupleCompare::compare@42efc0
       9   1.5%  52.2%        9   1.5% vy_cache_on_write
       9   1.5%  53.7%       57   9.5% vy_merge_iterator_next_key
       8   1.3%  55.0%        8   1.3% __nss_passwd_lookup
       6   1.0%  56.0%       25   4.2% gc_onestep
       6   1.0%  57.0%        6   1.0% lj_tab_next
       5   0.8%  57.9%        5   0.8% lj_alloc_malloc
       5   0.8%  58.7%      131  21.9% vy_prepare
```

perf

This tool for performance monitoring and analysis is installed separately via your package manager. Try running the perf command in the terminal and follow the prompts to install the necessary package(s).

Note: By default, some perf commands are restricted to root, so, to be on the safe side, either run all commands as root or prepend them with sudo.

To start gathering performance statistics, say:

```
$ perf record -g -p $(pidof tarantool INSTANCENAME.lua)
```

This command saves the gathered data to a file named perf.data inside the current working directory. To stop this process (usually, after 10-15 seconds), press ctrl+C. In your console, you'll see:

```
^C[ perf record: Woken up 1 times to write data ]
[ perf record: Captured and wrote 0.225 MB perf.data (1573 samples) ]
```

Now run the following command:

```
$ perf report -n -g --stdio | tee perf-report.txt
```

It formats the statistical data in the perf.data file into a performance report and writes it to the perf-report.txt file.

The resulting output should look similar to this:

```
# Samples: 14K of event 'cycles'
# Event count (approx.): 9927346847
#
# Children Self Samples Command Shared Object Symbol
# ........ ........ ............ ......... .................. .......................................
#
    35.50% 0.55% 79 tarantool tarantool [.] lj_gc_step
            |
             --34.95%--lj_gc_step
                        |
                        |--29.26%--gc_onestep
                        | |
                        | |--13.85%--gc_sweep
                        | | |
                        | | |--5.59%--lj_alloc_free
                        | | |
                        | | |--1.33%--lj_tab_free
                        | | | |
                        | | | --1.01%--lj_alloc_free
                        | | |
                        | | --1.17%--lj_cdata_free
                        | |
                        | |--5.41%--gc_finalize
                        | | |
                        | | |--1.06%--lj_obj_equal
                        | | |
                        | | --0.95%--lj_tab_set
                        | |
                        | |--4.97%--rehashtab
                        | | |
                        | | --3.65%--lj_tab_resize
                        | | |
                        | | |--0.74%--lj_tab_set
                        | | |
                        | | --0.72%--lj_tab_newkey
                        | |
                        | |--0.91%--propagatemark
                        | |
                        | --0.67%--lj_cdata_free
                        |
                         --5.43%--propagatemark
                                   |
                                    --0.73%--gc_mark
```

Unlike the poor man's profilers, gperftools and perf have low overhead (almost negligible as compared with pstack and gdb): they don't result in long delays when attaching to a process and therefore can be used without serious consequences.

jit.p

The jit.p profiler comes with the Tarantool application server, to load it one only needs to say require('jit.p') or require('jit.profile'). There are many options for sampling and display, they are described in the documentation for The LuaJIT Profiler.

Example

Make a function that calls a function named f1 that does 500,000 inserts and deletes in a Tarantool space. Start the profiler, execute the function, stop the profiler, and show what the profiler sampled.

```
box.space.t:drop()
box.schema.space.create('t')
box.space.t:create_index('i')
function f1() for i = 1,500000 do
  box.space.t:insert{i}
  box.space.t:delete{i}
  end
return 1
end
function f3() f1() end
jit_p = require("jit.profile")
sampletable = {}
jit_p.start("f", function(thread, samples, vmstate)
  local dump=jit_p.dumpstack(thread, "f", 1)
  sampletable[dump] = (sampletable[dump] or 0) + samples
end)
f3()
jit_p.stop()
for d,v in pairs(sampletable) do print(v, d) end
```

Typically the result will show that the sampling happened within f1() many times, but also within internal Tarantool functions, whose names may change with each new version.

4.5.6 Daemon supervision

Server signals

Tarantool processes these signals during the event loop in the transaction processor thread:

Signal	Effect
SIGHUP	May cause log file rotation. See the example in reference on Tarantool logging parameters.
SIGUSR1	May cause a database checkpoint. See box.snapshot.
SIGTERM	May cause graceful shutdown (information will be saved first).
SIGINT (also known as keyboard interrupt)	May cause graceful shutdown.
SIGKILL	Causes an immediate shutdown.

Other signals will result in behavior defined by the operating system. Signals other than SIGKILL may be ignored, especially if Tarantool is executing a long-running procedure which prevents return to the event loop in the transaction processor thread.

Automatic instance restart

On systemd-enabled platforms, systemd automatically restarts all Tarantool instances in case of failure. To demonstrate it, let's try to destroy an instance:

```
$ systemctl status tarantool@my_app|grep PID
Main PID: 5885 (tarantool)
$ tarantoolctl enter my_app
/bin/tarantoolctl: Found my_app.lua in /etc/tarantool/instances.available
/bin/tarantoolctl: Connecting to /var/run/tarantool/my_app.control
/bin/tarantoolctl: connected to unix/:/var/run/tarantool/my_app.control
unix/:/var/run/tarantool/my_app.control> os.exit(-1)
/bin/tarantoolctl: unix/:/var/run/tarantool/my_app.control: Remote host closed connection
```

Now let's make sure that systemd has restarted the instance:

```
$ systemctl status tarantool@my_app|grep PID
Main PID: 5914 (tarantool)
```

Finally, let's check the boot logs:

```
$ journalctl -u tarantool@my_app -n 8
-- Logs begin at Fri 2016-01-08 12:21:53 MSK, end at Thu 2016-01-21 21:09:45 MSK. --
Jan 21 21:09:45 localhost.localdomain systemd[1]: tarantool@my_app.service: Unit entered failed state.
Jan 21 21:09:45 localhost.localdomain systemd[1]: tarantool@my_app.service: Failed with result 'exit-code'.
Jan 21 21:09:45 localhost.localdomain systemd[1]: tarantool@my_app.service: Service hold-off time over,␣
↪scheduling restart.
Jan 21 21:09:45 localhost.localdomain systemd[1]: Stopped Tarantool Database Server.
Jan 21 21:09:45 localhost.localdomain systemd[1]: Starting Tarantool Database Server...
Jan 21 21:09:45 localhost.localdomain tarantoolctl[5910]: /usr/bin/tarantoolctl: Found my_app.lua in /etc/
↪tarantool/instances.available
Jan 21 21:09:45 localhost.localdomain tarantoolctl[5910]: /usr/bin/tarantoolctl: Starting instance...
Jan 21 21:09:45 localhost.localdomain systemd[1]: Started Tarantool Database Server.
```

Core dumps

Tarantool makes a core dump if it receives any of the following signals: SIGSEGV, SIGFPE, SIGABRT or SIGQUIT. This is automatic if Tarantool crashes.

On systemd-enabled platforms, coredumpctl automatically saves core dumps and stack traces in case of a crash. Here is a general "how to" for how to enable core dumps on a Unix system:

1. Ensure session limits are configured to enable core dumps, i.e. say ulimit -c unlimited. Check "man 5 core" for other reasons why a core dump may not be produced.
2. Set a directory for writing core dumps to, and make sure that the directory is writable. On Linux, the directory path is set in a kernel parameter configurable via /proc/sys/kernel/core_pattern.
3. Make sure that core dumps include stack trace information. If you use a binary Tarantool distribution, this is automatic. If you build Tarantool from source, you will not get detailed information if you pass -DCMAKE_BUILD_TYPE=Release to CMake.

To simulate a crash, you can execute an illegal command against a Tarantool instance:

```
$ # !!! please never do this on a production system !!!
$ tarantoolctl enter my_app
unix/:/var/run/tarantool/my_app.control> require('ffi').cast('char *', 0)[0] = 48
/bin/tarantoolctl: unix/:/var/run/tarantool/my_app.control: Remote host closed connection
```

Alternatively, if you know the process ID of the instance (here we refer to it as $PID), you can abort a Tarantool instance by running gdb debugger:

```
$ gdb -batch -ex "generate-core-file" -p $PID
```

or manually sending a SIGABRT signal:

```
$ kill -SIGABRT $PID
```

Note: To find out the process id of the instance ($PID), you can:

- look it up in the instance's box.info.pid,
- find it with ps -A | grep tarantool, or
- say systemctl status tarantool@my_app|grep PID.

On a systemd-enabled system, to see the latest crashes of the Tarantool daemon, say:

```
$ coredumpctl list /usr/bin/tarantool
MTIME                          PID   UID   GID SIG PRESENT EXE
Sat 2016-01-23 15:21:24 MSK   20681  1000  1000   6   /usr/bin/tarantool
Sat 2016-01-23 15:51:56 MSK   21035   995   992   6   /usr/bin/tarantool
```

To save a core dump into a file, say:

```
$ coredumpctl -o filename.core info <pid>
```

Stack traces

Since Tarantool stores tuples in memory, core files may be large. For investigation, you normally don't need the whole file, but only a "stack trace" or "backtrace".

To save a stack trace into a file, say:

```
$ gdb -se "tarantool" -ex "bt full" -ex "thread apply all bt" --batch -c core> /tmp/tarantool_trace.txt
```

where:

- "tarantool" is the path to the Tarantool executable,
- "core" is the path to the core file, and
- "/tmp/tarantool_trace.txt" is a sample path to a file for saving the stack trace.

Note: Occasionally, you may find that the trace file contains output without debug symbols – the lines will contain "??" instead of names. If this happens, check the instructions on these Tarantool wiki pages: How to debug core dump of stripped tarantool and How to debug core from different OS.

To see the stack trace and other useful information in console, say:

```
$ coredumpctl info 21035
          PID: 21035 (tarantool)
          UID: 995 (tarantool)
          GID: 992 (tarantool)
```

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```
       Signal: 6 (ABRT)
    Timestamp: Sat 2016-01-23 15:51:42 MSK (4h 36min ago)
 Command Line: tarantool my_app.lua <running>
   Executable: /usr/bin/tarantool
Control Group: /system.slice/system-tarantool.slice/tarantool@my_app.service
         Unit: tarantool@my_app.service
        Slice: system-tarantool.slice
      Boot ID: 7c686e2ef4dc4e3ea59122757e3067e2
   Machine ID: a4a878729c654c7093dc6693f6a8e5ee
     Hostname: localhost.localdomain
      Message: Process 21035 (tarantool) of user 995 dumped core.

               Stack trace of thread 21035:
               #0  0x00007f84993aa618 raise (libc.so.6)
               #1  0x00007f84993ac21a abort (libc.so.6)
               #2  0x0000560d0a9e9233 _ZL12sig_fatal_cbi (tarantool)
               #3  0x00007f849a211220 __restore_rt (libpthread.so.0)
               #4  0x0000560d0aaa5d9d lj_cconv_ct_ct (tarantool)
               #5  0x0000560d0aaa687f lj_cconv_ct_tv (tarantool)
               #6  0x0000560d0aaabe33 lj_cf_ffi_meta___newindex (tarantool)
               #7  0x0000560d0aaae2f7 lj_BC_FUNCC (tarantool)
               #8  0x0000560d0aa9aabd lua_pcall (tarantool)
               #9  0x0000560d0aa71400 lbox_call (tarantool)
               #10 0x0000560d0aa6ce36 lua_fiber_run_f (tarantool)
               #11 0x0000560d0a9e8d0c _ZL16fiber_cxx_invokePFiP13__va_list_tagES0_ (tarantool)
               #12 0x0000560d0aa7b255 fiber_loop (tarantool)
               #13 0x0000560d0ab38ed1 coro_init (tarantool)
               ...
```

Debugger

To start gdb debugger on the core dump, say:

```
$ coredumpctl gdb <pid>
```

It is highly recommended to install tarantool-debuginfo package to improve gdb experience, for example:

```
$ dnf debuginfo-install tarantool
```

gdb also provides information about the debuginfo packages you need to install:

```
$ gdb -p <pid>
...
Missing separate debuginfos, use: dnf debuginfo-install
glibc-2.22.90-26.fc24.x86_64 krb5-libs-1.14-12.fc24.x86_64
libgcc-5.3.1-3.fc24.x86_64 libgomp-5.3.1-3.fc24.x86_64
libselinux-2.4-6.fc24.x86_64 libstdc++-5.3.1-3.fc24.x86_64
libyaml-0.1.6-7.fc23.x86_64 ncurses-libs-6.0-1.20150810.fc24.x86_64
openssl-libs-1.0.2e-3.fc24.x86_64
```

Symbolic names are present in stack traces even if you don't have tarantool-debuginfo package installed.

4.5.7 Disaster recovery

The minimal fault-tolerant Tarantool configuration would be a replication cluster that includes a master and a replica, or two masters.

The basic recommendation is to configure all Tarantool instances in a cluster to create snapshot files at a regular basis.

Here follow action plans for typical crash scenarios.

Master-replica

Configuration: One master and one replica.

Problem: The master has crashed.

Your actions:

1. Ensure the master is stopped for good. For example, log in to the master machine and use systemctl stop tarantool@<instance_name>.
2. Switch the replica to master mode by setting box.cfg.read_only parameter to false and let the load be handled by the replica (effective master).
3. Set up a replacement for the crashed master on a spare host, with replication parameter set to replica (effective master), so it begins to catch up with the new master's state. The new instance should have box.cfg.read_only parameter set to true.

You lose the few transactions in the master write ahead log file, which it may have not transferred to the replica before crash. If you were able to salvage the master .xlog file, you may be able to recover these. In order to do it:

1. Find out the position of the crashed master, as reflected on the new master.

   a. Find out instance UUID from the crashed master xlog:

   ```
   $ head -5 *.xlog | grep Instance
   Instance: ed607cad-8b6d-48d8-ba0b-dae371b79155
   ```

   b. On the new master, use the UUID to find the position:

   ```
   tarantool> box.info.vclock[box.space._cluster.index.uuid:select{'ed607cad-8b6d-48d8-ba0b-
   ↪dae371b79155'}[1][1]]
   ---
   - 23425
   <...>
   ```

2. Play the records from the crashed .xlog to the new master, starting from the new master position:

   a. Issue this request locally at the new master's machine to find out instance ID of the new master:

   ```
   tarantool> box.space._cluster:select{}
   ---
   - - [1, '88580b5c-4474-43ab-bd2b-2409a9af80d2']
   ...
   ```

   b. Play the records to the new master:

   ```
   $ tarantoolctl <new_master_uri> <xlog_file> play --from 23425 --replica 1
   ```

Master-master

Configuration: Two masters.

Problem: Master#1 has crashed.

Your actions:

1. Let the load be handled by master#2 (effective master) alone.

2. Follow the same steps as in the master-replica recovery scenario to create a new master and salvage lost data.

Data loss

Configuration: Master-master or master-replica.

Problem: Data was deleted at one master and this data loss was propagated to the other node (master or replica).

The following steps are applicable only to data in memtx storage engine. Your actions:

1. Put all nodes in read-only mode and disable deletion of expired checkpoints with box.backup.start(). This will prevent the Tarantool garbage collector from removing files made with older checkpoints until box.backup.stop() is called.
2. Get the latest valid .snap file and use tarantoolctl cat command to calculate at which lsn the data loss occurred.
3. Start a new instance (instance#1) and use tarantoolctl play command to play to it the contents of .snap/.xlog files up to the calculated lsn.
4. Bootstrap a new replica from the recovered master (instance#1).

4.5.8 Backups

Tarantool has an append-only storage architecture: it appends data to files but it never overwrites earlier data. The Tarantool garbage collector removes old files after a checkpoint. You can prevent or delay the garbage collector's action by configuring the checkpoint daemon. Backups can be taken at any time, with minimal overhead on database performance.

Two functions are helpful for backups in certain situations:

- box.backup.start() informs the server that activities related to the removal of outdated backups must be suspended and returns a table with the names of snapshot and vinyl files that should be copied.
- box.backup.stop() later informs the server that normal operations may resume.

Hot backup (memtx)

This is a special case when there are only in-memory tables.

The last snapshot file is a backup of the entire database; and the WAL files that are made after the last snapshot are incremental backups. Therefore taking a backup is a matter of copying the snapshot and WAL files.

1. Use tar to make a (possibly compressed) copy of the latest .snap and .xlog files on the memtx_dir and wal_dir directories.
2. If there is a security policy, encrypt the .tar file.

3. Copy the .tar file to a safe place.

Later, restoring the database is a matter of taking the .tar file and putting its contents back in the memtx_dir and wal_dir directories.

Hot backup (vinyl/memtx)

Vinyl stores its files in vinyl_dir, and creates a folder for each database space. Dump and compaction processes are append-only and create new files. The Tarantool garbage collector may remove old files after each checkpoint.

To take a mixed backup:

1. Issue box.backup.start() on the administrative console. This will return a list of files to back up and suspend garbage collection for them till the next box.backup.stop().
2. Copy the files from the list to a safe location. This will include memtx snapshot files, vinyl run and index files, at a state consistent with the last checkpoint.
3. Issue box.backup.stop() so the garbage collector can continue as usual.

Continuous remote backup (memtx)

The replication feature is useful for backup as well as for load balancing.

Therefore taking a backup is a matter of ensuring that any given replica is up to date, and doing a cold backup on it. Since all the other replicas continue to operate, this is not a cold backup from the end user's point of view. This could be done on a regular basis, with a cron job or with a Tarantool fiber.

Continuous backup (memtx)

The logged changes done since the last cold backup must be secured, while the system is running.

For this purpose, you need a file copy utility that will do the copying remotely and continuously, copying only the parts of a write ahead log file that are changing. One such utility is rsync.

Alternatively, you need an ordinary file copy utility, but there should be frequent production of new snapshot files or new WAL files as changes occur, so that only the new files need to be copied.

4.5.9 Upgrades

Upgrading a Tarantool database

If you created a database with an older Tarantool version and have now installed a newer version, make the request box.schema.upgrade(). This updates Tarantool system spaces to match the currently installed version of Tarantool.

For example, here is what happens when you run box.schema.upgrade() with a database created with Tarantool version 1.6.4 to version 1.7.2 (only a small part of the output is shown):

```
tarantool> box.schema.upgrade()
alter index primary on _space set options to {"unique":true}, parts to [[0,"unsigned"]]
alter space _schema set options to {}
create view _vindex...
grant read access to 'public' role for _vindex view
```

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```
set schema version to 1.7.0
---
...
```

Upgrading a Tarantool instance

Tarantool is backward compatible between two adjacent versions. For example, you should have no or little trouble when upgrading from Tarantool 1.6 to 1.7, or from Tarantool 1.7 to 2.x. Meanwhile Tarantool 2.x may have incompatible changes when migrating from Tarantool 1.6. to 2.x directly.

How to upgrade from Tarantool 1.7 to 2.x

1. Stop the Tarantool server.
2. Make a copy of all data (see an appropriate hot backup procedure in Backups) and the package from which the current (old) version was installed (for rollback purposes).
3. Update the Tarantool server. See installation instructions at Tarantool download page.
4. Launch the updated Tarantool server using tarantoolctl or systemctl.

How to upgrade from Tarantool 1.6 to 2.x

The procedure is fully analogous to upgrading from 1.7 to 2.x.

How to upgrade from Tarantool 1.6 to 1.7

This procedure is for upgrading a standalone Tarantool instance in production from 1.6.x to 1.7.x. Notice that this will always imply a downtime. To upgrade without downtime, you need several Tarantool servers running in a replication cluster (see below).

Tarantool 1.7 has an incompatible .snap and .xlog file format: 1.6 files are supported during upgrade, but you won't be able to return to 1.6 after running under 1.7 for a while. It also renames a few configuration parameters, but old parameters are supported. The full list of breaking changes is available in release notes for Tarantool 1.7.

1. Check with application developers whether application files need to be updated due to incompatible changes (see 1.7 release notes). If yes, back up the old application files.
2. Stop the Tarantool server.
3. Make a copy of all data (see an appropriate hot backup procedure in Backups) and the package from which the current (old) version was installed (for rollback purposes).
4. Update the Tarantool server. See installation instructions at Tarantool download page.
5. Update the Tarantool database. Put the request box.schema.upgrade() inside a box.once() function in your Tarantool initialization file. On startup, this will create new system spaces, update data type names (e.g. num -> unsigned, str -> string) and options in Tarantool system spaces.
6. Update application files, if needed.
7. Launch the updated Tarantool server using tarantoolctl or systemctl.

Upgrading Tarantool in a replication cluster

Tarantool 1.7 can work as a replica for Tarantool 1.6 and vice versa. Replicas perform capability negotiation on handshake, and new 1.7 replication features are not used with 1.6 replicas. This allows upgrading clustered configurations.

This procedure allows for a rolling upgrade without downtime and works for any cluster configuration: master-master or master-replica.

1. Upgrade Tarantool at all replicas (or at any master in a master-master cluster). See details in Upgrading a Tarantool instance.
2. Verify installation on the replicas:
   a. Start Tarantool.
   b. Attach to the master and start working as before.

   The master runs the old Tarantool version, which is always compatible with the next major version.
3. Upgrade the master. The procedure is similar to upgrading a replica.
4. Verify master installation:
   a. Start Tarantool with replica configuration to catch up.
   b. Switch to master mode.
5. Upgrade the database on any master node in the cluster. Make the request box.schema.upgrade(). This updates Tarantool system spaces to match the currently installed version of Tarantool. Changes are propagated to other nodes via the regular replication mechanism.

4.5.10 Notes for operating systems

Mac OS

On Mac OS, you can administer Tarantool instances only with tarantoolctl. No native system tools are supported.

FreeBSD

To make tarantoolctl work along with init.d utilities on FreeBSD, use paths other than those suggested in Instance configuration. Instead of /usr/share/tarantool/ directory, use /usr/local/etc/tarantool/ and create the following subdirectories:

- default for tarantoolctl defaults (see example below),
- instances.available for all available instance files, and
- instances.enabled for instance files to be auto-started by sysvinit.

Here is an example of tarantoolctl defaults on FreeBSD:

```
default_cfg = {
    pid_file   = "/var/run/tarantool", -- /var/run/tarantool/${INSTANCE}.pid
    wal_dir    = "/var/db/tarantool", -- /var/db/tarantool/${INSTANCE}/
    snap_dir   = "/var/db/tarantool", -- /var/db/tarantool/${INSTANCE}
    vinyl_dir = "/var/db/tarantool", -- /var/db/tarantool/${INSTANCE}
    logger     = "/var/log/tarantool", -- /var/log/tarantool/${INSTANCE}.log
    username   = "tarantool",
```

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```
}

-- instances.available - all available instances
-- instances.enabled - instances to autostart by sysvinit
instance_dir = "/usr/local/etc/tarantool/instances.available"
```

Gentoo Linux

The section below is about a dev-db/tarantool package installed from the official layman overlay (named tarantool).

The default instance directory is /etc/tarantool/instances.available, can be redefined in /etc/default/tarantool.

Tarantool instances can be managed (start/stop/reload/status/. . .) using OpenRC. Consider the example how to create an OpenRC-managed instance:

```
$ cd /etc/init.d
$ ln -s tarantool your_service_name
$ ln -s /usr/share/tarantool/your_service_name.lua /etc/tarantool/instances.available/your_service_name.lua
```

Checking that it works:

```
$ /etc/init.d/your_service_name start
$ tail -f -n 100 /var/log/tarantool/your_service_name.log
```

4.5.11 Bug reports

If you found a bug in Tarantool, you're doing us a favor by taking the time to tell us about it.

Please create an issue at Tarantool repository at GitHub. We encourage you to include the following information:

- Steps needed to reproduce the bug, and an explanation why this differs from the expected behavior according to our manual. Please provide specific unique information. For example, instead of "I can't get certain information", say "box.space.x:delete() didn't report what was deleted".
- Your operating system name and version, the Tarantool name and version, and any unusual details about your machine and its configuration.
- Related files like a stack trace or a Tarantool log file.

If this is a feature request or if it affects a special category of users, be sure to mention that.

Usually within one or two workdays a Tarantool team member will write an acknowledgment, or some questions, or suggestions for a workaround.

4.5.12 Troubleshooting guide

Problem: INSERT/UPDATE-requests result in ER_MEMORY_ISSUE error

Possible reasons

- Lack of RAM (parameters arena_used_ratio and quota_used_ratio in box.slab.info() report are getting close to 100%).

  To check these parameters, say:

  ```
  $ # attaching to a Tarantool instance
  $ tarantoolctl enter <instance_name>
  $ # -- OR --
  $ tarantoolctl connect <URI>
  ```

  ```
  -- requesting arena_used_ratio value
  tarantool> box.slab.info().arena_used_ratio

  -- requesting quota_used_ratio value
  tarantool> box.slab.info().quota_used_ratio
  ```

Solution

Try either of the following measures:

- In Tarantool's instance file, increase the value of box.cfg{memtx_memory} (if memory resources are available).

  In versions of Tarantool before 1.10, the server needs to be restarted to change this parameter. The Tarantool server will be unavailable while restarting from .xlog files, unless you restart it using hot standby mode. In the latter case, nearly 100% server availability is guaranteed.

- Clean up the database.
- Check the indicators of memory fragmentation:

  ```
  -- requesting quota_used_ratio value
  tarantool> box.slab.info().quota_used_ratio

  -- requesting items_used_ratio value
  tarantool> box.slab.info().items_used_ratio
  ```

  In case of heavy memory fragmentation (quota_used_ratio is getting close to 100%, items_used_ratio is about 50%), we recommend restarting Tarantool in the hot standby mode.

Problem: Tarantool generates too heavy CPU load

Possible reasons

The transaction processor thread consumes over 60% CPU.

Solution

Attach to the Tarantool instance with tarantoolctl utility, analyze the query statistics with box.stat() and spot the CPU consumption leader. The following commands can help:

```
$ # attaching to a Tarantool instance
$ tarantoolctl enter <instance_name>
$ # -- OR --
$ tarantoolctl connect <URI>
```

```
-- checking the RPS of calling stored procedures
tarantool> box.stat().CALL.rps
```

The critical RPS value is 75 000, boiling down to 10 000 - 20 000 for a rich Lua application (a Lua module of 200+ lines).

```
-- checking RPS per query type
tarantool> box.stat().<query_type>.rps
```

The critical RPS value for SELECT/INSERT/UPDATE/DELETE requests is 100 000.

If the load is mostly generated by SELECT requests, we recommend adding a slave server and let it process part of the queries.

If the load is mostly generated by INSERT/UPDATE/DELETE requests, we recommend sharding the database.

Problem: Query processing times out

Possible reasons

Note: All reasons that we discuss here can be identified by messages in Tarantool's log file, all starting with the words `'Too long...'`.

1. Both fast and slow queries are processed within a single connection, so the readahead buffer is cluttered with slow queries.

   Solution

   Try either of the following measures:

   - Increase the readahead buffer size (box.cfg{readahead} parameter).

     This parameter can be changed on the fly, so you don't need to restart Tarantool. Attach to the Tarantool instance with tarantoolctl utility and call box.cfg{} with a new readahead value:

     ```
     $ # attaching to a Tarantool instance
     $ tarantoolctl enter <instance_name>
     $ # -- OR --
     $ tarantoolctl connect <URI>
     ```

     ```
     -- changing the readahead value
     tarantool> box.cfg{readahead = 10 * 1024 * 1024}
     ```

     Example: Given 1000 RPS, 1 Kbyte of query size, and 10 seconds of maximal query processing time, the minimal readahead buffer size must be 10 Mbytes.

   - On the business logic level, split fast and slow queries processing by different connections.

2. Slow disks.

   Solution

   Check disk performance (use iostat, iotop or strace utility to check iowait parameter) and try to put .xlog files and snapshot files on different physical disks (i.e. use different locations for wal_dir and memtx_dir).

Problem: Replication "lag" and "idle" contain negative values

This is about box.info.replication.(upstream.)lag and box.info.replication.(upstream.)idle values in box.info.replication section.

Possible reasons

Operating system clock on the hosts is not synchronized, or the NTP server is faulty.

Solution

Check NTP server settings.

If you found no problems with the NTP server, just do nothing then. Lag calculation uses operating system clock from two different machines. If they get out of sync, the remote master clock can get consistently behind the local instance's clock.

Problem: Replication "idle" keeps growing, but no related log messages appear

This is about box.info.replication.(upstream.)idle value in box.info.replication section.

Possible reasons

Some server was assigned different IP addresses, or some server was specified twice in box.cfg{}, so duplicate connections were established.

Solution

Upgrade Tarantool 1.6 to 1.7, where this error is fixed: in case of duplicate connections, replication is stopped and the following message is added to the log: `'Incorrect value for option ''replication_source'': duplicate connection with the same replica UUID'`.

Problem: Replication statistics differ on replicas within a replica set

This is about a replica set that consists of one master and several replicas. In a replica set of this type, values in box.info.replication section, like box.info.replication.lsn, come from the master and must be the same on all replicas within the replica set. The problem is that they get different.

Possible reasons

Replication is broken.

Solution

Restart replication.

Problem: Master-master replication is stopped

This is about box.info.replication(.upstream).status = stopped.

Possible reasons

In a master-master replica set of two Tarantool instances, one of the masters has tried to perform an action already performed by the other server, for example re-insert a tuple with the same unique key. This would cause an error message like `'Duplicate key exists in unique index 'primary' in space <space_name>'`.

Solution

Restart replication with the following commands (at each master instance):

```
$ # attaching to a Tarantool instance
$ tarantoolctl enter <instance_name>
$ # -- OR --
$ tarantoolctl connect <URI>
```

```
-- restarting replication
tarantool> original_value = box.cfg.replication
tarantool> box.cfg{replication={}}
tarantool> box.cfg{replication=original_value}
```

We also recommend using text primary keys or setting up master-slave replication.

Problem: Tarantool works much slower than before

Possible reasons

Inefficient memory usage (RAM is cluttered with a huge amount of unused objects).

Solution

Call the Lua garbage collector with the collectgarbage('count') function and measure its execution time with the Tarantool functions clock.bench() or clock.proc().

Example of calculating memory usage statistics:

```
$ # attaching to a Tarantool instance
$ tarantoolctl enter <instance_name>
$ # -- OR --
$ tarantoolctl connect <URI>
```

```
-- loading Tarantool's "clock" module with time-related routines
tarantool> clock = require 'clock'
-- starting the timer
tarantool> b = clock.proc()
-- launching garbage collection
tarantool> c = collectgarbage('count')
-- stopping the timer after garbage collection is completed
tarantool> return c, clock.proc() - b
```

If the returned clock.proc() value is greater than 0.001, this may be an indicator of inefficient memory usage (no active measures are required, but we recommend to optimize your Tarantool application code).

If the value is greater than 0.01, your application definitely needs thorough code analysis aimed at optimizing memory usage.

Problem: Fiber switch is forbidden in __gc metamethod

Problem description

Fiber switch is forbidden in __gc metamethod since this change to avoid unexpected Lua OOM. However, one may need to use a yielding function to finalize resources, for example, to close a socket.

Below are examples of proper implementing such a procedure.

Solution

First, there come two simple examples illustrating the logic of the solution:

- Example 1
- Example 2.

Next comes the Example 3 illustrating the usage of the sched.lua module that is the recommended method.

All the explanations are given in the comments in the code listing. -- > indicates the output in console.

Example 1

Implementing a valid finalizer for a particular FFI type (custom_t).

```lua
local ffi = require('ffi')
local fiber = require('fiber')

ffi.cdef('struct custom { int a; };')

local function __custom_gc(self)
  print(("Entered custom GC finalizer for %s... (before yield)"):format(self.a))
  fiber.yield()
  print(("Leaving custom GC finalizer for %s... (after yield)"):format(self.a))
end

local custom_t = ffi.metatype('struct custom', {
  __gc = function(self)
    -- XXX: Do not invoke yielding functions in __gc metamethod.
    -- Create a new fiber to run after the execution leaves
    -- this routine.
    fiber.new(__custom_gc, self)
    print(("Finalization is scheduled for %s..."):format(self.a))
  end
})

-- Create a cdata object of <custom_t> type.
local c = custom_t(42)

-- Remove a single reference to that object to make it subject
-- for GC.
c = nil

-- Run full GC cycle to purge the unreferenced object.
collectgarbage('collect')
-- > Finalization is scheduled for 42...

-- XXX: There is no finalization made until the running fiber
-- yields its execution. Let's do it now.
fiber.yield()
-- > Entered custom GC finalizer for 42... (before yield)
-- > Leaving custom GC finalizer for 42... (after yield)
```

Example 2

Implementing a valid finalizer for a particular user type (struct custom).

custom.c

```c
#include <lauxlib.h>
#include <lua.h>
#include <module.h>
#include <stdio.h>

struct custom {
  int a;
};
```

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```
const char *CUSTOM_MTNAME = "CUSTOM_MTNAME";

/*
 * XXX: Do not invoke yielding functions in __gc metamethod.
 * Create a new fiber to be run after the execution leaves
 * this routine. Unfortunately we can't pass the parameters to the
 * routine to be executed by the created fiber via <fiber_new_ex>.
 * So there is a workaround to load the Lua code below to create
 * __gc metamethod passing the object for finalization via Lua
 * stack to the spawned fiber.
 */
const char *gc_wrapper_constructor = " local fiber = require('fiber')          "
             " print('constructor is initialized')    "
             " return function(__custom_gc)             "
             "   print('constructor is called')       "
             "   return function(self)                "
             "     print('__gc is called')            "
             "     fiber.new(__custom_gc, self)        "
             "     print('Finalization is scheduled') "
             "   end                                  "
             " end                                    "
        ;

int custom_gc(lua_State *L) {
  struct custom *self = luaL_checkudata(L, 1, CUSTOM_MTNAME);
  printf("Entered custom_gc for %d... (before yield)\n", self->a);
  fiber_sleep(0);
  printf("Leaving custom_gc for %d... (after yield)\n", self->a);
  return 0;
}

int custom_new(lua_State *L) {
  struct custom *self = lua_newuserdata(L, sizeof(struct custom));
  luaL_getmetatable(L, CUSTOM_MTNAME);
  lua_setmetatable(L, -2);
  self->a = lua_tonumber(L, 1);
  return 1;
}

static const struct luaL_Reg libcustom_methods [] = {
  { "new", custom_new },
  { NULL, NULL }
};

int luaopen_custom(lua_State *L) {
  int rc;

  /* Create metatable for struct custom type */
  luaL_newmetatable(L, CUSTOM_MTNAME);
  /*
   * Run the constructor initializer for GC finalizer:
   * - load fiber module as an upvalue for GC finalizer
   *   constructor
   * - return GC finalizer constructor on the top of the
   *   Lua stack
```

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```
  */
  rc = luaL_dostring(L, gc_wrapper_constructor);
  /*
   * Check whether constructor is initialized (i.e. neither
   * syntax nor runtime error is raised).
   */
  if (rc != LUA_OK)
    luaL_error(L, "test module loading failed: constructor init");
  /*
   * Create GC object for <custom_gc> function to be called
   * in scope of the GC finalizer and push it on top of the
   * constructor returned before.
   */
  lua_pushcfunction(L, custom_gc);
  /*
   * Run the constructor with <custom_gc> GCfunc object as
   * a single argument. As a result GC finalizer is returned
   * on the top of the Lua stack.
   */
  rc = lua_pcall(L, 1, 1, 0);
  /*
   * Check whether GC finalizer is created (i.e. neither
   * syntax nor runtime error is raised).
   */
  if (rc != LUA_OK)
    luaL_error(L, "test module loading failed: __gc init");
  /*
   * Assign the returned function as a __gc metamethod to
   * custom type metatable.
   */
  lua_setfield(L, -2, "__gc");

  /*
   * Initialize Lua table for custom module and fill it
   * with the custom methods.
   */
  lua_newtable(L);
  luaL_register(L, NULL, libcustom_methods);
  return 1;
}
```

custom_c.lua

```
-- Load custom Lua C extension.
local custom = require('custom')
-- > constructor is initialized
-- > constructor is called

-- Create a userdata object of <struct custom> type.
local c = custom.new(9)

-- Remove a single reference to that object to make it subject
-- for GC.
c = nil

-- Run full GC cycle to purge the unreferenced object.
```

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```
collectgarbage('collect')
-- > __gc is called
-- > Finalization is scheduled

-- XXX: There is no finalization made until the running fiber
-- yields its execution. Let's do it now.
require('fiber').yield()
-- > Entered custom_gc for 9... (before yield)

-- XXX: Finalizer yields the execution, so now we are here.
print('We are here')
-- > We are here

-- XXX: This fiber finishes its execution, so yield to the
-- remaining fiber to finish the postponed finalization.
-- > Leaving custom_gc for 9... (after yield)
```

Example 3

It is important to note that the finalizer implementations in the examples above increase pressure on the platform performance by creating a new fiber on each __gc call. To prevent such an excessive fibers spawning, it's better to start a single "scheduler" fiber and provide the interface to postpone the required asynchronous action.

For this purpose, the module called sched.lua is implemented (see the listing below). It is a part of Tarantool and should be made required in your custom code. The usage example is given in the init.lua file below.

sched.lua

```
local fiber = require('fiber')

local worker_next_task = nil
local worker_last_task
local worker_fiber
local worker_cv = fiber.cond()

-- XXX: the module is not ready for reloading, so worker_fiber is
-- respawned when sched.lua is purged from package.loaded.

--
-- Worker is a singleton fiber for not urgent delayed execution of
-- functions. Main purpose - schedule execution of a function,
-- which is going to yield, from a context, where a yield is not
-- allowed. Such as an FFI object's GC callback.
--
local function worker_f()
  while true do
    local task
    while true do
      task = worker_next_task
      if task then break end
      -- XXX: Make the fiber wait until the task is added.
      worker_cv:wait()
    end
    worker_next_task = task.next
    task.f(task.arg)
    fiber.yield()
```

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```
  end
end

local function worker_safe_f()
  pcall(worker_f)
  -- The function <worker_f> never returns. If the execution is
  -- here, this fiber is probably canceled and now is not able to
  -- sleep. Create a new one.
  worker_fiber = fiber.new(worker_safe_f)
end

worker_fiber = fiber.new(worker_safe_f)

local function worker_schedule_task(f, arg)
  local task = { f = f, arg = arg }
  if not worker_next_task then
    worker_next_task = task
  else
    worker_last_task.next = task
  end
  worker_last_task = task
  worker_cv:signal()
end

return {
  postpone = worker_schedule_task
}
```

init.lua

```
local ffi = require('ffi')
local fiber = require('fiber')
local sched = require('sched')

local function __custom_gc(self)
  print(("Entered custom GC finalizer for %s... (before yield)"):format(self.a))
  fiber.yield()
  print(("Leaving custom GC finalizer for %s... (after yield)"):format(self.a))
end

ffi.cdef('struct custom { int a; };')
local custom_t = ffi.metatype('struct custom', {
  __gc = function(self)
    -- XXX: Do not invoke yielding functions in __gc metamethod.
    -- Schedule __custom_gc call via sched.postpone to be run
    -- after the execution leaves this routine.
    sched.postpone(__custom_gc, self)
    print(("Finalization is scheduled for %s..."):format(self.a))
  end
})

-- Create several <custom_t> objects to be finalized later.
local t = { }
for i = 1, 10 do t[i] = custom_t(i) end

-- Run full GC cycle to collect the existing garbage. Nothing is
```

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```
-- going to be printed, since the table <t> is still "alive".
collectgarbage('collect')

-- Remove the reference to the table and, ergo, all references to
-- the objects.
t = nil

-- Run full GC cycle to collect the table and objects inside it.
-- As a result all <custom_t> objects are scheduled for further
-- finalization, but the finalizer itself (i.e. __custom_gc
-- functions) is not called.
collectgarbage('collect')
-- > Finalization is scheduled for 10...
-- > Finalization is scheduled for 9...
-- > ...
-- > Finalization is scheduled for 2...
-- > Finalization is scheduled for 1...

-- XXX: There is no finalization made until the running fiber
-- yields its execution. Let's do it now.
fiber.yield()
-- > Entered custom GC finalizer for 10... (before yield)

-- XXX: Oops, we are here now, since the scheduler fiber yielded
-- the execution to this one. Check this out.
print("We're here now. Let's continue the scheduled finalization.")
-- > We're here now. Let's continue the finalization

-- OK, wait a second to allow the scheduler to cleanup the
-- remaining garbage.
fiber.sleep(1)
-- > Leaving custom GC finalizer for 10... (after yield)
-- > Entered custom GC finalizer for 9... (before yield)
-- > Leaving custom GC finalizer for 9... (after yield)
-- > ...
-- > Entered custom GC finalizer for 1... (before yield)
-- > Leaving custom GC finalizer for 1... (after yield)

print("Did we finish? I guess so.")
-- > Did we finish? I guess so.

-- Stop the instance.
os.exit(0)
```

4.5.13 Monitoring

Monitoring is the process of measuring and tracking Tarantool performance according to key metrics influencing it. These metrics are typically monitored in real time, allowing you to identify or predict issues.

This chapter includes the following sections:

Monitoring: getting started

Tarantool

First, you need to install the metrics package:

```
$ cd ${PROJECT_ROOT}
$ tarantoolctl rocks install metrics
```

Next, require it in your code:

```
local metrics = require('metrics')
```

Set a global label for your metrics:

```
metrics.set_global_labels({alias = 'alias'})
```

Enable default Tarantool metrics such as network, memory, operations, etc:

```
metrics.enable_default_metrics()
```

If you use Cartridge, enable Cartridge metrics:

```
metrics.enable_cartridge_metrics()
```

Initialize the Prometheus Exporter, or export metrics in any other format:

```
local httpd = require('http.server')
local http_handler = require('metrics.plugins.prometheus').collect_http


httpd.new('0.0.0.0', 8088)
    :route({path = '/metrics'}, function(...)
        return http_handler(...)
end)
    :start()

box.cfg{
    listen = 3302
}
```

Now you can use the HTTP API endpoint /metrics to collect your metrics in the Prometheus format. If you need your custom metrics, see the API reference.

Instance health check

In production environments Tarantool Cluster usually has a large number of so called “routers”, Tarantool instances that handle input load and it is required to evenly distribute the load. Various load-balancers are used for this, but any load-balancer have to know which “routers” are ready to accept the load at that very moment. Metrics library has a special plugin that creates an http handler that can be used by the load-balancer to check the current state of any Tarantool instance. If the instance is ready to accept the load, it will return a response with a 200 status code, if not, with a 500 status code.

Cartridge role

cartridge.roles.metrics is a role for Tarantool Cartridge. It allows using default metrics in a Cartridge application and manage them via configuration.

Usage

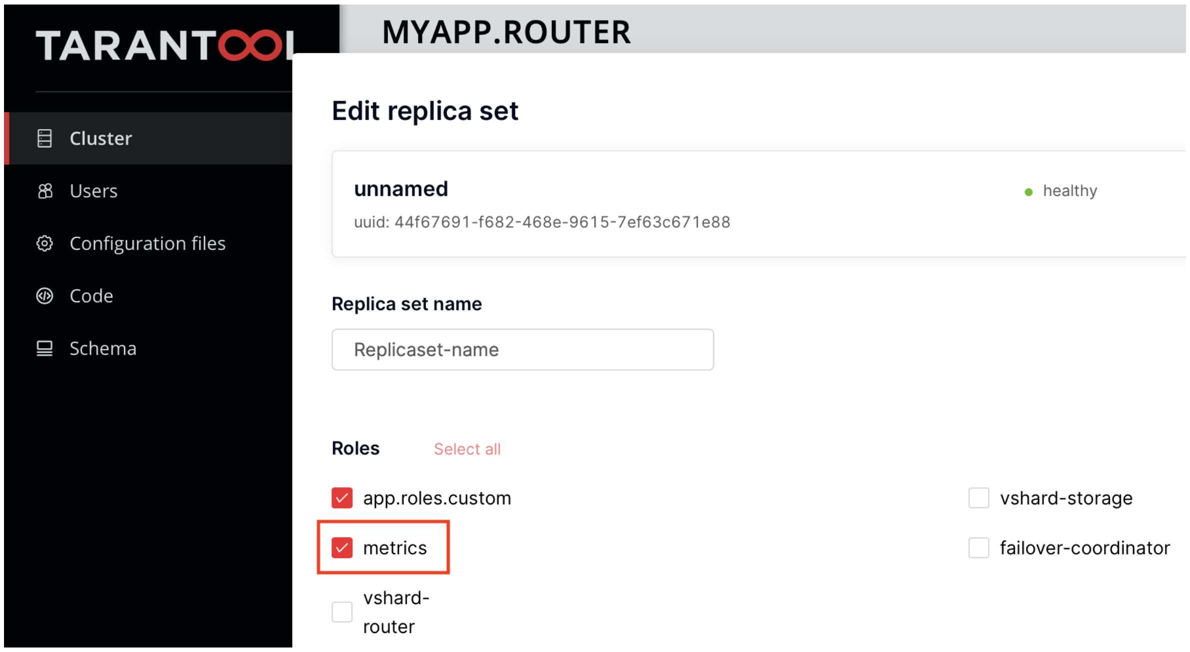
1. Add metrics package to dependencies in the .rockspec file. Make sure that you are using version 0.3.0 or higher.

```
dependencies = {
    ...
    'metrics >= 0.3.0-1',
    ...
}
```

2. Make sure that you have cartridge.roles.metrics in the roles list in cartridge.cfg in your entry-point file (e.g. init.lua).

```
local ok, err = cartridge.cfg({
    ...
    roles = {
        ...
        'cartridge.roles.metrics',
        ...
    },
})
```

3. Enable role in the interface:



Edit replica set

unnamed ● healthy
uuid: 44f67691-f682-468e-9615-7ef63c671e88

Replica set name: Replicaset-name

Roles Select all

- [✓] app.roles.custom
- [✓] metrics
- [ ] vshard-router
- [ ] vshard-storage
- [ ] failover-coordinator

Since version 0.6.0 metrics role is permanent and enabled on instances by default.

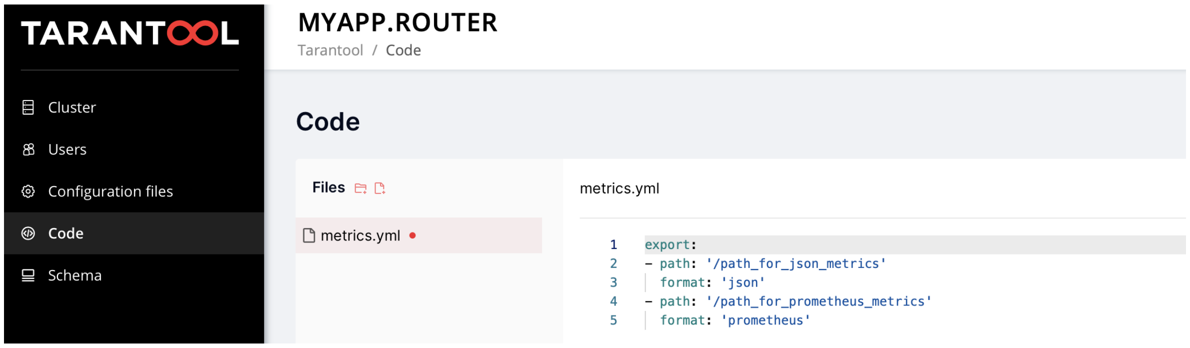
4. After role initialization, default metrics will be enabled and the global label 'alias' will be set. Note that 'alias' label value is set by instance configuration option alias or instance_name (since 0.6.1).

   If you need to use the functionality of any metrics package, you may get it as a Cartridge service and use it like a regular package after require:

```
local cartridge = require('cartridge')
local metrics = cartridge.service_get('metrics')
```

5. To view metrics via API endpoints, use the following configuration (to learn more about Cartridge configuration, see this):

```
metrics:
  export:
  - path: '/path_for_json_metrics'
    format: 'json'
  - path: '/path_for_prometheus_metrics'
    format: 'prometheus'
  - path: '/health'
    format: 'health'
```



```
export:
- path: '/path_for_json_metrics'
  format: 'json'
- path: '/path_for_prometheus_metrics'
  format: 'prometheus'
```

OR

Use set_export:

NOTE that set_export has lower priority than clusterwide config and won't work if metrics config is present.

```
metrics.set_export({
    {
        path = '/path_for_json_metrics',
        format = 'json'
    },
    {
        path = '/path_for_prometheus_metrics',
        format = 'prometheus'
    },
    {
        path = '/health',
        format = 'health'
    }
})
```

The metrics will be available on the path specified in path in the format specified in format.

You can add several entry points of the same format by different paths, like this:

```
metrics:
  export:
    - path: '/path_for_json_metrics'
      format: 'json'
    - path: '/another_path_for_json_metrics'
      format: 'json'
```

Metrics reference

This page provides detailed description of metrics from module metrics.

General metrics

General instance information.

- tnt_cfg_current_time - instance system time in Unix timestamp format
- tnt_info_uptime – time since instance was started, in seconds

Memory general

These metrics provide a picture of memory usage by Tarantool process.

- tnt_info_info_memory_cache - number of bytes in the cache for the tuples stored for the vinyl storage engine.
- tnt_info_info_memory_data - number of bytes used for storing user data (the tuples) with the memtx engine and with level 0 of the vinyl engine, without taking memory fragmentation into account.
- tnt_info_info_memory_index - number of bytes used for indexing user data, including memtx and vinyl memory tree extents, the vinyl page index, and the vinyl bloom filters.
- tnt_info_info_memory_lua - number of bytes used for Lua runtime. Lua memory is bounded by 2 GB per instance. Monitoring of this metric can prevent memory overflow.
- tnt_info_info_memory_net - number of bytes used for network input/output buffers.
- tnt_info_info_memory_tx - number of bytes in use by active transactions. For the vinyl storage engine, this is the total size of all allocated objects (struct txv, struct vy_tx, struct vy_read_interval) and tuples pinned for those objects.

Memory allocation

Provides memory usage report for the slab allocator. The slab allocator is the main allocator used to store tuples. This can be used to monitor the total memory usage and memory fragmentation. To learn more about use cases, see this

Available memory, bytes:

- tnt_slab_quota_size - the amount of memory available to store tuples and indexes, equals memtx_memory
- tnt_slab_arena_size - the total memory used for tuples and indexes together (including allocated, but currently free slabs)
- tnt_slab_items_size - the total amount of memory (including allocated, but currently free slabs) used only for tuples, no indexes

Memory usage, bytes:

- tnt_slab_quota_used - the amount of memory that is already reserved by the slab allocator
- tnt_slab_arena_used - the efficient memory used for storing tuples and indexes together (omitting allocated, but currently free slabs)

- tnt_slab_items_used - the efficient amount of memory (omitting allocated, but currently free slabs) used only for tuples, no indexes

Memory utilization, %:

- tnt_slab_quota_used_ratio - tnt_slab_quota_used / tnt_slab_quota_size
- tnt_slab_arena_used_ratio - tnt_slab_arena_used / tnt_slab_arena_used
- tnt_slab_items_used_ratio - tnt_slab_items_used / tnt_slab_items_size

Spaces

Those metrics provide specific information about each individual space in Tarantool instance.

- tnt_space_len - number of records in space. This metric always has 2 labels - {name="test", engine="memtx"}. name - the name of the space, engine - is the engine of the space.
- tnt_space_bsize - the total number of bytes in all tuples. This metric always has 2 labels - {name="test", engine="memtx"}. name - the name of the space, engine - is the engine of the space.
- tnt_space_index_bsize - the total number of bytes taken by the index. This metric always has 2 labels - {name="test", index_name="pk"}. name - the name of the space, index_name - is the name of the index.
- tnt_space_total_bsize - the total size of tuples and all indexes in space. This metric always has 2 labels - {name="test", engine="memtx"}. name - the name of the space, engine - is the engine of the space.
- tnt_space_count - the total tuples count for vinyl. This metric always has labels - {name="test", engine="vinyl"}. name - the name of the space. engine - is the engine of the space.

Network

Network activity stats. This can be used to monitor network load, usage peaks and traffic drops.

Sent bytes:

- tnt_net_sent_total - bytes sent from this instance over network since instance start

Received bytes:

- tnt_net_received_total - bytes this instance has received since instance start

Connections:

- tnt_net_connections_total - number of incoming network connections since instance start
- tnt_net_connections_current - number of active network connections

Requests:

- tnt_net_requests_total - number of network requests this instance has handled since instance start
- tnt_net_requests_current - amount of pending network requests

Fibers

Provides statistics of fibers. If your app creates a lot of fibers, it can be used for monitoring fibers count and memory usage.

- tnt_fiber_count - number of fibers
- tnt_fiber_csw - averall amount of fibers context switches
- tnt_fiber_memalloc - the amount of memory that is reserved for fibers
- tnt_fiber_memused - the amount of memory that is used by fibers

Operations

Number of iproto requests this instance has processed, aggregated by request type. It can be used to find out which type of operation clients make more often.

- tnt_stats_op_total - total number of calls since server start

That metric have operation label to be able to distinguish different request types, e.g.: {operation="select"}

Request type could be one of:

- delete - delete calls
- error - requests resulted in an error
- update - update calls
- call - requests to execute stored procedures
- auth - authentication requests
- eval - calls to evaluate lua code
- replace - replace call
- execute - execute SQL calls
- select - select calls
- upsert - upsert calls
- prepare - SQL prepare calls
- insert - insert calls

Replication

Provides information of current replication status. To learn more about replication mechanism in Tarantool, see this

- tnt_info_lsn – LSN of instance
- tnt_info_vclock – LSN number in vclock. This metric always has label - {id="id"}, where id is instance number in replicaset
- tnt_replication_replica_<id>_lsn / tnt_replication_master_<id>_lsn - LSN of master/replica, id is instance number in replicaset
- tnt_replication_<id>_lag - replication lag value in seconds, id is instance number in replicaset

Runtime

- tnt_runtime_lua – Lua garbage collector size in bytes
- tnt_runtime_used - number of bytes used for Lua runtime

Cartridge

- cartridge_issues - Number of issues <https://www.tarantool.io/en/doc/latest/book/cartridge/cartridge_api/modules/ across cluster instances. This metric always has labels - {level="critical"}. level - the level of the issue. critical level is associated with critical cluster problems, e.g. memory used ratio > 90%, warning is associated with other cluster problems, e.g. replication issues on cluster.

LuaJIT metrics

LuaJIT metrics help to understand Lua GC state. Only in Tarantool 2.6+.

General JIT metrics:

- lj_jit_snap_restore - overall number of snap restores
- lj_jit_trace_num - number of JIT traces
- lj_jit_trace_abort - overall number of abort traces
- lj_jit_mcode_size - total size of all allocated machine code areas

JIT strings:

- lj_strhash_hit - number of strings being interned
- lj_strhash_miss - total number of string allocations

GC steps:

- lj_gc_steps_atomic - count of incremental GC steps (atomic state)
- lj_gc_steps_sweepstring - count of incremental GC steps (sweepstring state)
- lj_gc_steps_finalize - count of incremental GC steps (finalize state)
- lj_gc_steps_sweep - count of incremental GC steps (sweep state)
- lj_gc_steps_propagate - count of incremental GC steps (propagate state)
- lj_gc_steps_pause - count of incremental GC steps (pause state)

Allocations:

- lj_gc_strnum - number of allocated string objects
- lj_gc_tabnum - number of allocated table objects
- lj_gc_cdatanum - number of allocated cdata objects
- lj_gc_udatanum - number of allocated udata objects
- lj_gc_freed - total amount of freed memory
- lj_gc_total - current allocated Lua memory
- lj_gc_allocated - total amount of allocated memory

CPU metrics

Those metrics provides CPU usage statistics. Only for Linux.

- tnt_cpu_count - total number of processors configured by the operating system
- tnt_cpu_total - host CPU time
- tnt_cpu_thread - Tarantool thread cpu time. This metric always has labels - {kind="user", thread_name="tarantool", thread_pid="pid", file_name="init.lua"}, where kind is user or system, thread_name is tarantool, wal, iproto or coio, file_name is entrypoint file name, e.g. init.lua.

API reference

Collectors

An application using the metrics module has 4 primitives (called "collectors") at its disposal:

- Counter
- Gauge
- Histogram
- Summary

A collector represents one or more observations that are changing over time.

Counter

metrics.counter(name[, help])
: Registers a new counter.

  Parameters

  - name (string) – Collector name. Must be unique.
  - help (string) – Help description.

  Return Counter object

  Rtype counter_obj

object counter_obj

counter_obj:inc(num, label_pairs)
: Increments an observation under label_pairs. If label_pairs didn't exist before, this creates it.

  Parameters

  - num (number) – Increase value.
  - label_pairs (table) – Table containing label names as keys, label values as values.

counter_obj:collect()

  Return Array of observation objects for the given counter.

```
{
    label_pairs: table,          -- `label_pairs` key-value table
    timestamp: ctype<uint64_t>,  -- current system time (in microseconds)
    value: number,               -- current value
    metric_name: string,          -- collector
}
```

Rtype table

Gauge

metrics.gauge(name[, help])

Registers a new gauge. Returns a Gauge object.

Parameters

- name (string) – Collector name. Must be unique.
- help (string) – Help description.

Return Gauge object

Rtype gauge_obj

object gauge_obj

gauge_obj:inc(num, label_pairs)

Same as Counter inc().

gauge_obj:inc(num, label_pairs)

Same as inc(), but decreases the observation.

gauge_obj:set(num, label_pairs)

Same as inc(), but sets the observation.

gauge_obj:collect()

Returns an array of observation objects for the given gauge. For observation description, see counter_obj:collect().

Histogram

metrics.histogram(name[, help, buckets])

Registers a new histogram.

Parameters

- name (string) – Collector name. Must be unique.
- help (string) – Help description.
- buckets (table) – Histogram buckets (an array of sorted positive numbers). Infinity bucket (INF) is appended automatically. Default is {.005, .01, .025, .05, .075, .1, .25, .5, .75, 1.0, 2.5, 5.0, 7.5, 10.0, INF}.

Return Histogram object

Rtype histogram_obj

Note: The histogram is just a set of collectors:

- name .. "_sum" - A counter holding the sum of added observations. Contains only an empty label set.
- name .. "_count" - A counter holding the number of added observations. Contains only an empty label set.
- name .. "_bucket" - A counter holding all bucket sizes under the label le (low or equal). So to access a specific bucket x (x is a number), you should specify the value x for the label le.

object histogram_obj

histogram_obj:observe(num, label_pairs)
Records a new value in a histogram. This increments all buckets sizes under labels le >= num and labels matching label_pairs.

Parameters

- num (number) – Value to put in the histogram.
- label_pairs (table) – Table containing label names as keys, label values as values (table). A new value is observed by all internal counters with these labels specified.

histogram_obj:collect()
Returns a concatenation of counter_obj:collect() across all internal counters of histogram_obj. For observation description, see counter_obj:collect().

Summary

metrics.summary(name[, help, objectives])
Registers a new summary. Quantile computation is based on the algorithm "Effective computation of biased quantiles over data streams"

Parameters

- name (string) – Collector name. Must be unique.
- help (string) – Help description.
- objectives (table) – Quantiles to observe in the form {quantile = error, ... }. For example: {[0.5]=0.01, [0.9]=0.01, [0.99]=0.01}

Return Summary object

Rtype summary_obj

Note: The summary is just a set of collectors:

- name .. "_sum" - A counter holding the sum of added observations.
- name .. "_count" - A counter holding the number of added observations.
- name - It's holding all quantiles under observation under the label quantile (low or equal). So to access a specific quantile x (x is a number), you should specify the value x for the label quantile.

object summary_obj

summary_obj:observe(num, label_pairs)
Records a new value in a summary.

Parameters

- num (number) – Value to put in the data stream.
- label_pairs (table) – Table containing label names as keys, label values as values (table). A new value is observed by all internal counters with these labels specified.

summary_obj:collect()
Returns a concatenation of counter_obj:collect() across all internal counters of summary_obj. For observation description, see counter_obj:collect().

Labels

All collectors support providing label_pairs on data modification. Labels are basically a metainfo that you associate with a metric in the format of key-value pairs. See tags in Graphite and labels in Prometheus. Labels are used to differentiate the characteristics of a thing being measured. For example, in a metric associated with the total number of http requests, you can use methods and statuses label pairs:

```
http_requests_total_counter:inc(1, {method = 'POST', status = '200'})
```

You don't have to predefine labels in advance.

Using labels on your metrics allows you to later derive new time series (visualize their graphs) by specifying conditions on label values. In the example above, we could derive these time series:

1. The total number of requests over time with method = "POST" (and any status).
2. The total number of requests over time with status = 500 (and any method).

You can also set global labels by calling metrics.set_global_labels({ label = value, ...}).

Metrics functions

metrics.enable_default_metrics()
Enables Tarantool metrics collections. See metrics reference for details.

metrics.enable_cartridge_metrics()
Enables Cartridge metrics collections. See metrics reference for details.

metrics.set_global_labels(label_pairs)
Set global labels that will be added to every observation.

Parameters

- label_pairs (table) – Table containing label names as string keys, label values as values (table).

Global labels are applied only on metrics collection and have no effect on how observations are stored.

Global labels can be changed on the fly.

Observation label_pairs has priority over global labels: if you pass label_pairs to an observation method with the same key as some global label, the method argument value will be used.

metrics.register_callback(callback)
Registers a function callback which will be called right before metrics collection on plugin export.

Parameters

- callback (function) – Function which takes no parameters.

Most common usage is for gauge metrics updates.

Collecting HTTP requests latency statistics

metrics also provides a middleware for monitoring HTTP (set by the http module) latency statistics.

metrics.http_middleware.configure_default_collector(type_name, name, help)
Registers a collector for the middleware and sets it as default.

Parameters

- type_name (string) – Collector type: "histogram" or "summary". Default is "histogram".
- name (string) – Collector name. Default is "http_server_request_latency".
- help (string) – Help description. Default is "HTTP Server Request Latency".

If a collector with the same type and name already exists in the registry, throws an error.

metrics.http_middleware.build_default_collector(type_name, name[, help])
Registers a collector for the middleware and returns it.

Parameters

- type_name (string) – Collector type: "histogram" or "summary". Default is "histogram".
- name (string) – Collector name. Default is "http_server_request_latency".
- help (string) – Help description. Default is "HTTP Server Request Latency".

If a collector with the same type and name already exists in the registry, throws an error.

metrics.http_middleware.set_default_collector(collector)
Sets the default collector.

Parameters

- collector – Middleware collector object.

metrics.http_middleware.get_default_collector()
Returns the default collector. If the default collector hasn't been set yet, registers it (with default http_middleware.build_default_collector(...) parameters) and sets it as default.

metrics.http_middleware.v1(handler, collector)
Latency measure wrap-up for HTTP ver. 1.x.x handler. Returns a wrapped handler.

Parameters

- handler (function) – Handler function.
- collector – Middleware collector object. If not set, uses the default collector (like in http_middleware.get_default_collector()).

Usage: httpd:route(route, http_middleware.v1(request_handler, collector))

For a more detailed example, see https://github.com/tarantool/metrics/blob/master/example/HTTP/latency_v1.lua

metrics.http_middleware.v2(collector)
Returns the latency measure middleware for HTTP ver. 2.x.x.

Parameters

- collector – Middleware collector object. If not set, uses the default collector (like in http_middleware.get_default_collector()).

Usage:

```
router = require('http.router').new()
router:route(route, request_handler)
router:use(http_middleware.v2(collector), {name = 'http_instrumentation'}) -- the second argument is
↪optional, see HTTP docs
```

For a more detailed example, see https://github.com/tarantool/metrics/blob/master/example/HTTP/latency_v2.lua

CPU usage metrics

CPU metrics work only on Linux. See metrics reference for details. To enable it you should register callback:

```
local metrics = require('metrics')

metrics.register_callback(function()
    local cpu_metrics = require('metrics.psutils.cpu')
    cpu_metrics.update()
end)
```

Collected metrics example

```
# HELP tnt_cpu_total Host CPU time
# TYPE tnt_cpu_total gauge
tnt_cpu_total 15006759
# HELP tnt_cpu_thread Tarantool thread cpu time
# TYPE tnt_cpu_thread gauge
tnt_cpu_thread{thread_name="coio",file_name="init.lua",thread_pid="699",kind="system"} 160
tnt_cpu_thread{thread_name="tarantool",file_name="init.lua",thread_pid="1",kind="user"} 949
tnt_cpu_thread{thread_name="tarantool",file_name="init.lua",thread_pid="1",kind="system"} 920
tnt_cpu_thread{thread_name="coio",file_name="init.lua",thread_pid="11",kind="user"} 79
tnt_cpu_thread{thread_name="coio",file_name="init.lua",thread_pid="699",kind="user"} 44
tnt_cpu_thread{thread_name="coio",file_name="init.lua",thread_pid="11",kind="system"} 294
```

Prometheus query aggregated by thread name

```
sum by (thread_name) (idelta(tnt_cpu_thread[$__interval]))
  / scalar(idelta(tnt_cpu_total[$__interval]) / tnt_cpu_count)
```

Examples

Below are examples of using metrics primitives.

Notice that this usage is independent of export-plugins such as Prometheus / Graphite / etc. For documentation on plugins usage, see their the Metrics plugins section.

Using counters:

```
local metrics = require('metrics')

-- create a counter
local http_requests_total_counter = metrics.counter('http_requests_total')

-- somewhere in the HTTP requests middleware:
http_requests_total_counter:inc(1, {method = 'GET'})
```

Using gauges:

```
local metrics = require('metrics')

-- create a gauge
local cpu_usage_gauge = metrics.gauge('cpu_usage', 'CPU usage')

-- register a lazy gauge value update
-- this will be called whenever the export is invoked in any plugins
metrics.register_callback(function()
    local current_cpu_usage = math.random()
    cpu_usage_gauge:set(current_cpu_usage, {app = 'tarantool'})
end)
```

Using histograms:

```
local metrics = require('metrics')

-- create a histogram
local http_requests_latency_hist = metrics.histogram(
    'http_requests_latency', 'HTTP requests total', {2, 4, 6})

-- somewhere in the HTTP requests middleware:
local latency = math.random(1, 10)
http_requests_latency_hist:observe(latency)
```

Using summaries:

```
local metrics = require('metrics')

-- create a summary
local http_requests_latency = metrics.summary(
    'http_requests_latency', 'HTTP requests total',
    {[0.5]=0.01, [0.9]=0.01, [0.99]=0.01}
)

-- somewhere in the HTTP requests middleware:
local latency = math.random(1, 10)
http_requests_latency:observe(latency)
```

Metrics plugins

Plugins allow using a unified interface to collect metrics without worrying about the way metrics export is performed. If you want to use another DB to store metrics data, you can use an appropriate export plugin just by changing one line of code.

Available plugins

Prometheus

Usage

Import the Prometheus plugin:

```
local prometheus = require('metrics.plugins.prometheus')
```

Further, use the prometheus.collect_http() function, which returns:

```
{
    status = 200,
    headers = <headers>,
    body = <body>,
}
```

See the Prometheus exposition format for details on <body> and <headers>.

Use in Tarantool http.server as follows:

- In Tarantool http.server v1 (currently used in Tarantool Cartridge):

```
local httpd = require('http.server').new(...)
...
httpd:route( { path = '/metrics' }, prometheus.collect_http)
```

- In Tarantool http.server v2 (the latest version):

```
local httpd = require('http.server').new(...)
local router = require('http.router').new(...)
httpd:set_router(router)
...
router:route( { path = '/metrics' }, prometheus.collect_http)
```

Sample settings

- For Tarantool http.server v1:

```
metrics = require('metrics')
metrics.enable_default_metrics()
prometheus = require('metrics.plugins.prometheus')
httpd = require('http.server').new('0.0.0.0', 8080)
httpd:route( { path = '/metrics' }, prometheus.collect_http)
httpd:start()
```

- For Tarantool Cartridge (with http.server v1):

```
cartridge = require('cartridge')
httpd = cartridge.service_get('httpd')
metrics = require('metrics')
metrics.enable_default_metrics()
prometheus = require('metrics.plugins.prometheus')
httpd:route( { path = '/metrics' }, prometheus.collect_http)
```

- For Tarantool http.server v2:

```
metrics = require('metrics')
metrics.enable_default_metrics()
prometheus = require('metrics.plugins.prometheus')
httpd = require('http.server').new('0.0.0.0', 8080)
router = require('http.router').new({charset = "utf8"})
httpd:set_router(router) router:route( { path = '/metrics' },
prometheus.collect_http)
httpd:start()
```

Graphite

Usage

Import the Graphite plugin:

```
local graphite = require('metrics.plugins.graphite')
```

To start automatically exporting the current values of all metrics.{counter,gauge,histogram}, just call:

metrics.plugins.graphite.init(options)

Parameters

- options (table) – Possible options:
  - prefix (string) - metrics prefix (default is 'tarantool');
  - host (string) - graphite server host (default is '127.0.0.1');
  - port (number) - graphite server port (default is 2003);
  - send_interval (number) - metrics collect interval in seconds (default is 2);

This creates a background fiber that periodically sends all metrics to a remote Graphite server.

Exported metric name is sent in the format <prefix>.<metric_name>.

JSON

Usage

Import the JSON plugin:

```
local json_metrics = require('metrics.plugins.json')
```

metrics.plugins.json.export()

Return the following structure

```
[
    {
        "name": "<name>",
        "label_pairs": {
            "<name>": "<value>",
            "...": "..."
        },
        "timestamp": "<number>",
        "value": "<value>"
```

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```
    },
    "..."
]
```

Rtype string

Important: Values can be +-math.huge, math.huge * 0. Then:

- math.inf is serialized to "inf"
- -math.inf is serialized to "-inf"
- nan is serialized to "nan"

Example

```
[
    {
        "label_pairs": {
            "type": "nan"
        },
        "timestamp": 1559211080514607,
        "metric_name": "test_nan",
        "value": "nan"
    },
    {
        "label_pairs": {
            "type": "-inf"
        },
        "timestamp": 1559211080514607,
        "metric_name": "test_inf",
        "value": "-inf"
    },
    {
        "label_pairs": {
            "type": "inf"
        },
        "timestamp": 1559211080514607,
        "metric_name": "test_inf",
        "value": "inf"
    }
]
```

To be used in Tarantool http.server as follows:

```
local httpd = require('http.server').new(...)
...
httpd:route({
        method = 'GET',
        path = '/metrics',
        public = true,
    },
    function(req)
        return req:render({
            text = json_exporter.export()
        })
```

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```
    end
)
```

Plugin-specific API

We encourage you to use the following methods only when developing a new plugin.

metrics.invoke_callbacks()
Invokes the function registered via metrics.register_callback(<callback>). Used in exporters.

metrics.collectors()
Designed to be used in exporters in favor of metrics.collect().

Return a list of created collectors

object collector_object

collector_object:collect()

Note: You'll probably want to use metrics.collectors() instead.

Equivalent to:

```
for _, c in pairs(metrics.collectors()) do
    for _, obs in ipairs(c:collect()) do
        ...  -- handle observation
    end
end
```

Return

Concatenation of observation objects across all created collectors.

```
{
    label_pairs: table,          -- `label_pairs` key-value table
    timestamp: ctype<uint64_t>, -- current system time (in microseconds)
    value: number,               -- current value
    metric_name: string,         -- collector
}
```

Rtype table

Writing custom plugins

Inside your main export function:

```
-- Invoke all callbacks registered via `metrics.register_callback(<callback-function>)`.
metrics.invoke_callbacks()

-- Loop over collectors
for _, c in pairs(metrics.collectors()) do
```

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```
    ...

    -- Loop over instant observations in the collector.
    for _, obs in pairs(c:collect()) do
        -- Export observation `obs`
        ...
    end

end
```

4.6 Replication

Replication allows multiple Tarantool instances to work on copies of the same databases. The databases are kept in sync because each instance can communicate its changes to all the other instances.

This chapter includes the following sections:

4.6.1 Replication architecture

Replication mechanism

A pack of instances which operate on copies of the same databases make up a replica set. Each instance in a replica set has a role, master or replica.

A replica gets all updates from the master by continuously fetching and applying its write ahead log (WAL). Each record in the WAL represents a single Tarantool data-change request such as INSERT, UPDATE or DELETE, and is assigned a monotonically growing log sequence number (LSN). In essence, Tarantool replication is row-based: each data-change request is fully deterministic and operates on a single tuple. However, unlike a classical row-based log, which contains entire copies of the changed rows, Tarantool's WAL contains copies of the requests. For example, for UPDATE requests, Tarantool only stores the primary key of the row and the update operations, to save space.

Invocations of stored programs are not written to the WAL. Instead, records of the actual data-change requests, performed by the Lua code, are written to the WAL. This ensures that possible non-determinism of Lua does not cause replication to go out of sync.

Data definition operations on temporary spaces, such as creating/dropping, adding indexes, truncating, etc., are written to the WAL, since information about temporary spaces is stored in non-temporary system spaces, such as box.space._space. Data change operations on temporary spaces are not written to the WAL and are not replicated.

Data change operations on replication-local spaces (spaces created with is_local = true) are written to the WAL but are not replicated.

To create a valid initial state, to which WAL changes can be applied, every instance of a replica set requires a start set of checkpoint files, such as .snap files for memtx and .run files for vinyl. A replica joining an existing replica set, chooses an existing master and automatically downloads the initial state from it. This is called an initial join.

When an entire replica set is bootstrapped for the first time, there is no master which could provide the initial checkpoint. In such a case, replicas connect to each other and elect a master, which then creates the starting set of checkpoint files, and distributes it to all the other replicas. This is called an automatic bootstrap of a replica set.

When a replica contacts a master (there can be many masters) for the first time, it becomes part of a replica set. On subsequent occasions, it should always contact a master in the same replica set. Once connected to the master, the replica requests all changes that happened after the latest local LSN (there can be many LSNs – each master has its own LSN).

Each replica set is identified by a globally unique identifier, called the replica set UUID. The identifier is created by the master which creates the very first checkpoint, and is part of the checkpoint file. It is stored in system space box.space._schema. For example:

```
tarantool> box.space._schema:select{'cluster'}
---
- - ['cluster', '6308acb9-9788-42fa-8101-2e0cb9d3c9a0']
...
```

Additionally, each instance in a replica set is assigned its own UUID, when it joins the replica set. It is called an instance UUID and is a globally unique identifier. The instance UUID is checked to ensure that instances do not join a different replica set, e.g. because of a configuration error. A unique instance identifier is also necessary to apply rows originating from different masters only once, that is, to implement multi-master replication. This is why each row in the write ahead log, in addition to its log sequence number, stores the instance identifier of the instance on which it was created. But using a UUID as such an identifier would take too much space in the write ahead log, thus a shorter integer number is assigned to the instance when it joins a replica set. This number is then used to refer to the instance in the write ahead log. It is called instance id. All identifiers are stored in system space box.space._cluster. For example:

```
tarantool> box.space._cluster:select{}
---
- - [1, '88580b5c-4474-43ab-bd2b-2409a9af80d2']
...
```

Here the instance ID is 1 (unique within the replica set), and the instance UUID is 88580b5c-4474-43ab-bd2b-2409a9af80d2 (globally unique).

Using instance IDs is also handy for tracking the state of the entire replica set. For example, box.info.vclock describes the state of replication in regard to each connected peer.

```
tarantool> box.info.vclock
---
- {1: 827, 2: 584}
...
```

Here vclock contains log sequence numbers (827 and 584) for instances with instance IDs 1 and 2.

Starting in Tarantool 1.7.7, it is possible for administrators to assign the instance UUID and the replica set UUID values, rather than let the system generate them – see the description of the replicaset_uuid configuration parameter.

Replication setup

To enable replication, you need to specify two parameters in a box.cfg{} request:

- replication which defines the replication source(s), and
- read_only which is true for a replica and false for a master.

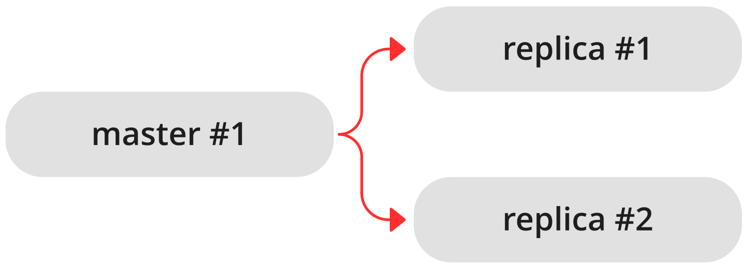
Both these parameters are "dynamic". This allows a replica to become a master and vice versa on the fly with the help of a box.cfg{} request.

Later we will give a detailed example of bootstrapping a replica set.

Replication roles: master and replica

The replication role (master or replica) is set by the read_only configuration parameter. The recommended role is “read_only” (replica) for all but one instance in the replica set.

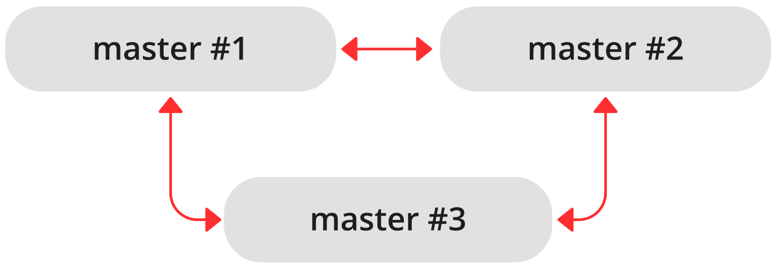
In a master-replica configuration, every change that happens on the master will be visible on the replicas, but not vice versa.



A simple two-instance replica set with the master on one machine and the replica on a different machine provides two benefits:

- failover, because if the master goes down then the replica can take over, and
- load balancing, because clients can connect to either the master or the replica for read requests.

In a master-master configuration (also called “multi-master”), every change that happens on either instance will be visible on the other one.



The failover benefit in this case is still present, and the load-balancing benefit is enhanced, because any instance can handle both read and write requests. Meanwhile, for multi-master configurations, it is necessary to understand the replication guarantees provided by the asynchronous protocol that Tarantool implements.

Tarantool multi-master replication guarantees that each change on each master is propagated to all instances and is applied only once. Changes from the same instance are applied in the same order as on the originating instance. Changes from different instances, however, can be mixed and applied in a different order on different instances. This may lead to replication going out of sync in certain cases.

For example, assuming the database is only appended to (i.e. it contains only insertions), a multi-master configuration is safe. If there are also deletions, but it is not mission critical that deletion happens in the same order on all replicas (e.g. the DELETE is used to prune expired data), a master-master configuration is also safe.

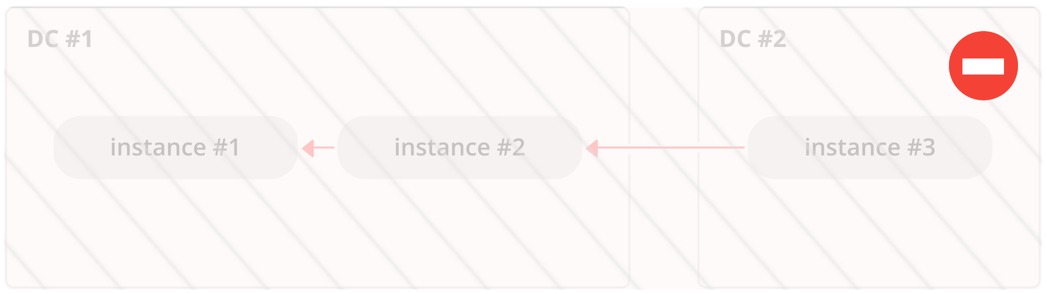
UPDATE operations, however, can easily go out of sync. For example, assignment and increment are not commutative, and may yield different results if applied in different order on different instances.

More generally, it is only safe to use Tarantool master-master replication if all database changes are commutative: the end result does not depend on the order in which the changes are applied. You can start learning more about conflict-free replicated data types here.

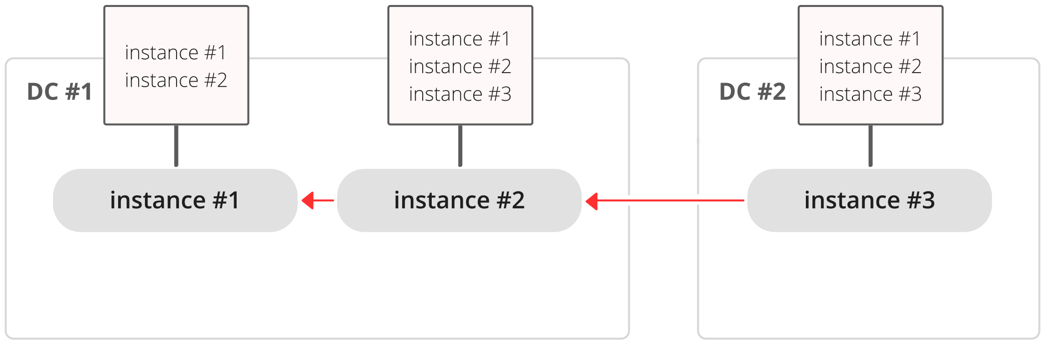
Replication topologies: cascade, ring and full mesh

Replication topology is set by the replication configuration parameter. The recommended topology is a full mesh, because it makes potential failover easy.

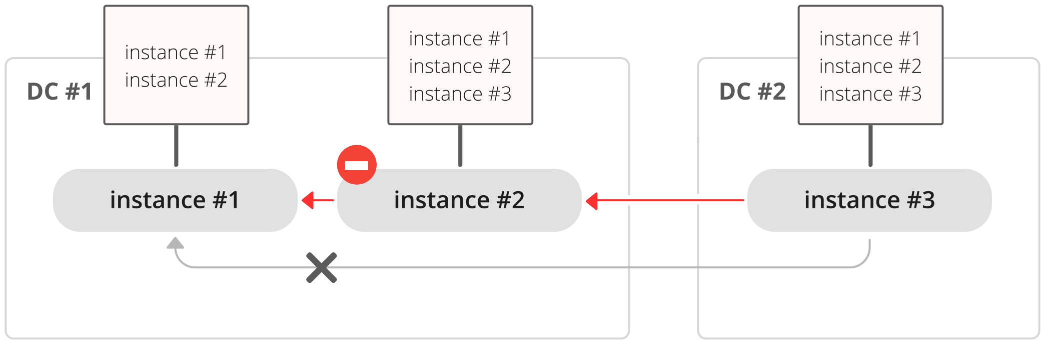
Some database products offer cascading replication topologies: creating a replica on a replica. Tarantool does not recommend such setup.



The problem with a cascading replica set is that some instances have no connection to other instances and may not receive changes from them. One essential change that must be propagated across all instances in a replica set is an entry in box.space._cluster system space with the replica set UUID. Without knowing the replica set UUID, a master refuses to accept connections from such instances when replication topology changes. Here is how this can happen:

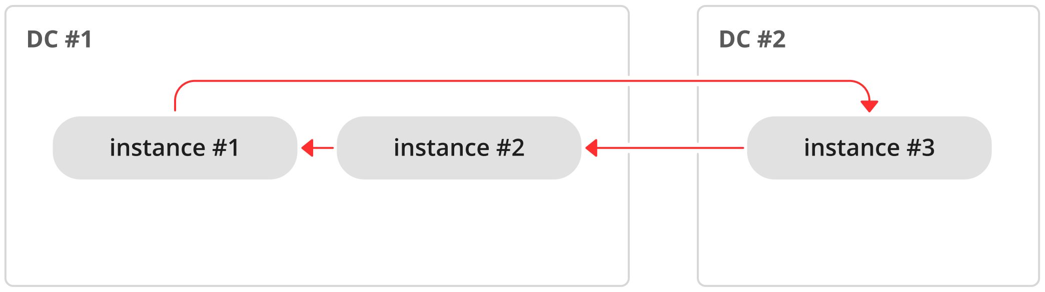


We have a chain of three instances. Instance #1 contains entries for instances #1 and #2 in its _cluster space. Instances #2 and #3 contain entries for instances #1, #2 and #3 in their _cluster spaces.



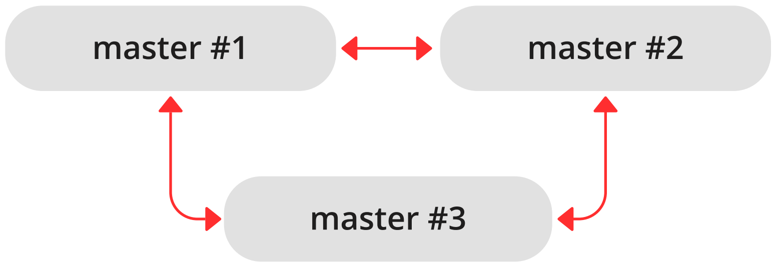
Now instance #2 is faulty. Instance #3 tries connecting to instance #1 as its new master, but the master refuses the connection since it has no entry for instance #3.

Ring replication topology is, however, supported:



So, if you need a cascading topology, you may first create a ring to ensure all instances know each other's UUID, and then disconnect the chain in the place you desire.

A stock recommendation for a master-master replication topology, however, is a full mesh:



You then can decide where to locate instances of the mesh – within the same data center, or spread across a few data centers. Tarantool will automatically ensure that each row is applied only once on each instance. To remove a degraded instance from a mesh, simply change the replication configuration parameter.

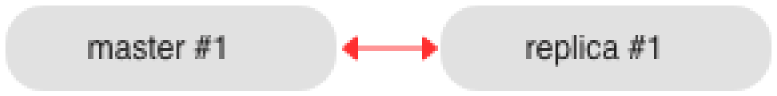
This ensures full cluster availability in case of a local failure, e.g. one of the instances failing in one of the data centers, as well as in case of an entire data center failure.

The maximal number of replicas in a mesh is 32.

4.6.2 Bootstrapping a replica set

Master-replica bootstrap

Let us first bootstrap a simple master-replica set containing two instances, each located on its own machine. For easier administration, we make the instance files almost identical.



Here is an example of the master's instance file:

```
-- instance file for the master
box.cfg{
  listen = 3301,
  replication = {'replicator:password@192.168.0.101:3301',  -- master URI
                 'replicator:password@192.168.0.102:3301'}, -- replica URI
  read_only = false
}
box.once("schema", function()
   box.schema.user.create('replicator', {password = 'password'})
   box.schema.user.grant('replicator', 'replication') -- grant replication role
   box.schema.space.create("test")
   box.space.test:create_index("primary")
   print('box.once executed on master')
end)
```

where:

- the box.cfg() listen parameter defines a URI (port 3301 in our example), on which the master can accept connections from replicas.
- the box.cfg() replication parameter defines the URIs at which all instances in the replica set can accept connections. It includes the replica's URI as well, although the replica is not a replication source right now. This parameter is mandatory only for master-master or full-mesh cluster setups.

  Note: For security reasons, we recommend that administrators prevent unauthorized replication sources by associating a password with every user that has a replication role. That way, the URI for replication parameter must have the long form username:password@host:port.

- the read_only = false parameter setting enables data-change operations on the instance and makes the instance act as a master, not as a replica. That is the only parameter setting in our instance files that will differ.
- the box.once() function contains database initialization logic that should be executed only once during the replica set lifetime.

In this example, we create a space with a primary index, and a user for replication purposes. We also say print('box.once executed on master') so that it will later be visible on a console whether box.once() was executed.

Note: Replication requires privileges. We can grant privileges for accessing spaces directly to the user who will start the instance. However, it is more usual to grant privileges for accessing spaces to a role, and then grant the role to the user who will start the replica.

Here we use Tarantool's predefined role named "replication" which by default grants "read" privileges for all database objects ("universe"), and we can change privileges for this role as required.

In the replica's instance file, we set the read_only parameter to "true", and say print('box.once executed on replica') so that later it will be visible that box.once() was not executed more than once. Otherwise the replica's instance file is identical to the master's instance file.

```lua
-- instance file for the replica
box.cfg{
  listen = 3301,
  replication = {'replicator:password@192.168.0.101:3301',  -- master URI
                 'replicator:password@192.168.0.102:3301'}, -- replica URI
  read_only = true
}
box.once("schema", function()
   box.schema.user.create('replicator', {password = 'password'})
   box.schema.user.grant('replicator', 'replication') -- grant replication role
   box.schema.space.create("test")
   box.space.test:create_index("primary")
   print('box.once executed on replica')
end)
```

Note: The replica does not inherit the master's configuration parameters, such as those making the checkpoint daemon run on the master. To get the same behavior, set the relevant parameters explicitly so that they are the same on both master and replica.

Now we can launch the two instances. The master…

```
$ # launching the master
$ tarantool master.lua
2017-06-14 14:12:03.847 [18933] main/101/master.lua C> version 1.7.4-52-g980d30092
2017-06-14 14:12:03.848 [18933] main/101/master.lua C> log level 5
2017-06-14 14:12:03.849 [18933] main/101/master.lua I> mapping 268435456 bytes for tuple arena...
2017-06-14 14:12:03.859 [18933] iproto/101/main I> binary: bound to [::]:3301
2017-06-14 14:12:03.861 [18933] main/105/applier/replicator@192.168.0. I> can't connect to master
2017-06-14 14:12:03.861 [18933] main/105/applier/replicator@192.168.0. coio.cc:105 !> SystemError connect,␣
↪called on fd 14, aka 192.168.0.102:56736: Connection refused
2017-06-14 14:12:03.861 [18933] main/105/applier/replicator@192.168.0. I> will retry every 1 second
2017-06-14 14:12:03.861 [18933] main/104/applier/replicator@192.168.0. I> remote master is 1.7.4 at 192.168.0.
↪101:3301
2017-06-14 14:12:19.878 [18933] main/105/applier/replicator@192.168.0. I> remote master is 1.7.4 at 192.168.0.
↪102:3301
2017-06-14 14:12:19.879 [18933] main/101/master.lua I> initializing an empty data directory
2017-06-14 14:12:19.908 [18933] snapshot/101/main I> saving snapshot `/var/lib/tarantool/master/
↪00000000000000000000.snap.inprogress'
2017-06-14 14:12:19.914 [18933] snapshot/101/main I> done
2017-06-14 14:12:19.914 [18933] main/101/master.lua I> vinyl checkpoint done
2017-06-14 14:12:19.917 [18933] main/101/master.lua I> ready to accept requests
2017-06-14 14:12:19.918 [18933] main/105/applier/replicator@192.168.0. I> failed to authenticate
2017-06-14 14:12:19.918 [18933] main/105/applier/replicator@192.168.0. xrow.cc:431 E> ER_LOADING: Instance␣
↪bootstrap hasn't finished yet
box.once executed on master
2017-06-14 14:12:19.920 [18933] main C> entering the event loop
```

… (the display confirms that box.once() was executed on the master) – and the replica:

```
$ # launching the replica
$ tarantool replica.lua
2017-06-14 14:12:19.486 [18934] main/101/replica.lua C> version 1.7.4-52-g980d30092
2017-06-14 14:12:19.486 [18934] main/101/replica.lua C> log level 5
2017-06-14 14:12:19.487 [18934] main/101/replica.lua I> mapping 268435456 bytes for tuple arena...
2017-06-14 14:12:19.494 [18934] iproto/101/main I> binary: bound to [::]:3311
2017-06-14 14:12:19.495 [18934] main/104/applier/replicator@192.168.0. I> remote master is 1.7.4 at 192.168.0.
↪101:3301
2017-06-14 14:12:19.495 [18934] main/105/applier/replicator@192.168.0. I> remote master is 1.7.4 at 192.168.0.
↪102:3302
2017-06-14 14:12:19.496 [18934] main/104/applier/replicator@192.168.0. I> failed to authenticate
2017-06-14 14:12:19.496 [18934] main/104/applier/replicator@192.168.0. xrow.cc:431 E> ER_LOADING: Instance␣
↪bootstrap hasn't finished yet
```

In both logs, there are messages saying that the replica was bootstrapped from the master:

```
$ # bootstrapping the replica (from the master's log)
<...>
2017-06-14 14:12:20.503 [18933] main/106/main I> initial data sent.
2017-06-14 14:12:20.505 [18933] relay/[::ffff:192.168.0.101]:/101/main I> recover from `/var/lib/tarantool/master/
↪00000000000000000000.xlog'
2017-06-14 14:12:20.505 [18933] main/106/main I> final data sent.
2017-06-14 14:12:20.522 [18933] relay/[::ffff:192.168.0.101]:/101/main I> recover from `/Users/e.shebunyaeva/
↪work/tarantool-test-repl/master_dir/00000000000000000000.xlog'
2017-06-14 14:12:20.922 [18933] main/105/applier/replicator@192.168.0. I> authenticated
```

```
$ # bootstrapping the replica (from the replica's log)
<...>
```

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```
2017-06-14 14:12:20.498 [18934] main/104/applier/replicator@192.168.0. I> authenticated
2017-06-14 14:12:20.498 [18934] main/101/replica.lua I> bootstrapping replica from 192.168.0.101:3301
2017-06-14 14:12:20.512 [18934] main/104/applier/replicator@192.168.0. I> initial data received
2017-06-14 14:12:20.512 [18934] main/104/applier/replicator@192.168.0. I> final data received
2017-06-14 14:12:20.517 [18934] snapshot/101/main I> saving snapshot `/var/lib/tarantool/replica/
↪00000000000000000005.snap.inprogress'
2017-06-14 14:12:20.518 [18934] snapshot/101/main I> done
2017-06-14 14:12:20.519 [18934] main/101/replica.lua I> vinyl checkpoint done
2017-06-14 14:12:20.520 [18934] main/101/replica.lua I> ready to accept requests
2017-06-14 14:12:20.520 [18934] main/101/replica.lua I> set 'read_only' configuration option to true
2017-06-14 14:12:20.520 [18934] main C> entering the event loop
```

Notice that box.once() was executed only at the master, although we added box.once() to both instance files.

We could as well launch the replica first:

```
$ # launching the replica
$ tarantool replica.lua
2017-06-14 14:35:36.763 [18952] main/101/replica.lua C> version 1.7.4-52-g980d30092
2017-06-14 14:35:36.765 [18952] main/101/replica.lua C> log level 5
2017-06-14 14:35:36.765 [18952] main/101/replica.lua I> mapping 268435456 bytes for tuple arena...
2017-06-14 14:35:36.772 [18952] iproto/101/main I> binary: bound to [::]:3301
2017-06-14 14:35:36.772 [18952] main/104/applier/replicator@192.168.0. I> can't connect to master
2017-06-14 14:35:36.772 [18952] main/104/applier/replicator@192.168.0. coio.cc:105 !> SystemError connect,␣
↪called on fd 13, aka 192.168.0.101:56820: Connection refused
2017-06-14 14:35:36.772 [18952] main/104/applier/replicator@192.168.0. I> will retry every 1 second
2017-06-14 14:35:36.772 [18952] main/105/applier/replicator@192.168.0. I> remote master is 1.7.4 at 192.168.0.
↪102:3301
```

. . . and the master later:

```
$ # launching the master
$ tarantool master.lua
2017-06-14 14:35:43.701 [18953] main/101/master.lua C> version 1.7.4-52-g980d30092
2017-06-14 14:35:43.702 [18953] main/101/master.lua C> log level 5
2017-06-14 14:35:43.702 [18953] main/101/master.lua I> mapping 268435456 bytes for tuple arena...
2017-06-14 14:35:43.709 [18953] iproto/101/main I> binary: bound to [::]:3301
2017-06-14 14:35:43.709 [18953] main/105/applier/replicator@192.168.0. I> remote master is 1.7.4 at 192.168.0.
↪102:3301
2017-06-14 14:35:43.709 [18953] main/104/applier/replicator@192.168.0. I> remote master is 1.7.4 at 192.168.0.
↪101:3301
2017-06-14 14:35:43.709 [18953] main/101/master.lua I> initializing an empty data directory
2017-06-14 14:35:43.721 [18953] snapshot/101/main I> saving snapshot `/var/lib/tarantool/master/
↪00000000000000000000.snap.inprogress'
2017-06-14 14:35:43.722 [18953] snapshot/101/main I> done
2017-06-14 14:35:43.723 [18953] main/101/master.lua I> vinyl checkpoint done
2017-06-14 14:35:43.723 [18953] main/101/master.lua I> ready to accept requests
2017-06-14 14:35:43.724 [18953] main/105/applier/replicator@192.168.0. I> failed to authenticate
2017-06-14 14:35:43.724 [18953] main/105/applier/replicator@192.168.0. xrow.cc:431 E> ER_LOADING: Instance␣
↪bootstrap hasn't finished yet
box.once executed on master
2017-06-14 14:35:43.726 [18953] main C> entering the event loop
2017-06-14 14:35:43.779 [18953] main/103/main I> initial data sent.
2017-06-14 14:35:43.780 [18953] relay/[::ffff:192.168.0.101]:/101/main I> recover from `/var/lib/tarantool/master/
↪00000000000000000000.xlog'
2017-06-14 14:35:43.780 [18953] main/103/main I> final data sent.
2017-06-14 14:35:43.796 [18953] relay/[::ffff:192.168.0.102]:/101/main I> recover from `/var/lib/tarantool/master/
↪00000000000000000000.xlog'
```

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```
2017-06-14 14:35:44.726 [18953] main/105/applier/replicator@192.168.0. I> authenticated
```

In this case, the replica would wait for the master to become available, so the launch order doesn't matter. Our box.once() logic would also be executed only once, at the master.

```
$ # the replica has eventually connected to the master
$ # and got bootstrapped (from the replica's log)
2017-06-14 14:35:43.777 [18952] main/104/applier/replicator@192.168.0. I> remote master is 1.7.4 at 192.168.0.
↪101:3301
2017-06-14 14:35:43.777 [18952] main/104/applier/replicator@192.168.0. I> authenticated
2017-06-14 14:35:43.777 [18952] main/101/replica.lua I> bootstrapping replica from 192.168.0.199:3310
2017-06-14 14:35:43.788 [18952] main/104/applier/replicator@192.168.0. I> initial data received
2017-06-14 14:35:43.789 [18952] main/104/applier/replicator@192.168.0. I> final data received
2017-06-14 14:35:43.793 [18952] snapshot/101/main I> saving snapshot `/var/lib/tarantool/replica/
↪00000000000000000005.snap.inprogress'
2017-06-14 14:35:43.793 [18952] snapshot/101/main I> done
2017-06-14 14:35:43.795 [18952] main/101/replica.lua I> vinyl checkpoint done
2017-06-14 14:35:43.795 [18952] main/101/replica.lua I> ready to accept requests
2017-06-14 14:35:43.795 [18952] main/101/replica.lua I> set 'read_only' configuration option to true
2017-06-14 14:35:43.795 [18952] main C> entering the event loop
```

Controlled failover

To perform a controlled failover, that is, swap the roles of the master and replica, all we need to do is to set read_only=true at the master, and read_only=false at the replica. The order of actions is important here. If a system is running in production, we do not want concurrent writes happening both at the replica and the master. Nor do we want the new replica to accept any writes until it has finished fetching all replication data from the old master. To compare replica and master state, we can use box.info.signature.

1. Set read_only=true at the master.

   ```
   # at the master
   tarantool> box.cfg{read_only=true}
   ```

2. Record the master's current position with box.info.signature, containing the sum of all LSNs in the master's vector clock.

   ```
   # at the master
   tarantool> box.info.signature
   ```

3. Wait until the replica's signature is the same as the master's.

   ```
   # at the replica
   tarantool> box.info.signature
   ```

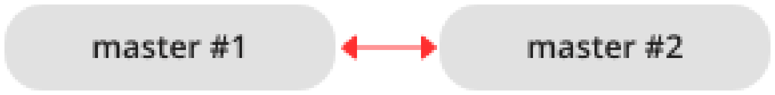
4. Set read_only=false at the replica to enable write operations.

   ```
   # at the replica
   tarantool> box.cfg{read_only=false}
   ```

These four steps ensure that the replica doesn't accept new writes until it's done fetching writes from the master.

Master-master bootstrap

Now let us bootstrap a two-instance master-master set. For easier administration, we make master#1 and master#2 instance files fully identical.



We re-use the master's instance file from the master-replica example above.

```
-- instance file for any of the two masters
box.cfg{
  listen      = 3301,
  replication = {'replicator:password@192.168.0.101:3301',  -- master1 URI
                 'replicator:password@192.168.0.102:3301'}, -- master2 URI
  read_only   = false
}
box.once("schema", function()
   box.schema.user.create('replicator', {password = 'password'})
   box.schema.user.grant('replicator', 'replication') -- grant replication role
   box.schema.space.create("test")
   box.space.test:create_index("primary")
   print('box.once executed on master #1')
end)
```

In the replication parameter, we define the URIs of both masters in the replica set and say print('box.once executed on master #1') so it will be clear when and where the box.once() logic is executed.

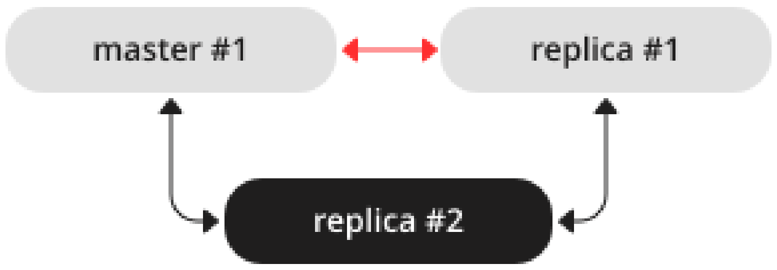
Now we can launch the two masters. Again, the launch order doesn't matter. The box.once() logic will also be executed only once, at the master which is elected as the replica set leader at bootstrap.

```
$ # launching master #1
$ tarantool master1.lua
2017-06-14 15:39:03.062 [47021] main/101/master1.lua C> version 1.7.4-52-g980d30092
2017-06-14 15:39:03.062 [47021] main/101/master1.lua C> log level 5
2017-06-14 15:39:03.063 [47021] main/101/master1.lua I> mapping 268435456 bytes for tuple arena...
2017-06-14 15:39:03.065 [47021] iproto/101/main I> binary: bound to [::]:3301
2017-06-14 15:39:03.065 [47021] main/105/applier/replicator@192.168.0.10 I> can't connect to master
2017-06-14 15:39:03.065 [47021] main/105/applier/replicator@192.168.0.10 coio.cc:107 !> SystemError connect,␣
↪called on fd 14, aka 192.168.0.102:57110: Connection refused
2017-06-14 15:39:03.065 [47021] main/105/applier/replicator@192.168.0.10 I> will retry every 1 second
2017-06-14 15:39:03.065 [47021] main/104/applier/replicator@192.168.0.10 I> remote master is 1.7.4 at 192.168.0.
↪101:3301
2017-06-14 15:39:08.070 [47021] main/105/applier/replicator@192.168.0.10 I> remote master is 1.7.4 at 192.168.0.
↪102:3301
2017-06-14 15:39:08.071 [47021] main/105/applier/replicator@192.168.0.10 I> authenticated
2017-06-14 15:39:08.071 [47021] main/101/master1.lua I> bootstrapping replica from 192.168.0.102:3301
2017-06-14 15:39:08.073 [47021] main/105/applier/replicator@192.168.0.10 I> initial data received
2017-06-14 15:39:08.074 [47021] main/105/applier/replicator@192.168.0.10 I> final data received
2017-06-14 15:39:08.074 [47021] snapshot/101/main I> saving snapshot `/Users/e.shebunyaeva/work/tarantool-
↪test-repl/master1_dir/00000000000000000008.snap.inprogress'
2017-06-14 15:39:08.074 [47021] snapshot/101/main I> done
2017-06-14 15:39:08.076 [47021] main/101/master1.lua I> vinyl checkpoint done
2017-06-14 15:39:08.076 [47021] main/101/master1.lua I> ready to accept requests
box.once executed on master #1
2017-06-14 15:39:08.077 [47021] main C> entering the event loop
```

```
$ # launching master #2
$ tarantool master2.lua
2017-06-14 15:39:07.452 [47022] main/101/master2.lua C> version 1.7.4-52-g980d30092
2017-06-14 15:39:07.453 [47022] main/101/master2.lua C> log level 5
2017-06-14 15:39:07.453 [47022] main/101/master2.lua I> mapping 268435456 bytes for tuple arena...
2017-06-14 15:39:07.455 [47022] iproto/101/main I> binary: bound to [::]:3301
2017-06-14 15:39:07.455 [47022] main/104/applier/replicator@192.168.0.19 I> remote master is 1.7.4 at 192.168.0.
↪101:3301
2017-06-14 15:39:07.455 [47022] main/105/applier/replicator@192.168.0.10 I> remote master is 1.7.4 at 192.168.0.
↪102:3301
2017-06-14 15:39:07.455 [47022] main/101/master2.lua I> initializing an empty data directory
2017-06-14 15:39:07.457 [47022] snapshot/101/main I> saving snapshot `/Users/e.shebunyaeva/work/tarantool-
↪test-repl/master2_dir/00000000000000000000.snap.inprogress'
2017-06-14 15:39:07.457 [47022] snapshot/101/main I> done
2017-06-14 15:39:07.458 [47022] main/101/master2.lua I> vinyl checkpoint done
2017-06-14 15:39:07.459 [47022] main/101/master2.lua I> ready to accept requests
2017-06-14 15:39:07.460 [47022] main C> entering the event loop
2017-06-14 15:39:08.072 [47022] main/103/main I> initial data sent.
2017-06-14 15:39:08.073 [47022] relay/[::ffff:192.168.0.102]:/101/main I> recover from `/Users/e.shebunyaeva/
↪work/tarantool-test-repl/master2_dir/00000000000000000000.xlog'
2017-06-14 15:39:08.073 [47022] main/103/main I> final data sent.
2017-06-14 15:39:08.077 [47022] relay/[::ffff:192.168.0.102]:/101/main I> recover from `/Users/e.shebunyaeva/
↪work/tarantool-test-repl/master2_dir/00000000000000000000.xlog'
2017-06-14 15:39:08.461 [47022] main/104/applier/replicator@192.168.0.10 I> authenticated
```

4.6.3 Adding instances

Adding a replica



To add a second replica instance to the master-replica set from our bootstrapping example, we need an analog of the instance file that we created for the first replica in that set:

```
-- instance file for replica #2
box.cfg{
  listen = 3301,
  replication = {'replicator:password@192.168.0.101:3301',  -- master URI
                 'replicator:password@192.168.0.102:3301',  -- replica #1 URI
                 'replicator:password@192.168.0.103:3301'}, -- replica #2 URI
  read_only = true
}
box.once("schema", function()
   box.schema.user.create('replicator', {password = 'password'})
   box.schema.user.grant('replicator', 'replication') -- grant replication role
   box.schema.space.create("test")
   box.space.test:create_index("primary")
```

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```
  print('box.once executed on replica #2')
end)
```

Here we add the URI of replica #2 to the replication parameter, so now it contains three URIs.

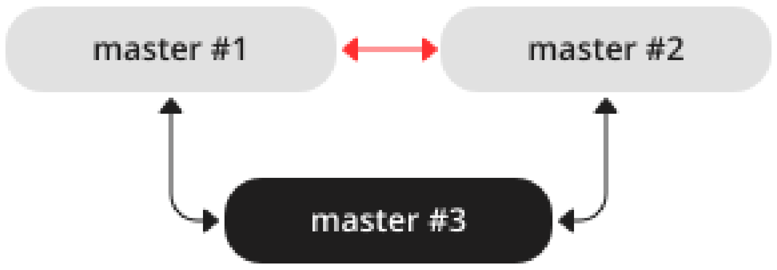
After we launch the new replica instance, it gets connected to the master instance and retrieves the master's write-ahead-log and snapshot files:

```
$ # launching replica #2
$ tarantool replica2.lua
2017-06-14 14:54:33.927 [46945] main/101/replica2.lua C> version 1.7.4-52-g980d30092
2017-06-14 14:54:33.927 [46945] main/101/replica2.lua C> log level 5
2017-06-14 14:54:33.928 [46945] main/101/replica2.lua I> mapping 268435456 bytes for tuple arena...
2017-06-14 14:54:33.930 [46945] main/104/applier/replicator@192.168.0.10 I> remote master is 1.7.4 at 192.168.0.
↪101:3301
2017-06-14 14:54:33.930 [46945] main/104/applier/replicator@192.168.0.10 I> authenticated
2017-06-14 14:54:33.930 [46945] main/101/replica2.lua I> bootstrapping replica from 192.168.0.101:3301
2017-06-14 14:54:33.933 [46945] main/104/applier/replicator@192.168.0.10 I> initial data received
2017-06-14 14:54:33.933 [46945] main/104/applier/replicator@192.168.0.10 I> final data received
2017-06-14 14:54:33.934 [46945] snapshot/101/main I> saving snapshot `/var/lib/tarantool/replica2/
↪00000000000000000010.snap.inprogress'
2017-06-14 14:54:33.934 [46945] snapshot/101/main I> done
2017-06-14 14:54:33.935 [46945] main/101/replica2.lua I> vinyl checkpoint done
2017-06-14 14:54:33.935 [46945] main/101/replica2.lua I> ready to accept requests
2017-06-14 14:54:33.935 [46945] main/101/replica2.lua I> set 'read_only' configuration option to true
2017-06-14 14:54:33.936 [46945] main C> entering the event loop
```

Since we are adding a read-only instance, there is no need to dynamically update the replication parameter on the other running instances. This update would be required if we added a master instance.

However, we recommend specifying the URI of replica #3 in all instance files of the replica set. This will keep all the files consistent with each other and with the current replication topology, and so will help to avoid configuration errors in case of further configuration updates and replica set restart.

Adding a master



To add a third master instance to the master-master set from our bootstrapping example, we need an analog of the instance files that we created to bootstrap the other master instances in that set:

```
-- instance file for master #3
box.cfg{
  listen      = 3301,
  replication = {'replicator:password@192.168.0.101:3301',  -- master#1 URI
                 'replicator:password@192.168.0.102:3301',  -- master#2 URI
                 'replicator:password@192.168.0.103:3301'}, -- master#3 URI
  read_only   = true, -- temporarily read-only
```

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```
}
box.once("schema", function()
  box.schema.user.create('replicator', {password = 'password'})
  box.schema.user.grant('replicator', 'replication') -- grant replication role
  box.schema.space.create("test")
  box.space.test:create_index("primary")
end)
```

Here we make the following changes:

- Add the URI of master #3 to the replication parameter.
- Temporarily specify read_only=true to disable data-change operations on the instance. After launch, master #3 will act as a replica until it retrieves all data from the other masters in the replica set.

After we launch master #3, it gets connected to the other master instances and retrieves their write-ahead-log and snapshot files:

```
$ # launching master #3
$ tarantool master3.lua
2017-06-14 17:10:00.556 [47121] main/101/master3.lua C> version 1.7.4-52-g980d30092
2017-06-14 17:10:00.557 [47121] main/101/master3.lua C> log level 5
2017-06-14 17:10:00.557 [47121] main/101/master3.lua I> mapping 268435456 bytes for tuple arena...
2017-06-14 17:10:00.559 [47121] iproto/101/main I> binary: bound to [::]:3301
2017-06-14 17:10:00.559 [47121] main/104/applier/replicator@192.168.0.10 I> remote master is 1.7.4 at 192.168.0.
↪101:3301
2017-06-14 17:10:00.559 [47121] main/105/applier/replicator@192.168.0.10 I> remote master is 1.7.4 at 192.168.0.
↪102:3301
2017-06-14 17:10:00.559 [47121] main/106/applier/replicator@192.168.0.10 I> remote master is 1.7.4 at 192.168.0.
↪103:3301
2017-06-14 17:10:00.559 [47121] main/105/applier/replicator@192.168.0.10 I> authenticated
2017-06-14 17:10:00.559 [47121] main/101/master3.lua I> bootstrapping replica from 192.168.0.102:3301
2017-06-14 17:10:00.562 [47121] main/105/applier/replicator@192.168.0.10 I> initial data received
2017-06-14 17:10:00.562 [47121] main/105/applier/replicator@192.168.0.10 I> final data received
2017-06-14 17:10:00.562 [47121] snapshot/101/main I> saving snapshot `/Users/e.shebunyaeva/work/tarantool-
↪test-repl/master3_dir/00000000000000000009.snap.inprogress'
2017-06-14 17:10:00.562 [47121] snapshot/101/main I> done
2017-06-14 17:10:00.564 [47121] main/101/master3.lua I> vinyl checkpoint done
2017-06-14 17:10:00.564 [47121] main/101/master3.lua I> ready to accept requests
2017-06-14 17:10:00.565 [47121] main/101/master3.lua I> set 'read_only' configuration option to true
2017-06-14 17:10:00.565 [47121] main C> entering the event loop
2017-06-14 17:10:00.565 [47121] main/104/applier/replicator@192.168.0.10 I> authenticated
```

Next, we add the URI of master #3 to the replication parameter on the existing two masters. Replication-related parameters are dynamic, so we only need to make a box.cfg{} request on each of the running instances:

```
# adding master #3 URI to replication sources
tarantool> box.cfg{replication =
         > {'replicator:password@192.168.0.101:3301',
         > 'replicator:password@192.168.0.102:3301',
         > 'replicator:password@192.168.0.103:3301'}}
---
...
```

When master #3 catches up with the other masters' state, we can disable read-only mode for this instance:

```
# making master #3 a real master
tarantool> box.cfg{read_only=false}
---
...
```

We also recommend to specify master #3 URI in all instance files in order to keep all the files consistent with each other and with the current replication topology.

Orphan status

Starting with Tarantool version 1.9, there is a change to the procedure when an instance joins a replica set. During box.cfg() the instance will try to join all masters listed in box.cfg.replication. If the instance does not succeed with at least the number of masters specified in replication_connect_quorum, then it will switch to orphan status. While an instance is in orphan status, it is read-only.

To "join" a master, a replica instance must "connect" to the master node and then "sync".

"Connect" means contact the master over the physical network and receive acknowledgment. If there is no acknowledgment after box.replication_connect_timeout seconds (usually 4 seconds), and retries fail, then the connect step fails.

"Sync" means receive updates from the master in order to make a local database copy. Syncing is complete when the replica has received all the updates, or at least has received enough updates that the replica's lag (see replication.upstream.lag in box.info()) is less than or equal to the number of seconds specified in box.cfg.replication_sync_lag. If replication_sync_lag is unset (nil) or set to TIMEOUT_INFINITY, then the replica skips the "sync" state and switches to "follow" immediately.

In order to leave orphan mode you need to sync with a sufficient number (replication_connect_quorum) of instances. To do so, you may either:

- Set replication_connect_quorum to a lower value.
- Reset box.cfg.replication to exclude instances that cannot be reached or synced with.
- Set box.cfg.replication to "" (empty string).

The following situations are possible.

Situation 1: bootstrap

Here box.cfg{} is being called for the first time. A replica is joining but no replica set exists yet.

1. Set status to 'orphan'.
2. Try to connect to all nodes from box.cfg.replication, or to the number of nodes required by replication_connect_quorum. Retrying up to 3 times in 30 seconds is possible because this is bootstrap, replication_connect_timeout is overridden.
3. Abort and throw an error if not connected to all nodes in box.cfg.replication or replication_connect_quorum.
4. This instance might be elected as the replica set 'leader'. Criteria for electing a leader include vclock value (largest is best), and whether it is read-only or read-write (read-write is best unless there is no other choice). The leader is the master that other instances must join. The leader is the master that executes box_once() functions.
5. If this instance is elected as the replica set leader, then perform an "automatic bootstrap":
    a. Set status to 'running'.
    b. Return from box.cfg{}.

Otherwise this instance will be a replica joining an existing replica set, so:

a. Bootstrap from the leader. See examples in section Bootstrapping a replica set.

b. In background, sync with all the other nodes in the replication set.

Situation 2: recovery

Here box.cfg{} is not being called for the first time. It is being called again in order to perform recovery.

1. Perform recovery from the last local snapshot and the WAL files.
2. Connect to at least replication_connect_quorum nodes. If failed – set status to 'orphan'. (Attempts to sync will continue in the background and when/if they succeed then 'orphan' will be changed to 'connected'.)
3. If connected - sync with all connected nodes, until the difference is not more than replication_sync_lag seconds.

Situation 3: configuration update

Here box.cfg{} is not being called for the first time. It is being called again because some replication parameter or something in the replica set has changed.

1. Try to connect to all nodes from box.cfg.replication, or to the number of nodes required by replication_connect_quorum, within the time period specified in replication_connect_timeout.
2. Try to sync with the connected nodes, within the time period specified in replication_sync_timeout.
3. If earlier steps fail, change status to 'orphan'. (Attempts to sync will continue in the background and when/if they succeed then 'orphan' status will end.)
4. If earlier steps succeed, set status to 'running' (master) or 'follow' (replica).

Situation 4: rebootstrap

Here box.cfg{} is not being called. The replica connected successfully at some point in the past, and is now ready for an update from the master. But the master cannot provide an update. This can happen by accident, or more likely can happen because the replica is slow (its lag is large), and the WAL (.xlog) files containing the updates have been deleted. This is not crippling. The replica can discard what it received earlier, and then ask for the master's latest snapshot (.snap) file contents. Since it is effectively going through the bootstrap process a second time, this is called "rebootstrapping". However, there has to be one difference from an ordinary bootstrap – the replica's replica id will remain the same. If it changed, then the master would think that the replica is a new addition to the cluster, and would maintain a record of an instance ID of a replica that has ceased to exist. Rebootstrapping was introduced in Tarantool version 1.10.2 and is completely automatic.

Server startup with replication

In addition to the recovery process described in the section Recovery process, the server must take additional steps and precautions if replication is enabled.

Once again the startup procedure is initiated by the box.cfg{} request. One of the box.cfg parameters may be replication which specifies replication source(-s). We will refer to this replica, which is starting up due to box.cfg, as the "local" replica to distinguish it from the other replicas in a replica set, which we will refer to as "distant" replicas.

If there is no snapshot .snap file and the replication parameter is empty and cfg.read_only=false: then the local replica assumes it is an unreplicated "standalone" instance, or is the first replica of a new replica set. It will generate new UUIDs for itself and for the replica set. The replica UUID is stored in the _cluster space; the replica set UUID is stored in the _schema space. Since a snapshot contains all the data in all the spaces, that means the local replica's snapshot will contain the replica UUID and the replica set UUID.

Therefore, when the local replica restarts on later occasions, it will be able to recover these UUIDs when it reads the .snap file.

If there is no snapshot .snap file and the replication parameter is empty and cfg.read_only=true: it cannot be the first replica of a new replica set because the first replica must be a master. Therefore an error message will occur: ER_BOOTSTRAP_READONLY. To avoid this, change the setting for this (local) instance to read_only = false, or ensure that another (distant) instance starts first and has the local instance's UUID in its _cluster space. In the latter case, if ER_BOOTSTRAP_READONLY still occurs, set the local instance's box.replication_connect_timeout to a larger value.

If there is no snapshot .snap file and the replication parameter is not empty and the _cluster space contains no other replica UUIDs: then the local replica assumes it is not a standalone instance, but is not yet part of a replica set. It must now join the replica set. It will send its replica UUID to the first distant replica which is listed in replication and which will act as a master. This is called the "join request". When a distant replica receives a join request, it will send back:

(1) the distant replica's replica set UUID,

(2) the contents of the distant replica's .snap file. When the local replica receives this information, it puts the replica set UUID in its _schema space, puts the distant replica's UUID and connection information in its _cluster space, and makes a snapshot containing all the data sent by the distant replica. Then, if the local replica has data in its WAL .xlog files, it sends that data to the distant replica. The distant replica will receive this and update its own copy of the data, and add the local replica's UUID to its _cluster space.

If there is no snapshot .snap file and the replication parameter is not empty and the _cluster space contains other replica UUIDs: then the local replica assumes it is not a standalone instance, and is already part of a replica set. It will send its replica UUID and replica set UUID to all the distant replicas which are listed in replication. This is called the "on-connect handshake". When a distant replica receives an on-connect handshake:

(1) the distant replica compares its own copy of the replica set UUID to the one in the on-connect handshake. If there is no match, then the handshake fails and the local replica will display an error.

(2) the distant replica looks for a record of the connecting instance in its _cluster space. If there is none, then the handshake fails. Otherwise the handshake is successful. The distant replica will read any new information from its own .snap and .xlog files, and send the new requests to the local replica.

In the end, the local replica knows what replica set it belongs to, the distant replica knows that the local replica is a member of the replica set, and both replicas have the same database contents.

If there is a snapshot file and replication source is not empty: first the local replica goes through the recovery process described in the previous section, using its own .snap and .xlog files. Then it sends a "subscribe" request to all the other replicas of the replica set. The subscribe request contains the server vector clock. The vector clock has a collection of pairs 'server id, lsn' for every replica in the _cluster system space. Each distant replica, upon receiving a subscribe request, will read its .xlog files' requests and send them to the local replica if (lsn of .xlog file request) is greater than (lsn of the vector clock in the subscribe request). After all the other replicas of the replica set have responded to the local replica's subscribe request, the replica startup is complete.

The following temporary limitations applied for Tarantool versions earlier than 1.7.7:

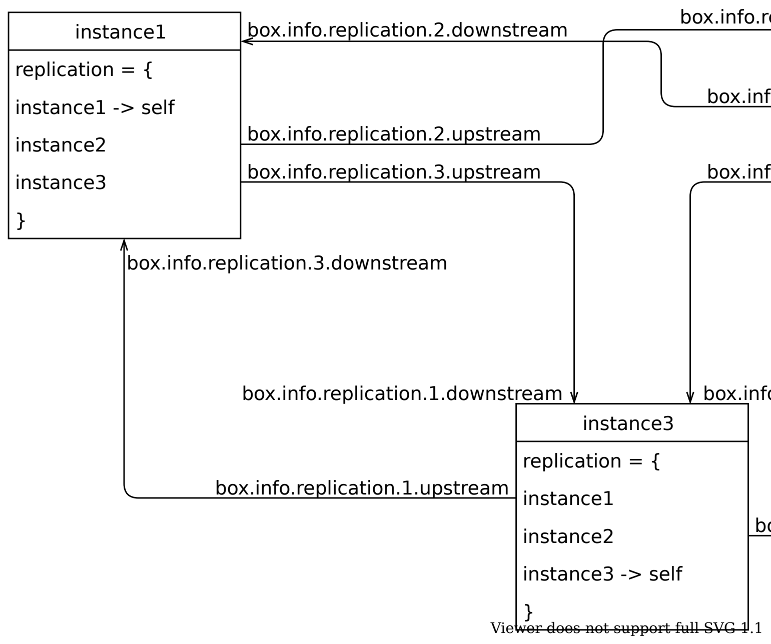
- The URIs in the replication parameter should all be in the same order on all replicas. This is not mandatory but is an aid to consistency.
- The replicas of a replica set should be started up at slightly different times. This is not mandatory but prevents a situation where each replica is waiting for the other replica to be ready.

The following limitation still applies for the current Tarantool version:

- The maximum number of entries in the _cluster space is 32. Tuples for out-of-date replicas are not automatically re-used, so if this 32-replica limit is reached, users may have to reorganize the _cluster space manually.

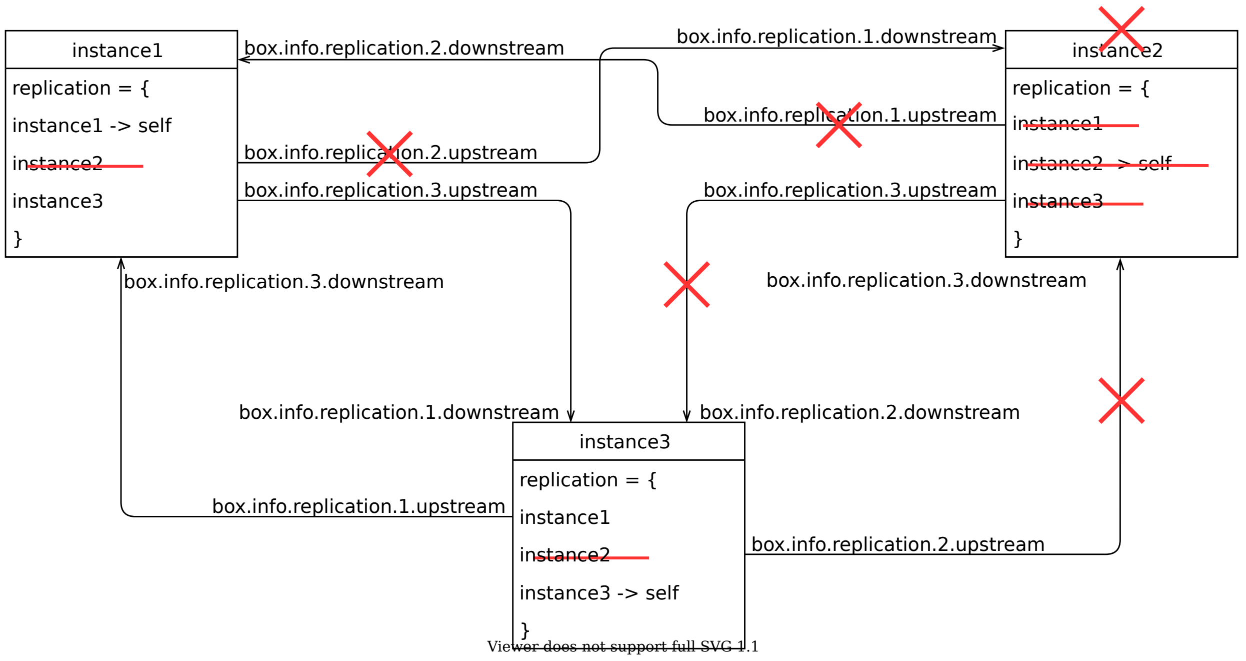
4.6.4 Removing instances

Let's assume that we have the following configured replica set with 3 instances (instance1, instance2 and intance3) and we want to remove instance2.


instance1
replication = {
instance1 -> self
instance2
instance3
}
instance2
replication = {
instance1
instance2 -> self
instance3
}
instance3
replication = {
instance1
instance2
instance3 -> self
}
box.info.replication.2.downstream
box.info.replication.1.downstream
box.info.replication.1.upstream
box.info.replication.2.upstream
box.info.replication.3.upstream
box.info.replication.3.upstream
box.info.replication.3.downstream
box.info.replication.3.downstream
box.info.replication.1.downstream
box.info.replication.2.downstream
box.info.replication.1.upstream
box.info.replication.2.upstream
~~Viewer does not support full SVG 1.1~~

To remove it politely, follow these steps:

1. Disconnect instance2 from the cluster.
2. Disconnect the cluster from instance2.
3. Remove instance2 from the _cluster space.


instance1
replication = {
instance1 -> self
~~instance2~~
instance3
}
instance2
replication = {
~~instance1~~
~~instance2 -> self~~
~~instance3~~
}
instance3
replication = {
instance1
~~instance2~~
instance3 -> self
}
box.info.replication.2.downstream
box.info.replication.1.downstream
box.info.replication.1.upstream
box.info.replication.2.upstream
box.info.replication.3.upstream
box.info.replication.3.upstream
box.info.replication.3.downstream
box.info.replication.3.downstream
box.info.replication.1.downstream
box.info.replication.2.downstream
box.info.replication.1.upstream
box.info.replication.2.upstream
Viewer does not support full SVG 1.1

Step 1: disconnecting an instance from the cluster

On the disconnecting instance instance2, run box.cfg{} with a blank replication source:

```
tarantool> box.cfg{replication=''}
```

Then check that it was disconnected. Take a look at box.info.replication on instance2 (notice that replication.{1,3}.upstream is absent):

```
tarantool> box.info.replication
---
- 1:
  id: 1
  uuid: db89978f-7115-4537-8417-9982bb5a256f
  lsn: 9
-- upstream is absent
  downstream:
    status: follow
    idle: 0.93983899999876
    vclock: {1: 9}
2:
  id: 2
  uuid: 0a756d14-e437-4296-85b0-d27a0621613e
  lsn: 0
3:
  id: 3
  uuid: bb362584-c265-4e53-aeb6-450ae818bf59
  lsn: 0
-- upstream is absent
  downstream:
    status: follow
    idle: 0.26624799999991
    vclock: {1: 9}
...
```

Check instance1 and instance3 as well (notice that the status of replication.2.downstream is stopped):

```
-- instance1
tarantool> box.info.replication
---
- 1:
    id: 1
    uuid: db89978f-7115-4537-8417-9982bb5a256f
    lsn: 9
  2:
    id: 2
    uuid: 0a756d14-e437-4296-85b0-d27a0621613e
    lsn: 0
    upstream:
      status: follow
      idle: 0.3533439999992
      peer: replicator@localhost:3302
      lag: 0.0001220703125
    downstream:
      status: stopped     -- status has changed:
      message: unexpected EOF when reading from socket, called on fd 13, aka [::1]:3301,
      peer of [::1]:53776
      system_message: Broken pipe
  3:
    id: 3
    uuid: bb362584-c265-4e53-aeb6-450ae818bf59
    lsn: 0
    upstream:
      status: follow
      idle: 0.35327999999936
      peer: replicator@localhost:3303
      lag: 0.00018095970153809
    downstream:
      status: follow
      idle: 0.68685100000221
      vclock: {1: 9}
...
```

Step 2: disconnecting the cluster from the decommissioned instance

On every other instance in the cluster remove instance2 from the box.cfg{ replication } list and call an appropriate box.cfg{ replication = {instance1, instance3} }:

```
tarantool> box.cfg{ replication = { 'instance1-uri', 'instance3-uri' } }
```

Take a look at box.info.replication on instance2 to check that instance1 and instance3 were disconnected (notice that the status of replication.{1,3}.downstream is stopped):

```
tarantool> box.info.replication
---
- 1:
    id: 1
    uuid: db89978f-7115-4537-8417-9982bb5a256f
    lsn: 9
    downstream:
      status: stopped    -- status has changed
      message: unexpected EOF when reading from socket, called on fd 16, aka [::1]:3302,
      peer of [::1]:53832
      system_message: Broken pipe
```

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```
2:
  id: 2
  uuid: 0a756d14-e437-4296-85b0-d27a0621613e
  lsn: 0
3:
  id: 3
  uuid: bb362584-c265-4e53-aeb6-450ae818bf59
  lsn: 0
  downstream:
    status: stopped    -- status has changed
    message: unexpected EOF when reading from socket, called on fd 18, aka [::1]:3302,
    peer of [::1]:53825
    system_message: Broken pipe
...
```

Check instance1 and instance3 as well (notice that the status of replication.2.upstream is stopped):

```
-- instance1
tarantool> box.info.replication
---
- 1:
  id: 1
  uuid: db89978f-7115-4537-8417-9982bb5a256f
  lsn: 9
2:
  id: 2
  uuid: 0a756d14-e437-4296-85b0-d27a0621613e
  lsn: 0
  downstream:
    status: stopped   -- status has changed
    message: unexpected EOF when reading from socket, called on fd 13, aka [::1]:3301,
    peer of [::1]:53776
    system_message: Broken pipe
3:
  id: 3
  uuid: bb362584-c265-4e53-aeb6-450ae818bf59
  lsn: 0
  upstream:
    status: follow
    idle: 0.50240100000156
    peer: replicator@localhost:3303
    lag: 0.00015711784362793
  downstream:
    status: follow
    idle: 0.14237199999843
    vclock: {1: 9}
...
```

Step 3: persistent removal

If a removed instance rejoins later, it will receive all the updates made by the other instances while it was disconnected.

If an instance is decommissioned forever, we should clean up the _cluster space. First, discover the id and uuid of the instance. On instance2, call return box.info.id, box.info.uuid:

```
tarantool> return box.info.id, box.info.uuid
---
- 2
- '0a756d14-e437-4296-85b0-d27a0621613e'
...
```

Take a note of id and uuid.

Now choose any master from the remaining cluster and perform the following actions on it (let's assume that we chose instance1):

1. Select all records from the _cluster space:

```
tarantool> box.space._cluster:select{}
---
- - [1, 'db89978f-7115-4537-8417-9982bb5a256f']
- [2, '0a756d14-e437-4296-85b0-d27a0621613e']
- [3, 'bb362584-c265-4e53-aeb6-450ae818bf59']
...
```

2. Check if the id and uuid of instance2 are correct and remove them from the cluster:

```
tarantool> box.space._cluster:delete(2)
---
- [2, '0a756d14-e437-4296-85b0-d27a0621613e']
...
```

Final ckecks

After all modifications, say box.info.replication to check the health status.

4.6.5 Monitoring a replica set

To learn what instances belong in the replica set, and obtain statistics for all these instances, issue a box.info.replication request:

```
tarantool> box.info.replication
---
  replication:
    1:
      id: 1
      uuid: b8a7db60-745f-41b3-bf68-5fcce7a1e019
      lsn: 88
    2:
      id: 2
      uuid: cd3c7da2-a638-4c5d-ae63-e7767c3a6896
      lsn: 31
      upstream:
        status: follow
        idle: 43.187747001648
        peer: replicator@192.168.0.102:3301
        lag: 0
      downstream:
        vclock: {1: 31}
    3:
      id: 3
      uuid: e38ef895-5804-43b9-81ac-9f2cd872b9c4
```

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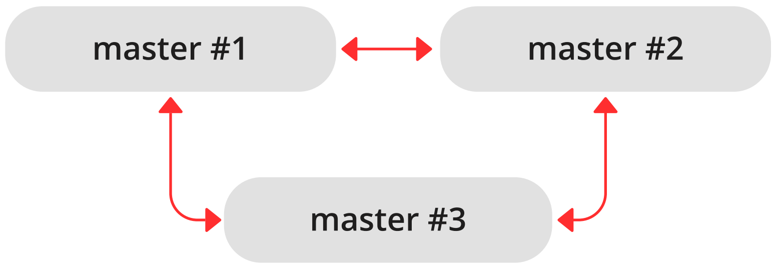
```
    lsn: 54
    upstream:
      status: follow
      idle: 43.187621831894
      peer: replicator@192.168.0.103:3301
      lag: 2
    downstream:
      vclock: {1: 54}
...
```

This report is for a master-master replica set of three instances, each having its own instance id, UUID and log sequence number.



The request was issued at master #1, and the reply includes statistics for the other two masters, given in regard to master #1.

The primary indicators of replication health are:

- idle, the time (in seconds) since the instance received the last event from a master.

  A master sends heartbeat messages to a replica every second, and the master is programmed to disconnect if it does not see acknowledgments of the heartbeat messages within replication_timeout * 4 seconds.

  Therefore, in a healthy replication setup, idle should never exceed replication_timeout: if it does, either the replication is lagging seriously behind, because the master is running ahead of the replica, or the network link between the instances is down.

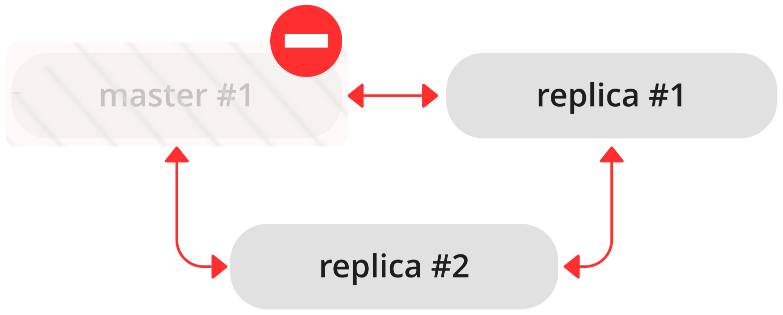
- lag, the time difference between the local time at the instance, recorded when the event was received, and the local time at another master recorded when the event was written to the write ahead log on that master.

  Since the lag calculation uses the operating system clocks from two different machines, do not be surprised if it's negative: a time drift may lead to the remote master clock being consistently behind the local instance's clock.

  For multi-master configurations, lag is the maximal lag.

4.6.6 Recovering from a degraded state

"Degraded state" is a situation when the master becomes unavailable – due to hardware or network failure, or due to a programming bug.



In a master-replica set, if a master disappears, error messages appear on the replicas stating that the connection is lost:

```
$ # messages from a replica's log
2017-06-14 16:23:10.993 [19153] main/105/applier/replicator@192.168.0. I> can't read row
2017-06-14 16:23:10.993 [19153] main/105/applier/replicator@192.168.0. coio.cc:349 !> SystemError
unexpected EOF when reading from socket, called on fd 17, aka 192.168.0.101:57815,
peer of 192.168.0.101:3301: Broken pipe
2017-06-14 16:23:10.993 [19153] main/105/applier/replicator@192.168.0. I> will retry every 1 second
2017-06-14 16:23:10.993 [19153] relay/[::ffff:192.168.0.101]:/101/main I> the replica has closed its socket, exiting
2017-06-14 16:23:10.993 [19153] relay/[::ffff:192.168.0.101]:/101/main C> exiting the relay loop
```

... and the master's status is reported as "disconnected":

```
# report from replica #1
tarantool> box.info.replication
---
- 1:
    id: 1
    uuid: 70e8e9dc-e38d-4046-99e5-d25419267229
    lsn: 542
    upstream:
      peer: replicator@192.168.0.101:3301
      lag: 0.00026607513427734
      status: disconnected
      idle: 182.36929893494
      message: connect, called on fd 13, aka 192.168.0.101:58244
  2:
    id: 2
    uuid: fb252ac7-5c34-4459-84d0-54d248b8c87e
    lsn: 0
  3:
    id: 3
```

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```
    uuid: fd7681d8-255f-4237-b8bb-c4fb9d99024d
    lsn: 0
    downstream:
      vclock: {1: 542}
...
```

```
# report from replica #2
tarantool> box.info.replication
---
- 1:
    id: 1
    uuid: 70e8e9dc-e38d-4046-99e5-d25419267229
    lsn: 542
    upstream:
      peer: replicator@192.168.0.101:3301
      lag: 0.00027203559875488
      status: disconnected
      idle: 186.76988101006
      message: connect, called on fd 13, aka 192.168.0.101:58253
  2:
    id: 2
    uuid: fb252ac7-5c34-4459-84d0-54d248b8c87e
    lsn: 0
    upstream:
      status: follow
      idle: 186.76960110664
      peer: replicator@192.168.0.102:3301
      lag: 0.00020599365234375
  3:
    id: 3
    uuid: fd7681d8-255f-4237-b8bb-c4fb9d99024d
    lsn: 0
...
```

To declare that one of the replicas must now take over as a new master:

1. Make sure that the old master is gone for good:
   - change network routing rules to avoid any more packets being delivered to the master, or
   - shut down the master instance, if you have access to the machine, or
   - power off the container or the machine.
2. Say box.cfg{read_only=false, listen=URI} on the replica, and box.cfg{replication=URI} on the other replicas in the set.

Note: If there are updates on the old master that were not propagated before the old master went down, re-apply them manually to the new master using tarantoolctl cat and tarantoolctl play commands.

There is no automatic way for a replica to detect that the master is gone forever, since sources of failure and replication environments vary significantly. So the detection of degraded state requires an external observer.

4.6.7 Reseeding a replica

If any of a replica's .xlog/.snap/.run files are corrupted or deleted, you can "re-seed" the replica:

1. Stop the replica and destroy all local database files (the ones with extensions .xlog/.snap/.run/.inprogress).
2. Delete the replica's record from the following locations:
   a. the replication parameter at all running instances in the replica set.
   b. the box.space._cluster tuple on the master instance.

   See section Removing instances for details.
3. Restart the replica with the same instance file to contact the master again. The replica will then catch up with the master by retrieving all the master's tuples.

Note: Remember that this procedure works only if the master's WAL files are present.

4.6.8 Resolving replication conflicts

Solving problems with master-master replication

Tarantool guarantees that every update is applied only once on every replica. However, due to the asynchronous nature of replication, the order of updates is not guaranteed. We now analyze this problem with more details, provide examples of replication going out of sync, and suggest solutions.

Replacing the same primary key

Case 1: You have two instances of Tarantool. For example, you try to make a replace operation with the same primary key on both instances in the same time. This will cause a conflict over which tuple to save and which one to discard.

Tarantool trigger functions can help here to implement the rules of conflict resolution on some condition. For example, if you have a timestamp, you can declare saving the tuple with the bigger one.

First, you need a before_replace() trigger on the space which may have conflicts. In this trigger you can compare the old and new replica records and choose which one to use (or skip the update entirely, or merge two records together).

Then you need to set the trigger at the right time, before the space starts to receive any updates. The way you usually set the before_replace trigger is right when the space is created, so you need a trigger to set another trigger on the system space _space, to capture the moment when your space is created and set the trigger there. This can be an on_replace() trigger.

The difference between before_replace and on_replace is that on_replace is called after a row is inserted into the space, and before_replace is called before that.

To set a _space:on_replace() trigger correctly, you also need the right timing. The best timing to use it is when _space is just created, which is the box.ctl.on_schema_init() trigger.

You will also need to utilize box.on_commit to get access to the space being created. The resulting snippet would be the following:

```
local my_space_name = 'my_space'
local my_trigger = function(old, new) ... end -- your function resolving a conflict
box.ctl.on_schema_init(function()
    box.space._space:on_replace(function(old_space, new_space)
        if not old_space and new_space and new_space.name == my_space_name then
```

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```
            box.on_commit(function()
                box.space[my_space_name]:before_replace(my_trigger)
            end
        end
    end)
end)
```

Preventing duplicate insert

Case 2: In a replica set of two masters, suppose master #1 tries to insert a tuple with the same unique key:

```
tarantool> box.space.tester:insert{1, 'data'}
```

This would cause an error saying Duplicate key exists in unique index 'primary' in space 'tester' and the replication would be stopped. (This is the behavior when the replication_skip_conflict configuration parameter has its default recommended value, false.)

```
$ # error messages from master #1
2017-06-26 21:17:03.233 [30444] main/104/applier/rep_user@100.96.166.1 I> can't read row
2017-06-26 21:17:03.233 [30444] main/104/applier/rep_user@100.96.166.1 memtx_hash.cc:226 E> ER_TUPLE_
↪FOUND:
Duplicate key exists in unique index 'primary' in space 'tester'
2017-06-26 21:17:03.233 [30444] relay/[::ffff:100.96.166.178]/101/main I> the replica has closed its socket, exiting
2017-06-26 21:17:03.233 [30444] relay/[::ffff:100.96.166.178]/101/main C> exiting the relay loop

$ # error messages from master #2
2017-06-26 21:17:03.233 [30445] main/104/applier/rep_user@100.96.166.1 I> can't read row
2017-06-26 21:17:03.233 [30445] main/104/applier/rep_user@100.96.166.1 memtx_hash.cc:226 E> ER_TUPLE_
↪FOUND:
Duplicate key exists in unique index 'primary' in space 'tester'
2017-06-26 21:17:03.234 [30445] relay/[::ffff:100.96.166.178]/101/main I> the replica has closed its socket, exiting
2017-06-26 21:17:03.234 [30445] relay/[::ffff:100.96.166.178]/101/main C> exiting the relay loop
```

If we check replication statuses with box.info, we will see that replication at master #1 is stopped (1. upstream.status = stopped). Additionally, no data is replicated from that master (section 1.downstream is missing in the report), because the downstream has encountered the same error:

```
# replication statuses (report from master #3)
tarantool> box.info
---
- version: 1.7.4-52-g980d30092
  id: 3
  ro: false
  vclock: {1: 9, 2: 1000000, 3: 3}
  uptime: 557
  lsn: 3
  vinyl: []
  cluster:
    uuid: 34d13b1a-f851-45bb-8f57-57489d3b3c8b
  pid: 30445
  status: running
  signature: 1000012
  replication:
    1:
```

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```
    id: 1
    uuid: 7ab6dee7-dc0f-4477-af2b-0e63452573cf
    lsn: 9
    upstream:
      peer: replicator@192.168.0.101:3301
      lag: 0.00050592422485352
      status: stopped
      idle: 445.8626639843
      message: Duplicate key exists in unique index 'primary' in space 'tester'
  2:
    id: 2
    uuid: 9afbe2d9-db84-4d05-9a7b-e0cbbf861e28
    lsn: 1000000
    upstream:
      status: follow
      idle: 201.99915885925
      peer: replicator@192.168.0.102:3301
      lag: 0.0015020370483398
    downstream:
      vclock: {1: 8, 2: 1000000, 3: 3}
  3:
    id: 3
    uuid: e826a667-eed7-48d5-a290-64299b159571
    lsn: 3
uuid: e826a667-eed7-48d5-a290-64299b159571
...
```

When replication is later manually resumed:

```
# resuming stopped replication (at all masters)
tarantool> original_value = box.cfg.replication
tarantool> box.cfg{replication={}}
tarantool> box.cfg{replication=original_value}
```

. . . the faulty row in the write-ahead-log files is skipped.

Solution #1: replication runs out of sync

In a master-master cluster of two instances, suppose we make the following operation:

```
tarantool> box.space.tester:upsert({1}, {{'=', 2, box.info.uuid}})
```

When this operation is applied on both instances in the replica set:

```
# at master #1
tarantool> box.space.tester:upsert({1}, {{'=', 2, box.info.uuid}})
# at master #2
tarantool> box.space.tester:upsert({1}, {{'=', 2, box.info.uuid}})
```

. . . we can have the following results, depending on the order of execution:

- each master's row contains the UUID from master #1,
- each master's row contains the UUID from master #2,
- master #1 has the UUID of master #2, and vice versa.

Solution #2: commutative changes

The cases described in the previous paragraphs represent examples of non-commutative operations, i.e. operations whose result depends on the execution order. On the contrary, for commutative operations, the execution order does not matter.

Consider for example the following command:

```
tarantool> box.space.tester:upsert{{1, 0}, {{'+', 2, 1)}
```

This operation is commutative: we get the same result no matter in which order the update is applied on the other masters.

Solution #3: trigger usage

The logic and the snippet setting a trigger will be the same here as in case 1. But the trigger function will differ:

```
local my_space_name = 'test'
local my_trigger = function(old, new, sp, op)
    -- op:  'INSERT', 'DELETE', 'UPDATE', or 'REPLACE'
    if new == nil then
        print("No new during "..op, old)
        return -- deletes are ok
    end
    if old == nil then
        print("Insert new, no old", new)
        return new  -- insert without old value: ok
    end
    print(op.." duplicate", old, new)
    if op == 'INSERT' then
        if new[2] > old[2] then
            -- Creating new tuple will change op to 'REPLACE'
            return box.tuple.new(new)
        end
        return old
    end
    if new[2] > old[2] then
        return new
    else
        return old
    end
    return
end

box.ctl.on_schema_init(function()
    box.space._space:on_replace(function(old_space, new_space)
        if not old_space and new_space and new_space.name == my_space_name then
            box.on_commit(function()
                box.space[my_space_name]:before_replace(my_trigger)
            end)
        end
    end)
end)
```

4.7 Connectors

This chapter documents APIs for various programming languages.

4.7.1 Protocol

Tarantool's binary protocol was designed with a focus on asynchronous I/O and easy integration with proxies. Each client request starts with a variable-length binary header, containing request id, request type, instance id, log sequence number, and so on.

The mandatory length, present in request header simplifies client or proxy I/O. A response to a request is sent to the client as soon as it is ready. It always carries in its header the same type and id as in the request. The id makes it possible to match a request to a response, even if the latter arrived out of order.

Unless implementing a client driver, you needn't concern yourself with the complications of the binary protocol. Language-specific drivers provide a friendly way to store domain language data structures in Tarantool. A complete description of the binary protocol is maintained in annotated Backus-Naur form in the source tree. For detailed examples and diagrams of all binary-protocol requests and responses, see Tarantool's binary protocol.

4.7.2 Packet example

The Tarantool API exists so that a client program can send a request packet to a server instance, and receive a response. Here is an example of a what the client would send for box.space[513]:insert{`'A'`, `'BB'`}. The BNF description of the components is on the page about Tarantool's binary protocol.

Component	Byte #0	Byte #1	Byte #2	Byte #3
code for insert	02			
rest of header	. . .	. . .	. . .	. . .
2-digit number: space id	cd	02	01	
code for tuple	21			
1-digit number: field count = 2	92			
1-character string: field[1]	a1	41		
2-character string: field[2]	a2	42	42	

Now, you could send that packet to the Tarantool instance, and interpret the response (the page about Tarantool's binary protocol has a description of the packet format for responses as well as requests). But it would be easier, and less error-prone, if you could invoke a routine that formats the packet according to typed parameters. Something like response = tarantool_routine("insert", 513, "A", "B");. And that is why APIs exist for drivers for Perl, Python, PHP, and so on.

4.7.3 Setting up the server for connector examples

This chapter has examples that show how to connect to a Tarantool instance via the Perl, PHP, Python, node.js, and C connectors. The examples contain hard code that will work if and only if the following conditions are met:

- the Tarantool instance (tarantool) is running on localhost (127.0.0.1) and is listening on port 3301 (box.cfg.listen = `'3301'`),
- space examples has id = 999 (box.space.examples.id = 999) and has a primary-key index for a numeric field (box.space[999].index[0].parts[1].type = "unsigned"),
- user 'guest' has privileges for reading and writing.

It is easy to meet all the conditions by starting the instance and executing this script:

```
box.cfg{listen=3301}
box.schema.space.create('examples',{id=999})
box.space.examples:create_index('primary', {type = 'hash', parts = {1, 'unsigned'}})
box.schema.user.grant('guest','read,write','space','examples')
box.schema.user.grant('guest','read','space','_space')
```

4.7.4 Java

See http://github.com/tarantool/tarantool-java/.

4.7.5 Go

Please see https://github.com/mialinx/go-tarantool.

4.7.6 R

See https://github.com/thekvs/tarantoolr.

4.7.7 Erlang

See Erlang tarantool driver.

4.7.8 Perl

The most commonly used Perl driver is tarantool-perl. It is not supplied as part of the Tarantool repository; it must be installed separately. The most common way to install it is by cloning from GitHub.

To avoid minor warnings that may appear the first time tarantool-perl is installed, start with installing some other modules that tarantool-perl uses, with CPAN, the Comprehensive Perl Archive Network:

```
$ sudo cpan install AnyEvent
$ sudo cpan install Devel::GlobalDestruction
```

Then, to install tarantool-perl itself, say:

```
$ git clone https://github.com/tarantool/tarantool-perl.git tarantool-perl
$ cd tarantool-perl
$ git submodule init
$ git submodule update --recursive
$ perl Makefile.PL
$ make
$ sudo make install
```

Here is a complete Perl program that inserts [99999,'BB'] into space[999] via the Perl API. Before trying to run, check that the server instance is listening at localhost:3301 and that the space examples exists, as described earlier. To run, paste the code into a file named example.pl and say perl example.pl. The program will connect using an application-specific definition of the space. The program will open a socket connection with the Tarantool instance at localhost:3301, then send an space_object:INSERT request, then — if all is well — end without displaying any messages. If Tarantool is not running on localhost with listen port = 3301, the program will print “Connection refused”.

```
#!/usr/bin/perl
use DR::Tarantool ':constant', 'tarantool';
use DR::Tarantool ':all';
use DR::Tarantool::MsgPack::SyncClient;

my $tnt = DR::Tarantool::MsgPack::SyncClient->connect(
  host    => '127.0.0.1',                      # look for tarantool on localhost
  port    => 3301,                             # on port 3301
  user    => 'guest',                          # username. for 'guest' we do not also say 'password=>...'

  spaces  => {
    999 => {                                   # definition of space[999] ...
      name => 'examples',                      #   space[999] name = 'examples'
      default_type => 'STR',                   #   space[999] field type is 'STR' if undefined
      fields => [ {                            #   definition of space[999].fields ...
          name => 'field1', type => 'NUM' } ], #     space[999].field[1] name='field1',type='NUM'
      indexes => {                             #   definition of space[999] indexes ...
        0 => {
          name => 'primary', fields => [ 'field1' ] } } } } );

$tnt->insert('examples' => [ 99999, 'BB' ]);
```

The example program uses field type names 'STR' and 'NUM' instead of 'string' and 'unsigned', due to a temporary Perl limitation.

The example program only shows one request and does not show all that's necessary for good practice. For that, please see the tarantool-perl repository.

4.7.9 PHP

tarantool-php is the official PHP connector for Tarantool. It is not supplied as part of the Tarantool repository and must be installed separately (see installation instructions in the connector's README file).

Here is a complete PHP program that inserts [99999,'BB'] into a space named examples via the PHP API.

Before trying to run, check that the server instance is listening at localhost:3301 and that the space examples exists, as described earlier.

To run, paste the code into a file named example.php and say:

```
$ php -d extension=~/tarantool-php/modules/tarantool.so example.php
```

The program will open a socket connection with the Tarantool instance at localhost:3301, then send an INSERT request, then – if all is well – print "Insert succeeded".

If the tuple already exists, the program will print "Duplicate key exists in unique index 'primary' in space 'examples'".

```
<?php
$tarantool = new Tarantool('localhost', 3301);

try {
    $tarantool->insert('examples', [99999, 'BB']);
    echo "Insert succeeded\n";
} catch (Exception $e) {
    echo $e->getMessage(), "\n";
}
```

The example program only shows one request and does not show all that's necessary for good practice. For that, please see tarantool/tarantool-php project at GitHub.

Besides, there is another community-driven GitHub project which includes an alternative connector written in pure PHP, an object mapper, a queue and other packages.

4.7.10 Python

tarantool-python is the official Python connector for Tarantool. It is not supplied as part of the Tarantool repository and must be installed separately (see below for details).

Here is a complete Python program that inserts [99999,'Value','Value'] into space examples via the high-level Python API.

```
#!/usr/bin/python
from tarantool import Connection

c = Connection("127.0.0.1", 3301)
result = c.insert("examples",(99999,'Value', 'Value'))
print result
```

To prepare, paste the code into a file named example.py and install the tarantool-python connector with either pip install tarantool>0.4 to install in /usr (requires root privilege) or pip install tarantool>0.4 --user to install in ~ i.e. user's default directory.

Before trying to run, check that the server instance is listening at localhost:3301 and that the space examples exists, as described earlier. To run the program, say python example.py. The program will connect to the Tarantool server, will send the INSERT request, and will not throw any exception if all went well. If the tuple already exists, the program will throw tarantool.error.DatabaseError: (3, "Duplicate key exists in unique index 'primary' in space 'examples'").

The example program only shows one request and does not show all that's necessary for good practice. For that, please see tarantool-python project at GitHub. For an example of using Python API with queue managers for Tarantool, see queue-python project at GitHub.

Also there are several community-driven Python connectors:

- asynctnt with asyncio support
- aiotarantool also with asyncio support
- gtarantool with gevent support no active maintenance

4.7.11 Node.js

The most commonly used node.js driver is the Node Tarantool driver. It is not supplied as part of the Tarantool repository; it must be installed separately. The most common way to install it is with npm. For example, on Ubuntu, the installation could look like this after npm has been installed:

```
$ npm install tarantool-driver --global
```

Here is a complete node.js program that inserts [99999,'BB'] into space[999] via the node.js API. Before trying to run, check that the server instance is listening at localhost:3301 and that the space examples exists, as described earlier. To run, paste the code into a file named example.rs and say node example.rs. The program will connect using an application-specific definition of the space. The program will open a socket connection with the Tarantool instance at localhost:3301, then send an INSERT request, then — if all is well — end after saying "Insert succeeded". If Tarantool is not running on localhost with listen port

= 3301, the program will print "Connect failed". If the 'guest' user does not have authorization to connect, the program will print "Auth failed". If the insert request fails for any reason, for example because the tuple already exists, the program will print "Insert failed".

```
var TarantoolConnection = require('tarantool-driver');
var conn = new TarantoolConnection({port: 3301});
var insertTuple = [99999, "BB"];
conn.connect().then(function() {
    conn.auth("guest", "").then(function() {
        conn.insert(999, insertTuple).then(function() {
            console.log("Insert succeeded");
            process.exit(0);
    }, function(e) { console.log("Insert failed");  process.exit(1); });
    }, function(e) { console.log("Auth failed");    process.exit(1); });
    }, function(e) { console.log("Connect failed"); process.exit(1); });
```

The example program only shows one request and does not show all that's necessary for good practice. For that, please see The node.js driver repository.

4.7.12 C#

The most commonly used C# driver is progaudi.tarantool, previously named tarantool-csharp. It is not supplied as part of the Tarantool repository; it must be installed separately. The makers recommend cross-platform installation using Nuget.

To be consistent with the other instructions in this chapter, here is a way to install the driver directly on Ubuntu 16.04.

1. Install .net core from Microsoft. Follow .net core installation instructions.

Note:

- Mono will not work, nor will .Net from xbuild. Only .net core supported on Linux and Mac.
- Read the Microsoft End User License Agreement first, because it is not an ordinary open-source agreement and there will be a message during installation saying "This software may collect information about you and your use of the software, and send that to Microsoft." Still you can set environment variables to opt out from telemetry.

2. Create a new console project.

```
$ cd ~
$ mkdir progaudi.tarantool.test
$ cd progaudi.tarantool.test
$ dotnet new console
```

3. Add progaudi.tarantool reference.

```
$ dotnet add package progaudi.tarantool
```

4. Change code in Program.cs.

```
$ cat <<EOT > Program.cs
using System;
using System.Threading.Tasks;
using ProGaudi.Tarantool.Client;
```

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```
public class HelloWorld
{
  static public void Main ()
  {
    Test().GetAwaiter().GetResult();
  }
  static async Task Test()
  {
    var box = await Box.Connect("127.0.0.1:3301");
    var schema = box.GetSchema();
    var space = await schema.GetSpace("examples");
    await space.Insert((99999, "BB"));
  }
}
EOT
```

5. Build and run your application.

   Before trying to run, check that the server is listening at localhost:3301 and that the space examples exists, as described earlier.

   ```
   $ dotnet restore
   $ dotnet run
   ```

   The program will:

   - connect using an application-specific definition of the space,
   - open a socket connection with the Tarantool server at localhost:3301,
   - send an INSERT request, and — if all is well — end without saying anything.

   If Tarantool is not running on localhost with listen port = 3301, or if user 'guest' does not have authorization to connect, or if the INSERT request fails for any reason, the program will print an error message, among other things (stacktrace, etc).

The example program only shows one request and does not show all that's necessary for good practice. For that, please see the progaudi.tarantool driver repository.

4.7.13 C

Here follow two examples of using Tarantool's high-level C API.

Example 1

Here is a complete C program that inserts [99999,'B'] into space examples via the high-level C API.

```
#include <stdio.h>
#include <stdlib.h>

#include <tarantool/tarantool.h>
#include <tarantool/tnt_net.h>
#include <tarantool/tnt_opt.h>

void main() {
```

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```
    struct tnt_stream *tnt = tnt_net(NULL);           /* See note = SETUP */
    tnt_set(tnt, TNT_OPT_URI, "localhost:3301");
    if (tnt_connect(tnt) < 0) {                        /* See note = CONNECT */
        printf("Connection refused\n");
        exit(-1);
    }
    struct tnt_stream *tuple = tnt_object(NULL);      /* See note = MAKE REQUEST */
    tnt_object_format(tuple, "[%d%s]", 99999, "B");
    tnt_insert(tnt, 999, tuple);                       /* See note = SEND REQUEST */
    tnt_flush(tnt);
    struct tnt_reply reply;  tnt_reply_init(&reply); /* See note = GET REPLY */
    tnt->read_reply(tnt, &reply);
    if (reply.code != 0) {
        printf("Insert failed %lu.\n", reply.code);
    }
    tnt_close(tnt);                                    /* See below = TEARDOWN */
    tnt_stream_free(tuple);
    tnt_stream_free(tnt);
}
```

Paste the code into a file named example.c and install tarantool-c. One way to install tarantool-c (using Ubuntu) is:

```
$ git clone git://github.com/tarantool/tarantool-c.git ~/tarantool-c
$ cd ~/tarantool-c
$ git submodule init
$ git submodule update
$ cmake .
$ make
$ make install
```

To compile and link the program, say:

```
$ # sometimes this is necessary:
$ export LD_LIBRARY_PATH=/usr/local/lib
$ gcc -o example example.c -ltarantool
```

Before trying to run, check that a server instance is listening at localhost:3301 and that the space examples exists, as described earlier. To run the program, say ./example. The program will connect to the Tarantool instance, and will send the request. If Tarantool is not running on localhost with listen address = 3301, the program will print "Connection refused". If the insert fails, the program will print "Insert failed" and an error number (see all error codes in the source file /src/box/errcode.h).

Here are notes corresponding to comments in the example program.

SETUP: The setup begins by creating a stream.

```
struct tnt_stream *tnt = tnt_net(NULL);
tnt_set(tnt, TNT_OPT_URI, "localhost:3301");
```

In this program, the stream will be named tnt. Before connecting on the tnt stream, some options may have to be set. The most important option is TNT_OPT_URI. In this program, the URI is localhost:3301, since that is where the Tarantool instance is supposed to be listening.

Function description:

```
struct tnt_stream *tnt_net(struct tnt_stream *s)
int tnt_set(struct tnt_stream *s, int option, variant option-value)
```

CONNECT: Now that the stream named tnt exists and is associated with a URI, this example program can connect to a server instance.

```
if (tnt_connect(tnt) < 0)
   { printf("Connection refused\n"); exit(-1); }
```

Function description:

```
int tnt_connect(struct tnt_stream *s)
```

The connection might fail for a variety of reasons, such as: the server is not running, or the URI contains an invalid password. If the connection fails, the return value will be -1.

MAKE REQUEST: Most requests require passing a structured value, such as the contents of a tuple.

```
struct tnt_stream *tuple = tnt_object(NULL);
tnt_object_format(tuple, "[%d%s]", 99999, "B");
```

In this program, the request will be an INSERT, and the tuple contents will be an integer and a string. This is a simple serial set of values, that is, there are no sub-structures or arrays. Therefore it is easy in this case to format what will be passed using the same sort of arguments that one would use with a C printf() function: %d for the integer, %s for the string, then the integer value, then a pointer to the string value.

Function description:

```
ssize_t tnt_object_format(struct tnt_stream *s, const char *fmt, ...)
```

SEND REQUEST: The database-manipulation requests are analogous to the requests in the box library.

```
tnt_insert(tnt, 999, tuple);
tnt_flush(tnt);
```

In this program, the choice is to do an INSERT request, so the program passes the tnt_stream that was used for connection (tnt) and the tnt_stream that was set up with tnt_object_format() (tuple).

Function description:

```
ssize_t tnt_insert(struct tnt_stream *s, uint32_t space, struct tnt_stream *tuple)
ssize_t tnt_replace(struct tnt_stream *s, uint32_t space, struct tnt_stream *tuple)
ssize_t tnt_select(struct tnt_stream *s, uint32_t space, uint32_t index,
                   uint32_t limit, uint32_t offset, uint8_t iterator,
                   struct tnt_stream *key)
ssize_t tnt_update(struct tnt_stream *s, uint32_t space, uint32_t index,
                   struct tnt_stream *key, struct tnt_stream *ops)
```

GET REPLY: For most requests, the client will receive a reply containing some indication whether the result was successful, and a set of tuples.

```
struct tnt_reply reply;  tnt_reply_init(&reply);
tnt->read_reply(tnt, &reply);
if (reply.code != 0)
   { printf("Insert failed %lu.\n", reply.code); }
```

This program checks for success but does not decode the rest of the reply.

Function description:

```
struct tnt_reply *tnt_reply_init(struct tnt_reply *r)
tnt->read_reply(struct tnt_stream *s, struct tnt_reply *r)
void tnt_reply_free(struct tnt_reply *r)
```

TEARDOWN: When a session ends, the connection that was made with tnt_connect() should be closed, and the objects that were made in the setup should be destroyed.

```
tnt_close(tnt);
tnt_stream_free(tuple);
tnt_stream_free(tnt);
```

Function description:

```
void tnt_close(struct tnt_stream *s)
void tnt_stream_free(struct tnt_stream *s)
```

Example 2

Here is a complete C program that selects, using index key [99999], from space examples via the high-level C API. To display the results, the program uses functions in the MsgPuck library which allow decoding of MessagePack arrays.

```
#include <stdio.h>
#include <stdlib.h>
#include <tarantool/tarantool.h>
#include <tarantool/tnt_net.h>
#include <tarantool/tnt_opt.h>

#define MP_SOURCE 1
#include <msgpuck.h>

void main() {
    struct tnt_stream *tnt = tnt_net(NULL);
    tnt_set(tnt, TNT_OPT_URI, "localhost:3301");
    if (tnt_connect(tnt) < 0) {
        printf("Connection refused\n");
        exit(1);
    }
    struct tnt_stream *tuple = tnt_object(NULL);
    tnt_object_format(tuple, "[%d]", 99999); /* tuple = search key */
    tnt_select(tnt, 999, 0, (2^32) - 1, 0, 0, tuple);
    tnt_flush(tnt);
    struct tnt_reply reply; tnt_reply_init(&reply);
    tnt->read_reply(tnt, &reply);
    if (reply.code != 0) {
        printf("Select failed.\n");
        exit(1);
    }
    char field_type;
    field_type = mp_typeof(*reply.data);
    if (field_type != MP_ARRAY) {
        printf("no tuple array\n");
        exit(1);
    }
    long unsigned int row_count;
```

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```
    uint32_t tuple_count = mp_decode_array(&reply.data);
    printf("tuple count=%u\n", tuple_count);
    unsigned int i, j;
    for (i = 0; i < tuple_count; ++i) {
        field_type = mp_typeof(*reply.data);
        if (field_type != MP_ARRAY) {
            printf("no field array\n");
            exit(1);
        }
        uint32_t field_count = mp_decode_array(&reply.data);
        printf("  field count=%u\n", field_count);
        for (j = 0; j < field_count; ++j) {
            field_type = mp_typeof(*reply.data);
            if (field_type == MP_UINT) {
                uint64_t num_value = mp_decode_uint(&reply.data);
                printf("    value=%lu.\n", num_value);
            } else if (field_type == MP_STR) {
                const char *str_value;
                uint32_t str_value_length;
                str_value = mp_decode_str(&reply.data, &str_value_length);
                printf("    value=%.*s.\n", str_value_length, str_value);
            } else {
                printf("wrong field type\n");
                exit(1);
            }
        }
    }
    tnt_close(tnt);
    tnt_stream_free(tuple);
    tnt_stream_free(tnt);
}
```

Similarly to the first example, paste the code into a file named example2.c.

To compile and link the program, say:

```
$ gcc -o example2 example2.c -ltarantool
```

To run the program, say ./example2.

The two example programs only show a few requests and do not show all that's necessary for good practice. See more in the tarantool-c documentation at GitHub.

4.7.14 Interpreting function return values

For all connectors, calling a function via Tarantool causes a return in the MsgPack format. If the function is called using the connector's API, some conversions may occur. All scalar values are returned as tuples (with a MsgPack type-identifier followed by a value); all non-scalar values are returned as a group of tuples (with a MsgPack array-identifier followed by the scalar values). If the function is called via the binary protocol command layer – "eval" – rather than via the connector's API, no conversions occur.

In the following example, a Lua function will be created. Since it will be accessed externally by a 'guest' user, a grant of an execute privilege will be necessary. The function returns an empty array, a scalar string, two booleans, and a short integer. The values are the ones described in the table Common Types and MsgPack Encodings.

```
tarantool> box.cfg{listen=3301}
2016-03-03 18:45:52.802 [27381] main/101/interactive I> ready to accept requests
---
...
tarantool> function f() return {},'a',false,true,127; end
---
...
tarantool> box.schema.func.create('f')
---
...
tarantool> box.schema.user.grant('guest','execute','function','f')
---
...
```

Here is a C program which calls the function. Although C is being used for the example, the result would be precisely the same if the calling program was written in Perl, PHP, Python, Go, or Java.

```
#include <stdio.h>
#include <stdlib.h>
#include <tarantool/tarantool.h>
#include <tarantool/tnt_net.h>
#include <tarantool/tnt_opt.h>
void main() {
  struct tnt_stream *tnt = tnt_net(NULL);              /* SETUP */
  tnt_set(tnt, TNT_OPT_URI, "localhost:3301");
   if (tnt_connect(tnt) < 0) {                         /* CONNECT */
       printf("Connection refused\n");
       exit(-1);
   }
   struct tnt_stream *arg; arg = tnt_object(NULL);     /* MAKE REQUEST */
   tnt_object_add_array(arg, 0);
   struct tnt_request *req1 = tnt_request_call(NULL);  /* CALL function f() */
   tnt_request_set_funcz(req1, "f");
   uint64_t sync1 = tnt_request_compile(tnt, req1);
   tnt_flush(tnt);                                     /* SEND REQUEST */
   struct tnt_reply reply;  tnt_reply_init(&reply);    /* GET REPLY */
   tnt->read_reply(tnt, &reply);
   if (reply.code != 0) {
     printf("Call failed %lu.\n", reply.code);
     exit(-1);
   }
   const unsigned char *p= (unsigned char*)reply.data; /* PRINT REPLY */
   while (p < (unsigned char *) reply.data_end)
   {
     printf("%x ", *p);
     ++p;
   }
   printf("\n");
   tnt_close(tnt);                                     /* TEARDOWN */
   tnt_stream_free(arg);
   tnt_stream_free(tnt);
}
```

When this program is executed, it will print:

```
dd 0 0 0 5 90 91 a1 61 91 c2 91 c3 91 7f
```

The first five bytes – dd 0 0 0 5 – are the MsgPack encoding for "32-bit array header with value 5" (see

MsgPack specification). The rest are as described in the table Common Types and MsgPack Encodings.

4.8 FAQ

Q Why Tarantool?

A Tarantool is the latest generation of a family of in-memory data servers developed for web applications. It is the result of practical experience and trials within Mail.Ru since development began in 2008.

Q Why Lua?

A Lua is a lightweight, fast, extensible multi-paradigm language. Lua also happens to be very easy to embed. Lua coroutines relate very closely to Tarantool fibers, and Lua architecture works well with Tarantool internals. Lua acts well as a stored program language for Tarantool, although connecting with other languages is also easy.

Q What's the key advantage of Tarantool?

A

Tarantool provides a rich database feature set (HASH, TREE, RTREE, BITSET indexes, secondary indexes, composite indexes, transactions, triggers, asynchronous replication) in a flexible environment of a Lua interpreter.

These two properties make it possible to be a fast, atomic and reliable in-memory data server which handles non-trivial application-specific logic. The advantage over traditional SQL servers is in performance: low-overhead, lock-free architecture means Tarantool can serve an order of magnitude more requests per second, on comparable hardware. The advantage over NoSQL alternatives is in flexibility: Lua allows flexible processing of data stored in a compact, denormalized format.

Q Who is developing Tarantool?

A There is an engineering team employed by Mail.Ru – check out our commit logs on github.com/tarantool. The development is fully open. Most of the connectors' authors, and the maintainers for different distributions, come from the wider community.

Q Are there problems associated with being an in-memory server?

A The principal storage engine (memtx) is designed for RAM plus persistent storage. It is immune to data loss because there is a write-ahead log. Its memory-allocation and compression techniques ensure there is no waste. And if Tarantool runs out of memory, then it will stop accepting updates until more memory is available, but will continue to handle read and delete requests without difficulty. However, for databases which are much larger than the available RAM space, Tarantool has a second storage engine (vinyl) which is only limited by the available disk space.

Q Can I store (large) BLOBs in Tarantool?

A Starting with Tarantool 1.7, there is no "hard" limit for the maximal tuple size. Tarantool, however, is designed for high-velocity workload with a lot of small chunks. For example, when you change an existing tuple, Tarantool creates a new version of the tuple in memory. Thus, an optimal tuple size is within kilobytes.

Q I delete data from vinyl, but disk usage stays the same. What gives?

A Data you write to vinyl is persisted in append-only run files. These files are immutable, and to perform a delete, a deletion marker (tombstone) is written to a newer run file instead. On compaction, new and old run files are merged, and a new run file is produced. Independently, the checkpoint manager keeps track of all run files involved in a checkpoint, and deletes obsolete files once they are no longer needed.

CHAPTER 5

Reference

5.1 SQL reference

This reference covers all the SQL statements and clauses supported by Tarantool.

5.1.1 SQL beginners' guide

What Tarantool's SQL product delivers

Tarantool's SQL is a major new feature that was first introduced with Tarantool version 2.1. The primary advantages are: - a high level of SQL compatibility - an easy way to switch from NoSQL to SQL and back - the Tarantool brand.

The "high level of SQL compatibility" includes support for joins, subqueries, triggers, indexes, groupings, transactions in a multi-user environment, and conformance with the majority of the mandatory requirements of the SQL:2016 standard.

The "easy way to switch" consists of the fact that the same tables can be operated on with SQL and with the long-established Tarantool-NoSQL product, meaning that when you want standard Relational-DBMS jobs you can do them, and when you want NoSQL capability you can have it (Tarantool-NoSQL outperforms other NoSQL products in public benchmarks).

The "Tarantool brand" comes from the support of a multi-billion-dollar internet / mail / social-network provider, a dozens-of-professionals staff of programmers and support people, a community who believes in open-source BSD licensing, and hundreds of corporations / government bodies using Tarantool products in production already.

The status of Tarantool's SQL feature is "release". So, it is working now and you can verify that by downloading it and trying all the features, which we will explain in the rest of this document. There is also a tutorial.

This document has four parts. The SQL BEGINNERS' GUIDE explains the basics of relational database management and SQL in particular. The USER GUIDE explains "How to get Started" and explains the terms and the syntax elements that apply for all SQL statements. The SQL STATEMENTS AND CLAUSES guide explains, for each SQL statement, the format and the rules and the exceptions and the examples and the limitations. The SQL PLUS LUA guide has the details about calling Lua from SQL, calling SQL from Lua, and using the same database objects in both SQL and Lua.

Users are expected to know what databases are, and experience with other SQL DBMSs would be an advantage.

SQL beginners' guide begins

The Beginners' Guide describes how users can start up with SQL with Tarantool, and necessary concepts.

The SQL Beginners' Guide is about databases in general, and about the relationship between Tarantool's NoSQL and SQL products. Most of the matters in the Beginners' Guide will already be familiar to people who have used relational databases before.

Sample Simple Table

In football training camp it is traditional for the trainer to begin by showing a football and saying "this is a football". In that spirit, this is a table:

```
TABLE
           [1]                [2]                [3]
       +-----------------+----------------+----------------+
 Row#1 | Row#1,Column#1  | Row#1,Column#2 | Row#1,Column#3 |
       +-----------------+----------------+----------------+
 Row#2 | Row#2,Column#1  | Row#2,Column#2 | Row#2,Column#3 |
       +-----------------+----------------+----------------+
 Row#3 | Row#3,Column#1  | Row#3,Column#2 | Row#3,Column#3 |
       +-----------------+----------------+----------------+
```

but the labels are misleading – we usually don't identify rows and columns by their ordinal positions, we prefer to pick out specific items by their contents. In that spirit, this is a table:

```
modules

+-----------------+------+---------------------+
| name            | size | purpose             |
+-----------------|------|---------------------|
| box             | 1432 | Database Management |
| clock           |  188 | Seconds             |
| crypto          |    4 | Cryptography        |
+-----------------+------+---------------------+
```

so we do not use longitude/latitude navigation by talking about "Row#2 Column #2", we use the contents of the Name column and the name of the Size column by talking about "the size, where the name is 'clock'". To be more exact, this is what we say:

SELECT size FROM modules WHERE name = `'clock'`;

If you're familiar with Tarantool's architecture – and we hope that you read about that before coming to this chapter – then you know that there is a NoSQL way to get the same thing:

box.space.MODULES:select()[2][2]

Well, you can do that. One of the advantages of Tarantool is that if you can get data via an SQL statement, then you can get the same data via a NoSQL request. But the reverse is not true, because not all NoSQL tuple sets are definable as SQL tables. These restrictions apply for SQL that do not apply for NoSQL: 1. Every column must have a name. 2. Every column must have a scalar type (Tarantool is relaxed about which particular scalar type you can have, but there is no way to index and search arrays, tables within tables, or what MessagePack calls "maps".)

Tarantool/NoSQL's "format" clause causes the same restrictions.

So an SQL "table" is a NoSQL "tuple set with format restrictions", an SQL "row" is a NoSQL "tuple", an SQL "column" is a NoSQL "list of fields within a tuple set".

Creating a table

This is how to create the modules table:

CREATE TABLE modules (name STRING, size INTEGER, purpose STRING, PRIMARY KEY (name));

The words that are IN CAPITAL LETTERS are "keywords" (although it is only a convention in this manual that keywords are in capital letters, in practice many programmers prefer to avoid shouting). A keyword has meaning for the SQL parser so many keywords are reserved, they cannot be used as names unless they are enclosed inside quotation marks.

The word "modules" is a "table name", and the words "name" and "size" and "purpose" are "column names". All tables and all columns must have names.

The words "STRING" and "INTEGER" are "data types". STRING means "the contents should be characters, the length is indefinite, the equivalent NoSQL type is 'string'". INTEGER means "the contents should be numbers without decimal points, the equivalent NoSQL type is 'integer'". Tarantool supports other data types but our example table has data types from the two main groups, namely, data types for numbers and data types for strings.

The final clause, PRIMARY KEY (name), means that the name column is the main column used to identify the row.

Nulls

Frequently it is necessary, at least temporarily, that a column value should be NULL. Typical situations are: the value is unknown, or the value is not applicable. For example, you might make a module as a placeholder but you don't want to say its size or purpose. If such things are possible, the column is "nullable". Our name column cannot contain nulls, and it could be defined explicitly as "name STRING NOT NULL", but in this case that's unnecessary – a column defined as PRIMARY KEY is automatically NOT NULL.

Is a NULL in SQL the same thing as a nil in Lua? No, but it is close enough that there will be confusion. When nil means "unknown" or "inapplicable", yes. But when nil means "nonexistent" or "type is nil", no. NULL is a value, it has a data type because it is inside a column which is defined with that data type.

Creating an index

This is how to create indexes for the modules table:

CREATE INDEX size ON modules (size); CREATE UNIQUE INDEX purpose ON modules (purpose);

There is no need to create an index on the name column, because Tarantool creates an index automatically when it sees a PRIMARY KEY clause in the CREATE TABLE statement. In fact there is no need to create indexes on the size or purpose columns either – if indexes don't exist, then it is still possible to use the columns for searches. Typically people create non-primary indexes, also called secondary indexes, when it becomes clear that the table will grow large and searches will be frequent, because searching with an index is generally much faster than searching without an index.

Another use for indexes is to enforce uniqueness. When an index is created with CREATE UNIQUE INDEX for the purpose column, it is not possible to have duplicate values in that column.

Data change

Putting data into a table is called "inserting". Changing data is called "updating". Removing data is called "deleting". Together, the three SQL statements INSERT plus UPDATE plus DELETE are the three main "data-change" statements.

This is how to insert, update, and delete a row in the modules table:

INSERT INTO modules VALUES ('json', 14, 'format functions for JSON'); UPDATE modules SET size = 15 WHERE name = 'json'; DELETE FROM modules WHERE name = 'json';

The corresponding non-SQL Tarantool requests would be:

box.space.MODULES:insert{'json', 14, 'format functions for JSON'} box.space.MODULES:update('json', {{'=', 2, 15}}) box.space.MODULES:delete{'json'}

This is how we would populate the table with the values that we showed earlier:

INSERT INTO modules VALUES ('box', 1432, 'Database Management'); INSERT INTO modules VALUES ('clock', 188, 'Seconds'); INSERT INTO modules VALUES ('crypto', 4, 'Cryptography');

Constraints

Some data-change statements are illegal due to something in the table's definition. This is called "constraining what can be done". We have already seen some types of constraints . . .

NOT NULL – if a column is defined with a NOT NULL clause, it is illegal to put NULL into it. A primary-key column is automatically NOT NULL.

UNIQUE – if a column has a UNIQUE index, it is illegal to put a duplicate into it. A primary-key column automatically has a UNIQUE index.

data domain – if a column is defined as having data type INTEGER, it is illegal to put a non-number into it. More generally, if a value doesn't correspond to the data type of the definition, it is illegal. However, some database management systems (DBMSs) are very forgiving and will try to make allowances for bad values rather than reject them; Tarantool is one of those DBMSs.

Now, here are other types of constraints . . .

CHECK – a table description can have a clause "CHECK (conditional expression)". For example, if the CREATE TABLE modules statement looked like this:

```
CREATE TABLE modules (name STRING,
                      size INTEGER,
                      purpose STRING,
                      PRIMARY KEY (name),
                      CHECK (size > 0));
```

then this INSERT statement would be illegal: INSERT INTO modules VALUES ('box', 0, 'The Database Kernel'); because there is a CHECK constraint saying that the second column, the size column, cannot contain a value which is less than or equal to zero. Try this instead: INSERT INTO modules VALUES ('box', 1, 'The Database Kernel');

FOREIGN KEY – a table description can have a clause "FOREIGN KEY (column-list) REFERENCES table (column-list)". For example, if there is a new table "submodules" which in a way depends on the modules table, it can be defined like this:

```
CREATE TABLE submodules (name STRING,
                         module_name STRING,
                         size INTEGER,
                         purpose STRING,
                         PRIMARY KEY (name),
                         FOREIGN KEY (module_name) REFERENCES
                         modules (name));
```

Now try to insert a new row into this submodules table:

INSERT INTO submodules VALUES ('space', 'Box', 10000, 'insert etc.');

The insert will fail because the second column (module_name) refers to the name column in the modules table, and the name column in the modules table does not contain 'Box'. However, it does contain 'box'. By default searches in Tarantool's SQL use a binary collation. This will work:

INSERT INTO submodules VALUES ('space', 'box', 10000, 'insert etc.');

Now try to delete the new row from the modules table:

DELETE FROM modules WHERE name = 'box';

The delete will fail because the second column (module_name) in the submodules table refers to the name column in the modules table, and the name column in the modules table would not contain 'box' if the delete succeeded. So the FOREIGN KEY constraint affects both the table which contains the FOREIGN KEY clause and the table that the FOREIGN KEY clause refers to.

The constraints in a table's definition – NOT NULL, UNIQUE, data domain, CHECK, and FOREIGN KEY – are guarantors of the database's integrity. It is important that they are fixed and well-defined parts of the definition, and hard to bypass with SQL. This is often seen as a difference between SQL and NoSQL – SQL emphasizes law and order, NoSQL emphasizes freedom and making your own rules.

Table Relationships

Think about the two tables that we have discussed so far:

```
CREATE TABLE modules (name STRING,
                      size INTEGER,
                       purpose STRING,
                       PRIMARY KEY (name),
                       CHECK (size > 0));

CREATE TABLE submodules (name STRING,
                         module_name STRING,
                         size INTEGER,
                         purpose STRING,
                         PRIMARY KEY (name),
                         FOREIGN KEY (module_name) REFERENCES
                         modules (name));
```

Because of the FOREIGN KEYS clause in the submodules table, there is clearly a many-to-one relationship: submodules –>> modules that is, every submodules row must refer to one (and only one) modules row, while every modules row can be referred to in zero or more submodules rows.

Table relationships are important, but beware: do not trust anyone who tells you that databases made with SQL are relational "because there are relationships between tables". That is wrong. We will see why when we talk about what makes a database relational, later.

Selecting with WHERE

We gave a simple example of a SELECT statement earlier:

SELECT size FROM modules WHERE name = 'clock';

The clause "WHERE name = 'clock'" is legal in other statements – we have seen it in UPDATE and DELETE – but here we will only give examples with SELECT.

The first variation is that the WHERE clause does not have to be specified at all, it is optional. So this statement would return all rows:

SELECT size FROM modules;

The second variation is that the comparison operator does not have to be '=', it can be anything that makes sense: '>' or '>=' or '<' or '<=', or 'LIKE' which is an operator that works with strings that may contain wildcard characters '_' meaning 'match any one character' or '%' meaning 'match any zero or one or many characters'. These are legal statements which return all rows:

SELECT size FROM modules WHERE name >= `''`; SELECT size FROM modules WHERE name LIKE `'%'`;

The third variation is that IS [NOT] NULL is a special condition. Remembering that the NULL value can mean "it is unknown what the value should be", and supposing that in some row the size is NULL, then the condition "size > 10" is not certainly true and it is not certainly false, so it is evaluated as "unknown". Ordinarily the application of a WHERE clause filters out both false and unknown results. So when searching for NULL, say IS NULL; when searching anything that is not NULL, say IS NOT NULL. This statement will return all rows because (due to the definition) there are no NULLs in the name column:

SELECT size FROM modules WHERE name IS NOT NULL;

The fourth variation is that conditions can be combined with AND / OR, and negated with NOT.

So this statement would return all rows (the first condition is false but the second condition is true, and OR means "return true if either condition is true"):

```
SELECT size
FROM modules
WHERE name = 'wombat' OR size IS NOT NULL;
```

Selecting with a select list

Yet again, here is a simple example of a SELECT statement:

SELECT size FROM modules WHERE name = `'clock'`;

The words between SELECT and FROM are the select list. In this case, the select list is just one word: size. Formally it means that the desire is to return the size values, and technically the name for picking a particular column is called "projection".

The first variation is that one can specify any column in any order:

SELECT name, purpose, size FROM modules;

The second variation is that one can specify an expression, it does not have to be a column name, it does not even have to include a column name. The common expression operators for numbers are the arithmetic operators + - / *; the common expression operator for strings is the concatenation operator ||. For example this statement will return 8, 'XY':

SELECT size * 2, `'X'` || `'Y'` FROM modules WHERE size = 4;

The third variation is that one can add a clause [AS name] after every expression, so that in the return the column titles will make sense. This is especially important when a title might otherwise be ambiguous or meaningless. For example this statement will return 8, 'XY' as before

SELECT size * 2 AS double_size, `'X'` || `'Y'` AS concatenated_literals FROM modules WHERE size = 4;

but displayed as a table the result will look like

```
+----------------+------------------------+
| double_size    | concatenated_literals  |
+----------------+------------------------+
|               8| XY                     |
+----------------+------------------------+
```

Selecting with a select list with asterisk

Instead of listing columns in a select list, one can just say `'*'`. For example

SELECT * FROM modules;

This is the same thing as

SELECT name, size, purpose FROM modules;

Selecting with "*" saves time for the writer, but it is unclear to a reader who has not memorized what the column names are. Also it is unstable, because there is a way to change a table's definition (the ALTER statement, which is an advanced topic). Nevertheless, although it might be bad to use it for production, it is handy to use it for introduction, so we will use "*" in several examples.

Select with subqueries

Remember that we have a modules table and we have a submodules table. Suppose that we want to list the submodules that refer to modules for which the purpose is X. That is, this involves a search of one table using a value in another table. This can be done by enclosing "(SELECT . . .)" within the WHERE clause. For example:

```
SELECT name FROM submodules
WHERE module_name =
   (SELECT name FROM modules WHERE purpose LIKE '%Database%');
```

Subqueries are also useful in the select list, when one wishes to combine information from more than one table. For example this statement will display submodules rows but will include values that come from the modules table:

```
SELECT name AS submodules_name,
   (SELECT purpose FROM modules
    WHERE modules.name = submodules.module_name)
    AS modules_purpose,
   purpose AS submodules_purpose
FROM submodules;
```

Whoa. What are "modules.name" and "submodules.name"? Whenever you see "x . y" you are looking at a "qualified column name", and the first part is a table identifier, the second part is a column identifier. It is always legal to use qualified column names, but until now it has not been necessary. Now it is necessary, or at least it is a good idea, because both tables have a column named "name".

The result will look like this:

```
+-----------------+---------------------+-------------------+
| submodules_name | modules_purpose     | submodules_purpose |
+-----------------+---------------------+-------------------+
| space           | Database Management | insert etc.       |
+-----------------+---------------------+-------------------+
```

Perhaps you have read somewhere that SQL stands for "Structured Query Language". That is not true any more. But it is true that the query syntax allows for a structural component, namely the subquery, and that was the original idea. However, there is a different way to combine tables – with joins instead of subqueries.

Select with Cartesian join

Until now we have only used "FROM modules" or "FROM submodules" in our SELECT statements. What if we used more than one table in the FROM clause? For example

SELECT * FROM modules, submodules; or SELECT * FROM modules JOIN submodules;

That is legal. Usually it is not what you want, but it is a learning aid. The result will be:

```
{ columns from modules table }          { columns from submodules table }
+--------+------+---------------------+-------+-------------+-------+-------------+
| name   | size | purpose             | name  | module_name | size  | purpose     |
+--------+------+---------------------+-------+-------------+-------+-------------+
| box    | 1432 | Database Management | space | box         | 10000 | insert etc. |
| clock  | 188  | Seconds             | space | box         | 10000 | insert etc. |
| crypto |    4 | Cryptography        | space | box         | 10000 | insert etc. |
+--------+------+---------------------+-------+-------------+-------+-------------+
```

It is not an error. The meaning of this type of join is "combine every row in table-1 with every row in table-2". It did not specify what the relationship should be, so the result has everything, even when the submodule has nothing to do with the module.

It is handy to look at the above result, called a "Cartesian join" result, to see what we really want. Probably for this case the row that actually makes sense is the one where the modules.name = submodules.module_name, and we should make that clear in both the select list and the WHERE clause, thus:

```
SELECT modules.name AS modules_name,
       modules.size AS modules_size,
       modules.purpose AS modules_purpose,
       submodules.name,
       module_name,
       submodules.size,
       submodules.purpose
FROM modules, submodules
WHERE modules.name = submodules.module_name;
```

The result will be:

```
+----------+-----------+------------+--------+---------+-------+-------------+
| modules_ |  modules_ | modules_   | name   | module_ | size  | purpose     |
| name     |  size     | purpose    |        | name    |       |             |
+----------+-----------+------------ --+--------+---------+-------+-------------|
| box      | 1432      | Database   | space  | box     | 10000 | insert etc. |
|          |           | Management |        |         |       |             |
+----------+-----------+------------+--------+---------+-------+-------------|
```

In other words, you can specify a Cartesian join in the FROM clause, then you can filter out the irrelevant rows in the WHERE clause, and then you can rename columns in the select list. This is fine, and every SQL DBMS supports this. But it is worrisome that the number of rows in a Cartesian join is always (number of rows in first table multiplied by number of rows in second table), which means that conceptually you are often filtering in a large set of rows.

It is good to start by looking at Cartesian joins because they show the concept. Many people, though, prefer to use different syntaxes for joins because they look better or clearer. We will look at those alternatives now.

Select with join with ON clause

The ON clause would have the same comparisons as the WHERE clause that we illustrated for the previous section, but by using different syntax we would be making it clear "this is for the sake of the join". Readers can see at a glance that it is, in concept at least, an initial step before the result rows are filtered. For example this

SELECT * FROM modules JOIN submodules   ON (modules.name = submodules.module_name);

is the same as

SELECT * FROM modules, submodules   WHERE modules.name = submodules.module_name;

Select with join with USING clause

The USING clause would take advantage of names that are held in common between the two tables, with the assumption that the intent is to match those columns with '=' comparisons. For example,

SELECT * FROM modules JOIN submodules USING (name);

has the same effect as

SELECT * FROM modules JOIN submodules WHERE modules.name = submodules.name;

If we had created our table with a plan in advance to use USING clauses, that would save time. But we did not. So, although the above example "works", the results will not be sensible.

Select with natural join

A natural join would take advantage of names that are held in common between the two tables, and would do the filtering automatically based on that knowledge, and throw away duplicate columns.

If we had created our table with a plan in advance to use natural joins, that would be very handy. But we did not. So, although the following example "works", the results won't be sensible.

SELECT * FROM modules NATURAL JOIN submodules;

Result: nothing, because modules.name does not match submodules.name, and so on And even if there had been a result, it would only have included four columns: name, module_name, size, purpose.

Select with left join

Now what if we want to join modules to submodules, but we want to be sure that we get all the modules? In other words, we want to get modules even if the condition submodules.module_name = modules.name is not true, because the module has no submodules.

When that is what we want, the type of join is an "outer join" (as opposed to the type we have used so far which is an "inner join"). Specifically we will use LEFT [OUTER] JOIN because our main table, modules, is on the left. For example:

```
SELECT *
FROM modules LEFT JOIN submodules
ON modules.name = submodules.module_name;
```

which returns:

```
{ columns from modules table }         { columns from submodules table }
+--------+------+---------------------+-------+-------------+-------+-------------+
| name   | size | purpose             | name  | module_name | size  | purpose     |
+--------+------+---------------------+-------+-------------+-------+-------------+
| box    | 1432 | Database Management | space | box         | 10000 | insert etc. |
| clock  | 188  | Seconds             | NULL  | NULL        | NULL  | NULL        |
| crypto |    4 | Cryptography        | NULL  | NULL        | NULL  | NULL        |
+--------+------+---------------------+-------+-------------+-------+-------------+
```

Thus, for the submodules of the clock module and the submodules of the crypto module – which do not exist – there are NULLs in every column.

Select with functions

A function can take any expression, including an expression that contains another function, and return a scalar value. There are many such functions. We will just describe one, SUBSTR, which returns a substring of a string.

Format: SUBSTR(input-string, start-with [, length])

Description: SUBSTR takes input-string, eliminates any characters before start-with, eliminates any characters after (start-with plus length), and returns the result.

Example: SUBSTR('abcdef', 2, 3) returns 'bcd'.

Select with aggregation, GROUP BY, and HAVING

Remember that our modules table looks like this:

```
modules

+-----------------+------+---------------------+
| name            | size | purpose             |
+-----------------|------|---------------------|
| box             | 1432 | Database Management |
| clock           |  188 | Seconds             |
| crypto          |    4 | Cryptography        |
+-----------------+------+---------------------+
```

Suppose that we do not want to know all the individual size values, we just want to know about their aggregation, that is, take the attributes of the collection. SQL allows five aggregation functions: AVG (average), SUM, MIN (minimum), MAX (maximum), and COUNT. For example

SELECT AVG(size), SUM(size), MIN(size), MAX(size), COUNT(size) FROM modules;

The result will look like this:

```
+--------------+-----------+-----------+-----------+-------------+
| AVG(size)    | SUM(size) | MIN(size) | MAX(size) | COUNT(size) |
+--------------+-----------+-----------+-----------+-------------|
| 5.413333E+02 | 1624      |         4 |      1432 |           3 |
+--------------+-----------+-----------+-----------+-------------+
```

Suppose that we want aggregations, but aggregations of rows that have some common characteristic. Supposing further, we want to divide the rows into two groups, the ones whose names begin with 'b' and the ones whose names begin with 'c'. This can be done by adding a clause [GROUP BY expression]. For example,

```
SELECT SUBSTR(name, 1, 1), AVG(size), SUM(size), MIN(size), MAX(size), COUNT(size)
FROM modules
GROUP BY SUBSTR(name, 1, 1);
```

The result will look like this:

```
+--------------------+--------------+-----------+-----------+-----------+-------------+
| SUBSTR(name, 1, 1) | AVG(size)    | SUM(size) | MIN(size) | MAX(size) | CoUNT(size) |
+--------------------+--------------+-----------+-----------+-----------|-------------|
| b                  |         1432 |      1432 |      1432 |      1432 |           1 |
| c                  |           96 |       192 |         4 |       188 |           2 |
+--------------------+--------------+-----------+-----------+-----------|-------------+
```

Select with common table expression

It is possible to define a temporary (viewed) table within a statement, usually within a SELECT statement, using a WITH clause. For example:

WITH tmp_table AS (SELECT x1 FROM t1) SELECT * FROM tmp_table;

Select with order, limit, and offset clauses

Every time we have searched in the modules table, the rows have come out in alphabetical order by name: 'box', then 'clock', then 'crypto'. However, if we want to be sure about the order, or if we want a different order, we will have to be explicit and add a clause: ORDER BY column-name [ASC|DESC]. (ASC stands for ASCending, DESC stands for DESCending.) For example:

SELECT * FROM modules ORDER BY name DESC;

The result will be the usual rows, in descending alphabetical order: 'crypto' then 'clock' then 'box'.

After the ORDER BY clause we can add a clause LIMIT n, where n is the maximum number of rows that we want. For example:

SELECT * FROM modules ORDER BY name DESC LIMIT 2;

The result will be the first two rows, 'crypto' and 'clock'.

After the ORDER BY clause and the LIMIT clause we can add a clause OFFSET n, where n is the row to start with. The first offset is 0. For example:

SELECT * FROM modules ORDER BY name DESC LIMIT 2 OFFSET 2;

The result will be the third row, 'box'.

Views

A view is a canned SELECT. If you have a complex SELECT that you want to run frequently, create a view and then do a simple SELECT on the view. For example:

```
CREATE VIEW v AS SELECT size, (size *5) AS size_times_5
FROM modules
GROUP BY size, name
ORDER BY size_times_5;
SELECT * FROM v;
```

Transactions

Tarantool has a "Write Ahead Log" (WAL). Effects of data-change statements are logged before they are permanently stored on disk. This is a reason that, although entire databases can be stored in temporary memory, they are not vulnerable in case of power failure.

Tarantool supports commits and rollbacks. In effect, asking for a commit means asking for all the recent data-change statements, since a transaction began, to become permanent. In effect, asking for a rollback means asking for all the recent data-change statements, since a transaction began, to be cancelled.

For example, consider these statements:

```
CREATE TABLE things (remark STRING, PRIMARY KEY (remark));
START TRANSACTION;
INSERT INTO things VALUES ('A');
COMMIT;
START TRANSACTION;
INSERT INTO things VALUES ('B');
ROLLBACK;
SELECT * FROM things;
```

The result will be: one row, containing 'A'. The ROLLBACK cancelled the second INSERT statement, but did not cancel the first one, because it had already been committed.

Ordinarily every statement is automatically committed.

After START TRANSACTION, statements are not automatically committed – Tarantool considers that a transaction is now "active", until the transaction ends with a COMMIT statement or a ROLLBACK statement. While a transaction is active, all statements are legal except another START TRANSACTION.

Implementing Tarantool's SQL On Top of NoSQL

Tarantool's SQL data is the same as Tarantool's NoSQL data. When you create a table or an index with SQL, you are creating a space or an index in NoSQL. For example:

```
CREATE TABLE things (remark STRING, PRIMARY KEY (remark));
INSERT INTO things VALUES ('X');
```

is somewhat similar to

```
box.schema.space.create('THINGS',
{
    format = {
              [1] = {["name"] = "REMARK", ["type"] = "string"}
              }
})
box.space.THINGS:create_index('pk_unnamed_THINGS_1',{unique=true,parts={1,'string'}})
box.space.THINGS:insert{'X'}
```

Therefore you can take advantage of Tarantool's NoSQL features even though your primary language is SQL. Here are some possibilities.

(1) NoSQL applications written in one of the connector languages may be slightly faster than SQL applications because SQL statements may require more parsing and may be translated to NoSQL requests.

(2) You can write stored procedures in Lua, combining Lua loop-control and Lua library-access statements with SQL statements. These routines are executed on the server, which is the principal advantage of pure-SQL stored procedures.

(3) There are some options that are implemented in NoSQL that are not (yet) implemented in SQL. For example you can use NoSQL to change an index option, and to deny access to users named 'guest'.

(4) System spaces such as _space and _index can be accessed with SQL SELECT statements. This is not quite the same as an information_schema, but it does mean that you can use SQL to access the database's metadata catalog.

Fields in NoSQL spaces can be accessed with SQL if and only if they are scalar and are defined in format clauses. Indexes of NoSQL spaces will be used with SQL if and only if they are TREE indexes.

Relational Databases

Edgar F. Codd, the person most responsible for researching and explaining relational database concepts, listed the main criteria as (Codd's 12 rules).

Although we do not advertise Tarantool as "relational", we claim that Tarantool complies with these rules, with the following caveats and exceptions ...

The rules state that all data must be viewable as relations. A Tarantool SQL table is a relation. However, it is possible to have duplicate values in SQL tables and it is possible to have an implicit ordering. Those characteristics are not allowed for true relations.

The rules state that there must be a dynamic online catalog. Tarantool has one but some metadata is missing from it.

The rules state that the data language must support authorization. Tarantool's SQL does not. Authorization occurs via NoSQL requests.

The rules require that data must be physically independent (from underlying storage changes) and logically independent (from application program changes). So far we do not have enough experience to make this guarantee.

The rules require certain types of updatable views. Tarantool's views are not updatable.

The rules state that it should be impossible to use a low-level language to bypass integrity as defined in the relational-level language. In our case, this is not true, for example one can execute a request with Tarantool's NoSQL to violate a foreign-key constraint that was defined with Tarantool's SQL.

5.1.2 SQL user guide

The User Guide describes how users can start up with SQL with Tarantool, and necessary concepts.

Getting Started

The explanations for installing and starting the Tarantool server are in earlier chapters of the Tarantool manual..

To get started specifically with the SQL features, using Tarantool as a client, execute these requests:

```
box.cfg{}
box.execute([[VALUES ('hello');]])
```

The bottom of the screen should now look like this:

```
tarantool> box.execute([[VALUES ('hello');]])
---
- metadata:
  - name: column1
    type: string
  rows:
  - ['hello']
...
```

That's an SQL statement done with Tarantool.

Now you are ready to execute any SQL statements via the connection. For example

```
box.execute([[CREATE TABLE things (id INTEGER PRIMARY key,
                                   remark STRING);]])
box.execute([[INSERT INTO things VALUES (55, 'Hello SQL world!');]])
box.execute([[SELECT * FROM things WHERE id > 0;]])
```

And you will see the results of the SQL query.

For the rest of this chapter, the box.execute([[…]]) enclosure will not be shown. Examples will simply say what a piece of syntax looks like, such as SELECT `'hello'`; and users should know that must be entered as box.execute([[SELECT `'hello'`;]]) It is also legal to enclose SQL statements inside single or double quote marks instead of [[…]].

Supported syntax

Keywords, for example CREATE or INSERT or VALUES, may be entered in either upper case or lower case.

Literal values, for example 55 or `'Hello SQL world!'`, should be entered without single quote marks if they are numeric, and should be entered with single quote marks if they are strings.

Object names, for example table1 or column1, should usually be entered without double quote marks and are subject to some restrictions. They may be enclosed in double quote marks and in that case they are subject to fewer restrictions.

Almost all keywords are reserved, which means that they cannot be used as object names unless they are enclosed in double quote marks.

Comments may be between /* and */ (bracketed) or between -- and the end of a line (simple).

```
INSERT /* This is a bracketed comment */ INTO t VALUES (5);
INSERT INTO t VALUES (5); -- this is a simple comment
```

Expressions, for example a + b OR a > b AND NOT a <= b, may have arithmetic operators + - / *, may have comparison operators = > < <= >= LIKE, and may be combined with AND OR NOT, with optional parentheses.

SQL statements should end with ; (semicolon); this is not mandatory but it is recommended.

In alphabetical order, the following statements are legal.

ALTER TABLE table-name [RENAME or ADD CONSTRAINT or DROP CONSTRAINT clauses]; ANALYZE [table-name]; – temporarily disabled in current version COMMIT; CREATE [UNIQUE] INDEX [IF NOT EXISTS] index-name ON table-name (column-name [, column-name …]); CREATE TABLE [IF NOT EXISTS] table-name (column-or-constraint-definition [, column-or-constraint-definition …]) [WITH ENGINE = engine-name]; CREATE TRIGGER [IF NOT EXISTS] trigger-name BEFORE|AFTER INSERT|UPDATE|DELETE ON table-name FOR EACH ROW BEGIN dml-statement [, dml-statement …] END; CREATE VIEW [IF NOT EXISTS] view-name [(column-name [, column-name …])] AS select-statement | values-statement; DROP INDEX [IF EXISTS] index-name ON table-name; DROP TABLE [IF EXISTS] table-name; DROP TRIGGER [IF EXISTS] trigger-name; DROP VIEW [IF EXISTS] view-name; EXPLAIN explainable-statement; INSERT INTO table-name [(column-name [, column-name …])] values-statement | select-statement; PRAGMA pragma-name[(value)]; RELEASE SAVEPOINT savepoint-name; REPLACE INTO table-name VALUES (expression [, expression …]); ROLLBACK [TO [SAVEPOINT] savepoint-name]; SAVEPOINT savepoint-name; SELECT [DISTINCT|ALL] expression [, expression …] FROM table-name | joined-table-names [AS alias] [WHERE expression] [GROUP BY expression [, expression …]] [HAVING expression] [ORDER BY expression] LIMIT expression [OFFSET expression]]; START TRANSACTION; TRUNCATE TABLE table-name; UPDATE table-name SET column-name=expression [,column-name=expression…] [WHERE expression]; VALUES (expression [, expression …]; WITH [RECURSIVE] common-table-expression;

Differences from other products

Differences from other SQL products: We believe that Tarantool's SQL conforms to the majority of the listed mandatory requirements of the core SQL:2016 standard, and we enumerate the specific conformance statements in the feature list in a section about "compliance with the official SQL standard". We believe that the deviations which most people will find notable are: type checking is less strict, and some data definition options must be done with NoSQL syntax.

Differences from other NoSQL products: We have examined attempts by others to paste relatively smaller subsets of SQL onto NoSQL products, and concluded that Tarantool's SQL has demonstrably more features and capabilities. The reason is that we started with a complete code base of a working SQL DBMS and made it work with Tarantool-NoSQL underneath, rather than starting with a NoSQL DBMS and adding syntax to it.

Concepts

In an earlier section of this documentation, we discussed: What are: relational databases, tables, views, rows, and columns? What are: transactions, write-ahead logs, commits and rollbacks? What are: security considerations? How do we: add, delete, or update rows in tables? How do we: work inside transactions with commits and/or rollbacks? How do we: select, join, filter, group, and sort rows?

Tarantool has a "schema". A schema is a container for all database objects. A schema may be called a "database" in other DBMS implementations

Tarantool allows four types of "database objects" to be created within the schema: tables, triggers, indexes, and constraints. Within tables, there are "columns".

Almost all Tarantool SQL statements begin with a reserved-word "verb" such as INSERT, and end optionally with a semicolon. For example: INSERT INTO t VALUES (1);

A Tarantool SQL database and a Tarantool NoSQL database are the same thing. However, some operations are only possible with SQL, and others are only possible with NoSQL. Mixing SQL statements with NoSQL requests is allowed.

Tokens

The token is the minimum SQL-syntax unit that Tarantool understands. These are the types of tokens:

Keywords – official words in the language, for example SELECT Literals – constants for numbers or strings, for example 15.7 or `'Taranto'` Identifiers – for example column55 or table_of_accounts Operators (strictly speaking "non-alphabetic operators") – for example * / + - ( ) , ; < = >=

Tokens can be separated from each other by one or more separators: * White space characters: tab (U+0009), line feed (U+000A), vertical tab (U+000B), form feed (U+000C), carriage return (U+000D), space (U+0020), next line (U+0085), and all the rare characters in Unicode classes Zl and Zp and Zs. For a full list see https://github.com/tarantool/tarantool/issues/2371. * Bracketed comments (beginning with /* and ending with */) * Simple comments (beginning with -- and ending with line feed) Separators are not necessary before or after operators. Separators are necessary after keywords or numbers or ordinary identifiers, unless the following token is an operator. Thus Tarantool can understand this series of six tokens: SELECT`'a'`FROM/**/t; but for readability one would usually use spaces to separate tokens: SELECT `'a'` FROM /**/ t;

Literals

There are five kinds of literals: BOOLEAN INTEGER DOUBLE STRING VARBINARY.

BOOLEAN literals: TRUE | FALSE | UNKNOWN A literal has data type = BOOLEAN if it is the keyword TRUE or FALSE. UNKNOWN is a synonym for NULL. A literal may have type = BOOLEAN if it is the keyword NULL and there is no context to indicate a different data type.

INTEGER literals: [plus-sign | minus-sign] digit [digit ...] or, for a hexadecimal integer literal, [plus-sign | minus-sign] 0X | 0x hexadecimal-digit [hexadecimal-digit ...] Examples: 5, -5, +5, 55555, 0X55, 0x55 Hexadecimal 0X55 is equal to decimal 85. A literal has data type = INTEGER if it contains only digits and is in the range -9223372036854775808 to +18446744073709551615, integers outside that range are illegal.

DOUBLE literals: [plus-sign | minus-sign] [digit [digit ...]] period [digit [digit ...]] [E|e [plus-sign | minus-sign] digit ...] Examples: .0, 1.0, 1E5, 1.1E5. A literal has data type = DOUBLE if it contains a period, or contains "E". DOUBLE literals are also known as floating-point literals or approximate-numeric literals. To represent "Inf" (infinity), write a real number outside the double-precision number range, for example 1E309. To represent "nan" (not a number), write an expression that does not result in a real number, for example 0/0, using Tarantool/NoSQL. This will appear as NULL in Tarantool/SQL. In an earlier version literals containing periods were considered to be NUMBER literals. In a future version "nan" may not appear as NULL.

STRING literals: [quote] [character ...] [quote] Examples: `'ABC'`, `'AB''C'` A literal has data type type = STRING if it is a sequence of zero or more characters enclosed in single quotes. The sequence `''` (two single quotes in a row) is treated as `'` (a single quote) when enclosed in quotes, that is, `'A''B'` is interpreted as A`'`B.

VARBINARY literals: X|x [quote] [hexadecimal-digit-pair ...] [quote] Example: X`'414243'`, which will be displayed as `'ABC'`. A literal has data type = VARBINARY ("variable-length binary") if it is the letter X followed by quotes containing pairs of hexadecimal digits, representing byte values.

Here are four ways to put non-ASCII characters,such as the Greek letter α alpha, in string literals: First make sure that your shell program is set to accept characters as UTF-8. A simple way to check is SELECT hex(`'`α`'`); If the result is CEB1 – which is the hexadecimal value for the UTF-8 representation of α – it is good. (1) Simply enclose the character inside `'...'`, `'`α`'` or (2) Find out what is the hexadecimal code for the UTF-8 representation of α, and enclose that inside X`'...'`, then cast to STRING because X`'...'` literals are data type VARBINARY not STRING, CAST(X`'CEB1'` AS STRING) or (3) Find out what is the Unicode code point for α, and pass that to the CHAR function. CHAR(945) /* remember that this is α as data type STRING not VARBINARY */ (4) Enclose statements inside double quotes and include

Lua escapes, for example box.execute("SELECT `'\206\177'`;") One can use the concatenation operator || to combine characters made with any of these methods.

Limitations: (Issue#2344) * Numeric literals may be quoted, one cannot depend on the presence or absence of quote marks to determine whether a literal is numeric. * LENGTH(`'A''B'`) = 3 which is correct, but the display from SELECT `A''B`; is `A''B`, which is misleading. * It is unfortunate that X`'41'` is a byte sequence which looks the same as `'A'`, but it is not the same. box.execute("select `'A'` < X`'41'`;") is not legal at the moment. This happens because TYPEOF(X`'41'`) yields `'varbinary'`. Also it is illegal to say UPDATE ... SET string_column = X`'41'`, one must say UPDATE ... SET string_column = CAST(X`'41'` AS STRING);. * It is non-standard to say that any number which contains a period has data type = DOUBLE.

Identifiers

All database objects – tables, triggers, indexes, columns, constraints, functions, collations – have identifiers. An identifier should begin with a letter or underscore (`'_'`) and should contain only letters, digits, dollar signs (`'$'`), or underscores. The maximum number of bytes in an identifier is between 64982 and 65000. For compatibility reasons, Tarantool recommends that an identifier should not have more than 30 characters.

Letters in identifiers do not have to come from the Latin alphabet, for example the Japanese syllabic and the Cyrillic letter д are legal. But be aware that a Latin letter needs only one byte but a Cyrillic letter needs two bytes, so Cyrillic identifiers consume a tiny amount more space.

Certain words are reserved and should not be used for identifiers. The simple rule is: if a word means something in Tarantool SQL syntax, do not try to use it for an identifier. The current list of reserved words is:

ALL ALTER ANALYZE AND ANY AS ASC ASENSITIVE AUTOINCREMENT BEGIN BETWEEN BINARY BLOB BOOL BOOLEAN BOTH BY CALL CASE CAST CHAR CHARACTER CHECK COLLATE COLUMN COMMIT CONDITION CONNECT CONSTRAINT CREATE CROSS CURRENT CURRENT_DATE CURRENT_TIME CURRENT_TIMESTAMP CURRENT_USER CURSOR DATE DATETIME dec DECIMAL DECLARE DEFAULT DEFERRABLE DELETE DENSE_RANK DESC DESCRIBE DETERMINISTIC DISTINCT DOUBLE DROP EACH ELSE ELSEIF END ESCAPE EXCEPT EXISTS EXPLAIN FALSE FETCH FLOAT FOR FOREIGN FROM FULL FUNCTION GET GRANT GROUP HAVING IF IMMEDIATE IN INDEX INNER INOUT INSENSITIVE INSERT INT INTEGER INTERSECT INTO IS ITERATE JOIN LEADING LEAVE LEFT LIKE LIMIT LOCALTIME LOCALTIMESTAMP LOOP MATCH NATURAL NOT NULL NUM NUMBER NUMERIC OF ON OR ORDER OUT OUTER OVER PARTIAL PARTITION PRAGMA PRECISION PRIMARY PROCEDURE RANGE RANK READS REAL RECURSIVE REFERENCES REGEXP RELEASE RENAME REPEAT REPLACE RESIGNAL RETURN REVOKE RIGHT ROLLBACK ROW ROWS ROW_NUMBER SAVEPOINT SCALAR SELECT SENSITIVE SET SIGNAL SIMPLE SMALLINT SPECIFIC SQL START STRING SYSTEM TABLE TEXT THEN TO TRAILING TRANSACTION TRIGGER TRIM TRUE TRUNCATE UNION UNIQUE UNKNOWN UNSIGNED UPDATE USER USING VALUES VARBINARY VARCHAR VIEW WHEN WHENEVER WHERE WHILE WITH

Identifiers may be enclosed in double quotes. These are called quoted identifiers or “delimited identifiers” (unquoted identifiers may be called “regular identifiers”). The double quotes are not part of the identifier. A delimited identifier may be a reserved word and may contain any printable character. Tarantool converts letters in regular identifiers to upper case before it accesses the database, so for statements like CREATE TABLE a (a INTEGER PRIMARY KEY); or SELECT a FROM a; the table name is A and the column name is A. However, Tarantool does not convert delimited identifiers to upper case, so for statements like CREATE TABLE "a" ("a" INTEGER PRIMARY KEY); or SELECT "a" FROM "a"; the table name is a and the column name is a. The sequence "" is treated as " when enclosed in double quotes, that is, "A""B" is interpreted as "A"B".

Examples: things, t45, journal_entries_for_2017, ддд, "into"

Inside certain statements, identifiers may have “qualifiers” to prevent ambiguity. A qualifier is an identifier of a higher-level object, followed by a period. For example column1 within table1 may be referred to as table1.column1. The "name" of an object is the same as its identifier, or its qualified identifier. For example, inside SELECT t1.column1, t2.column1 FROM t1, t2; the qualifiers make it clear that the first column is column1 from table1 and the second column is column2 from table2.

The rules are sometimes relaxed for compatibility reasons, for example some non-letter characters such as $ and « are legal in regular identifiers. However, it is better to assume that rules are never relaxed.

The following are examples of legal and illegal identifiers.

```
_A1   -- legal, begins with underscore and contains underscore | letter | digit
1_A   -- illegal, begins with digit
A$« -- legal, but not recommended, try to stick with digits and letters and underscores
+ -- illegal, operator token
grant -- illegal, GRANT is a reserved word
"grant" -- legal, delimited identifiers may be reserved words
"_space" -- legal, but Tarantool already uses this name for a system space
"A"."X" -- legal, for columns only, inside statements where qualifiers may be necessary
'a' -- illegal, single quotes are for literals not identifiers
A123456789012345678901234567890 -- legal, identifiers can be long
ддд -- legal, and will be converted to upper case in identifiers
```

The following example shows that conversion to upper case affects regular identifiers but not delimited identifiers.

```
CREATE TABLE "q" ("q" INTEGER PRIMARY KEY);
SELECT * FROM q;
-- Result = "error: 'no such table: Q'.
```

Operands

An operand is something that can be operated on. Literals and column identifiers are operands. So are NULL and DEFAULT.

NULL and DEFAULT are keywords which represent values whose data types are not known until they are assigned or compared, so they are known by the technical term "contextually typed value specifications". (Exception: for the non-standard statement "SELECT NULL FROM table-name;" NULL has data type BOOLEAN.)

Every operand has a data type.

For literals, as we saw earlier, the data type is usually determined by the format.

For identifiers, the data type is usually determined by the definition.

The usual determination may change because of context or because of explicit casting.

For some SQL data type names there are aliases. An alias may be used for data definition. For example VARCHAR(5) and TEXT are aliases of STRING and may appear in CREATE TABLE table_name (column_name VARCHAR(5) PRIMARY KEY); but Tarantool, if asked, will report that the data type of column_name is STRING.

For every SQL data type there is a corresponding NoSQL type, for example an SQL STRING is stored in a NoSQL space as type = 'string'.

To avoid confusion in this manual, all references to SQL data type names are in upper case and all similar words which refer to NoSQL types or to other kinds of object are in lower case, for example:

- STRING is a data type name, but string is a general term;
- NUMBER is a data type name, but number is a general term.

Although it is common to say that a VARBINARY value is a "binary string", this manual will not use that term and will instead say "byte sequence".

Here are all the SQL data types, their corresponding NoSQL types, their aliases, and minimum / maximum literal examples.

Data types

SQL type	NoSQL type	Aliases	Minimum	Maximum
BOOLEAN	boolean	BOOL	FALSE	TRUE
INTEGER	integer	INT	-9223372036854775808	18446744073709551615
UNSIGNED	unsigned	(none)	0	18446744073709551615
DOUBLE	double	(none)	-1.79769e308	1.79769e308
NUMBER	number	(none)	-1.79769e308	1.79769e308
STRING	string	TEXT, VARCHAR(n)	`''`	`'many-characters'`
VARBINARY	varbinary	(none)	`X''`	`X'many-hex-digits'`
SCALAR	scalar	(none)	FALSE	`X'many-hex-digits'`

BOOLEAN values are FALSE, TRUE, and UNKNOWN (which is the same as NULL). FALSE is less than TRUE.

INTEGER values are numbers that do not contain decimal points and are not expressed with exponential notation. The range of possible values is between -2^63 and +2^64, or NULL.

UNSIGNED values are numbers that do not contain decimal points and are not expressed with exponential notation. The range of possible values is between 0 and +2^64, or NULL.

DOUBLE values are numbers that do contain decimal points (for example 0.5) or are expressed with exponential notation (for example 5E-1). The range of possible values is the same as for the IEEE 754 floating-point standard, or NULL. Numbers outside the range of DOUBLE literals may be displayed as -inf or inf.

NUMBER values have the same range as DOUBLE values. But NUMBER values may also also be integers, and, if so, arithmetic operation results will be exact rather than approximate. There is no literal format for NUMBER (literals like 1.5 or 1E555 are considered to be DOUBLEs), so use CAST to insist that a number has data type NUMBER, but that is rarely necessary. See the description of NoSQL type 'number'.

STRING values are any sequence of zero or more characters encoded with UTF-8, or NULL. The possible character values are the same as for the Unicode standard. Byte sequences which are not valid UTF-8 characters are allowed but not recommended. STRING literal values are enclosed within single quotes, for example `'literal'`. If the VARCHAR alias is used for column definition, it must include a maximum length, for example column_1 VARCHAR(40). However, the maximum length is ignored. The data-type may be followed by [COLLATE collation-name].

VARBINARY values are any sequence of zero or more octets (bytes), or NULL. VARBINARY literal values are expressed as X followed by pairs of hexadecimal digits enclosed within single quotes, for example `X'0044'`. VARBINARY's NoSQL equivalent is `'varbinary'` but not character string – the MessagePack storage is MP_BIN (MsgPack binary).

SCALAR can be used for column definitions but the individual column values have one of the preceding types – BOOLEAN, INTEGER, DOUBLE, STRING, or VARBINARY. See more about SCALAR in the section Column definition – the rules for the SCALAR data type. The data-type may be followed by [COLLATE collation-name].

Any value of any data type may be NULL. Ordinarily NULL will be cast to the data type of any operand it is being compared to or to the data type of the column it is in. If the data type of NULL cannot be determined from context, it is BOOLEAN.

All the SQL data types correspond to Tarantool/NoSQL types with the same name. There are also some Tarantool/NoSQL data types which have no corresponding SQL data types. If Tarantool/SQL reads a Tarantool/NoSQL value which has a type which has no SQL equivalent, Tarantool/SQL may treat it as NULL or INTEGER or VARBINARY. For example, SELECT "flags" FROM "_space"; will return a column whose data type is `'map'`. Such columns can only be manipulated in SQL by invoking Lua functions.

Operators

An operator signifies what operation can be performed on operands.

Almost all operators are easy to recognize because they consist of one-character or two-character non-alphabetic tokens, except for six keyword operators (AND IN IS LIKE NOT OR).

Almost all operators are "dyadic", that is, they are performed on a pair of operands – the only operators that are performed on a single operand are NOT and ~ and (sometimes) -.

The result of an operation is a new operand. If the operator is a comparison operator then the result has data type BOOLEAN (TRUE or FALSE or UNKNOWN). Otherwise the result has the same data type as the original operands, except that: promotion to a broader type may occur to avoid overflow. Arithmetic with NULL operands will result in a NULL operand.

In the following list of operators, the tag "(arithmetic)" indicates that all operands are expected to be numbers and should result in a number; the tag "(comparison)" indicates that operands are expected to have similar data types and should result in a BOOLEAN; the tag "(logic)" indicates that operands are expected to be BOOLEAN and should result in a BOOLEAN. Exceptions may occur where operations are not possible, but see the "special situations" which are described after this list. Although all examples show literals, they could just as easily show column identifiers.

+ addition (arithmetic) Add two numbers according to standard arithmetic rules. Example: 1 + 5, result = 6.

- subtraction (arithmetic) Subtract second number from first number according to standard arithmetic rules. Example: 1 - 5, result = -4.

* multiplication (arithmetic) Multiply two numbers according to standard arithmetic rules. Example: 2 * 5, result = 10.

/ division (arithmetic) Divide second number into first number according to standard arithmetic rules. Division by zero is not legal. Division of integers always results in rounding down, use CAST to NUMBER to get non-integer results. Example: 5 / 2, result = 2.

% modulus (arithmetic) Divide second number into first number according to standard arithmetic rules. The result is the remainder. Example: 17 % 5, result = 2.

<< shift left (arithmetic) Shift the first number to the left N times, where N = the second number. For positive numbers, each 1-bit shift to the left is equivalent to multiplying times 2. Example: 5 << 1, result = 10.

>> shift right (arithmetic) Shift the first number to the right N times, where N = the second number. For positive numbers, each 1-bit shift to the right is equivalent to dividing by 2. Example: 5 >> 1, result = 2.

& and (arithmetic) Combine the two numbers, with 1 bits in the result if and only if both original numbers have 1 bits. Example: 5 & 4, result = 4.

| or (arithmetic) Combine the two numbers, with 1 bits in the result if either original number has a 1 bit. Example: 5 | 2, result = 7.

~ negate (arithmetic), sometimes called bit inversion Change 0 bits to 1 bits, change 1 bits to 0 bits. Example: ~5, result = -6.

< less than (comparison) Return TRUE if the first operand is less than the second by arithmetic or collation rules. Example for numbers: 5 < 2, result = FALSE. Example for strings: `'C' < ' '`, result = FALSE.

<= less than or equal (comparison) Return TRUE if the first operand is less than or equal to the second by arithmetic or collation rules. Example for numbers: 5 <= 5, result = TRUE. Example for strings: `'C' <= 'B'`, result = FALSE.

> greater than (comparison) Return TRUE if the first operand is greater than the second by arithmetic or collation rules. Example for numbers: 5 > -5, result = TRUE. Example for strings: `'C' > '!'`, result = TRUE.

>= greater than or equal (comparison) Return TRUE if the first operand is greater than or equal to the second by arithmetic or collation rules. Example for numbers: 0 >= 0, result = TRUE. Example for strings: `'Z' >= 'Γ'`, result = FALSE.

= equal (assignment or comparison) After the word SET, "=" means the first operand gets the value from the second operand. In other contexts, "=" returns TRUE if operands are equal. Example for assignment: … SET column1 = `'a'`; Example for numbers: 0 = 0, result = TRUE. Example for strings: `'1' = '2 '`, result = FALSE.

== equal (assignment), or equal (comparison) This is a non-standard equivalent of "= equal (assignment or comparison)".

<> not equal (comparison) Return TRUE if the first operand is not equal to the second by arithmetic or collation rules. Example for strings: `'A' <> 'A '` is TRUE.

!= not equal (comparison) This is a non-standard equivalent of "<> not equal (comparison)".

IS NULL and IS NOT NULL (comparison) For IS NULL: Return TRUE if the first operand is NULL, otherwise return FALSE. Example: column1 IS NULL, result = TRUE if column1 contains NULL. For IS NOT NULL: Return FALSE if the first operand is NULL, otherwise return TRUE. Example: column1 IS NOT NULL, result = FALSE if column1 contains NULL.

LIKE (comparison) Perform a comparison of two string operands. If the second operand contains `'_'`, the `'_'` matches any single character in the first operand. If the second operand contains `'%'`, the `'%'` matches 0 or more characters in the first operand. If it is necessary to search for either `'_'` or `'%'` within a string without treating it specially, an optional clause can be added, ESCAPE single-character-operand, for example `'abc_' LIKE 'abcX_' ESCAPE 'X'` is TRUE because X' means "following character is not special". Matching is also affected by the string's collation.

BETWEEN (comparison) x BETWEEN y AND z is shorthand for x >= y AND x <= z.

NOT negation (logic) Return TRUE if operand is FALSE return FALSE if operand is TRUE, else return UNKNOWN. Example: NOT (1 > 1), result = TRUE.

IN is equal to one of a list of operands (comparison) Return TRUE if first operand equals any of the operands in a parenthesized list. Example: 1 IN (2,3,4,1,7), result = TRUE.

AND and (logic) Return TRUE if both operands are TRUE. Return UNKNOWN if both operands are UNKNOWN. Return UNKNOWN if one operand is TRUE and the other operand is UNKNOWN. Return FALSE if one operand is FALSE and the other operand is (UNKNOWN or TRUE or FALSE).

OR or (logic) Return TRUE if either operand is TRUE. Return FALSE if both operands are FALSE. Return UNKNOWN if one operand is UNKNOWN and the other operand is (UNKNOWN or FALSE).

|| concatenate (string manipulation) Return the value of the first operand concatenated with the value of the second operand. Example: `'A' || 'B'`, result = `'AB'`.

The precedence of dyadic operators is:

```
||
* / %
+ -
<< >> & |
```

(continues on next page)

(continued from previous page)

```
<  <= > >=
=  == != <> IS IS NOT IN LIKE
AND
OR
```

To ensure a desired precedence, use () parentheses.

Special Situations

If one of the operands has data type DOUBLE, Tarantool uses floating-point arithmetic. This means that exact results are not guaranteed and rounding may occur without warning. For example, 4.7777777777777778 = 4.7777777777777777 is TRUE.

The floating-point values inf and -inf are possible. For example, SELECT 1e318, -1e318; will return "inf, -inf". Arithmetic on infinite values may cause NULL results, for example SELECT 1e318 - 1e318; is NULL and SELECT 1e318 * 0; is NULL.

SQL operations never return the floating-point value -nan, although it may exist in data created by Tarantool's NoSQL. In SQL, -nan is treated as NULL.

A string will be converted to a number if it is used with an arithmetic operator and conversion is possible, for example `'7'` + `'7'` = 14. And for comparison or assignment, `'7'` = 7. This is called implicit casting. It is applicable for STRINGs and all numeric data types.

Limitations: (Issue#2346) * Some words, for example MATCH and REGEXP, are reserved but are not necessary for current or planned Tarantool versions * 999999999999999 << 210 yields 0. (1 << 63) >> 63 yields -1.

Expressions

An expression is a chunk of syntax that causes return of a value. Expressions may contain literals, column-names, operators, and parentheses.

Therefore these are examples of expressions: 1, 1 + 1 << 1, (1 = 2) OR 4 > 3, `'x'` || `'y'` || `'z'`.

Also there are two expressions that involve keywords:

value IS [NOT] NULL ... for determining whether value is (not) NULL

CASE ... WHEN ... THEN ... ELSE ... END ... for setting a series of conditions.

See also: subquery.

Limitations: IS TRUE and IS FALSE return an error.

Comparing and Ordering

There are rules for determining whether value-1 is "less than", "equal to", or "greater than" value-2. These rules are applied for searches, for sorting results in order by column values, and for determining whether a column is unique. The result of a comparison of two values can be TRUE, FALSE, or UNKNOWN (the three BOOLEAN values). Sometimes for retrieval TRUE is converted to 1, FALSE is converted to 0, UNKNOWN is converted to NULL. For any comparisons where neither operand is NULL, the operands are "distinct" if the comparison result is FALSE. For any set of operands where all operands are distinct from each other, the set is considered to be "unique".

When comparing a number to a number: * infinity = infinity is true * regular numbers are compared according to usual arithmetic rules

When comparing any value to NULL: (for examples in this paragraph assume that column1 in table T contains {NULL, NULL, 1, 2}) * value comparison-operator NULL is UNKNOWN (not TRUE and not FALSE), which affects "WHERE condition" because the condition must be TRUE, and does not affect "CHECK (condition)" because the condition must be either TRUE or UNKNOWN. Therefore SELECT *

FROM T WHERE column1 > 0 OR column1 < 0 OR column1 = 0; returns only {1,2}, and the table can have been created with CREATE TABLE T (… column1 INTEGER, CHECK (column1 >= 0)); * for any operations that contain the keyword DISTINCT, NULLs are not distinct. Therefore SELECT DISTINCT column1 FROM T; will return {NULL,1,2}. * for grouping, NULL values sort together. Therefore SELECT column1, COUNT(*) FROM T GROUP BY column1; will include a row {NULL, 2}. * for ordering, NULL values sort together and are less than non-NULL values. Therefore SELECT column1 FROM T ORDER BY column1; returns {NULL, NULL, 1,2}. * for evaluating a UNIQUE constraint or UNIQUE index, any number of NULLs is okay. Therefore CREATE UNIQUE INDEX i ON T (column1); will succeed.

When comparing a number to a STRING: * If implicit casting is possible, the STRING operand is converted to a number before comparison. If implicit casting is not possible, and one of the operands is the name of a column which was defined as SCALAR, and the column is being compared with a number, then number is less than STRING. Otherwise, the comparison is not legal.

When comparing a BOOLEAN to a BOOLEAN: TRUE is greater than FALSE.

When comparing a VARBINARY to a VARBINARY: * The numeric value of each pair of bytes is compared until the end of the byte sequences or until inequality. If two byte sequences are otherwise equal but one is longer, then the longer one is greater.

When comparing for the sake of eliminating duplicates: * This is usually signalled by the word DISTINCT, so it applies to SELECT DISTINCT, to set operators such as UNION (where DISTINCT is implied), and to aggregate functions such as AVG(DISTINCT). * Two operators are “not distinct” if they are equal to each other, or are both NULL * If two values are equal but not identical, for example 1.0 and 1.00, they are non-distinct and there is no way to specify which one will be eliminated * Values in primary-key or unique columns are distinct due to definition.

When comparing a STRING to a STRING: * Ordinarily collation is “binary”, that is, comparison is done according to the numeric values of the bytes. This can be cancelled by adding a COLLATE clause at the end of either expression. So `'A'` < `'a'` and `'a'` < `'Ä'`, but `'A'` COLLATE "unicode_ci" = `'a'` and `'a'` COLLATE "unicode_ci" = `'Ä'`. * When comparing a column with a string literal, the column’s defined collation is used. * Ordinarily trailing spaces matter. So `'a'` = `'a '` is not TRUE. This can be cancelled by using the TRIM(TRAILING …) function.

Limitations: * LIKE comparisons return integer results according to meta-information. * LIKE is not expected to work with VARBINARY.

Data Type Conversion

Data type conversion, also called casting, is necessary for any operation involving two operands X and Y, when X and Y have different data types. Or, casting is necessary for assignment operations (when INSERT or UPDATE is putting a value of type X into a column defined as type Y). Casting can be “explicit” when a user uses the CAST function, or “implicit” when Tarantool does a conversion automatically.

The general rules are fairly simple: Assignments and operations involving NULL cause NULL or UNKNOWN results. For arithmetic, convert to the data type which can contain both operands and the result. For explicit casts, if a meaningful result is possible, the operation is allowed. For implicit casts, if a meaningful result is possible and the data types on both sides are either STRINGs or numbers (that is, are STRING or INTEGER or UNSIGNED or DOUBLE or NUMBER), the operation is sometimes allowed.

The specific situations in this chart follow the general rules:

~	To BOOLEAN	To INTEGER	To DOUBLE	To STRING	To VARBINARY
From BOOLEAN	AAA	A--	---	A--	---
From INTEGER	A--	AAA	AAA	AAA	---
From DOUBLE	A--	SSA	AAA	AAA	---
From STRING	S--	SSS	SSS	AAA	A--
From VARBINARY	---	---	---	A--	AAA

Where each entry in the chart has 3 characters: Where A = Always allowed, S = Sometimes allowed, - = Never allowed. The first character of an entry is for explicit casts, the second character is for implicit casts for assignment, the third character is for implicit cast for comparison. So AAA = Always for explicit, Always for Implicit (assignment), Always for Implicit (comparison).

The S "Sometimes allowed" character applies for these special situations: From STRING To BOOLEAN is allowed if UPPER(string-value) = `'TRUE'` or `'FALSE'`. From DOUBLE to INTEGER is allowed for cast and assignment only if the result is not out of range. From STRING to INTEGER or DOUBLE is allowed only if the string has a representation of a number.

The chart does not show To|From SCALAR because the conversions depend on the type of the value, not the type of the column definition. Explicit cast to SCALAR is allowed but has no effect, the result data type is always the same as the original data type. But comparisons of values of different types are allowed if the definition is SCALAR.

Examples of casts, illustrating the situations in the chart:

CAST(TRUE AS INTEGER) is legal because the intersection of the "From BOOLEAN" row with the "To INTEGER" column is A-- and the first letter of A-- is for explicit cast and A means Always Allowed. The result is 1.

UPDATE ... SET varbinary_column = `'A'` is illegal because the intersection of the "From STRING" row with the "To VARBINARY" column is A-- and the second letter of A-- is for implicit cast (assignment) and - means not allowed. The result is an error message.

1.7E-1 > 0 is legal because the intersection of the "From DOUBLE" row with the "To INTEGER" column is AAA, and the third letter of AAA is for implicit cast (comparison) and A means Always Allowed. The result is TRUE.

11 > `'2'` is legal because the intersection of the "From INTEGER" row with the "To STRING" column is AAA and the third letter of AAA is for implicit cast (comparison) and A means Always Allowed. The result is TRUE. For detailed explanation see the following section.

Implicit string/numeric cast

Special considerations may apply for casting STRINGs to/from INTEGERs/DOUBLEs (numbers) for comparison or assignment.

1 = `'1'` /* compare a STRING with a number */ UPDATE ... SET string_column = 1 /* assign a number to a STRING */

For comparisons, the cast is always from STRING to number. Therefore 1e2 = `'100'` is TRUE, and 11 > `'2'` is TRUE. If the cast fails, then the number is less than the STRING. Therefore 1e400 < `''` is TRUE. Exception: for BETWEEN the cast is to the data type of the first and last operands. Therefore `'66'` BETWEEN 5 AND `'7'` is TRUE.

For assignments, the cast is always from source to target. Therefore INSERT INTO t (integer_column) VALUES (`'5'`); inserts 5. If the cast fails, then the result is an error.

Implicit cast also happens if STRINGS are used in arithmetic. Therefore `'5'` / `'5'` = 1. If the cast fails, then the result is an error. Therefore `'5'` / `''` is an error.

Implicit cast does NOT happen if numbers are used in concatenation, or in LIKE. Therefore 5 || 5 is illegal.

In the following examples, implicit cast does not happen for SCALAR column values: DROP TABLE scalars; CREATE TABLE scalars (scalar_column SCALAR PRIMARY KEY); INSERT INTO scalars VALUES (11), (`'2'`); SELECT * FROM scalars WHERE scalar_column > 11; /* 0 rows. So 11 > `'2'`. */ SELECT * FROM scalars WHERE scalar_column < `'2'`; /* 1 row. So 11 < `'2'`. */ SELECT max(scalar_column) FROM scalars; /* 1 row: `'2'`. So 11 < `'2'`. */ SELECT sum(scalar_column) FROM scalars; /* 1 row: 13. So cast happened. */ These results are not affected by indexing, or by reversing the operands.

Implicit cast does NOT happen for GREATEST() or LEAST(). Therefore LEAST(`'5'`,6) is 6.

For function arguments: If the function description says that a parameter has a specific data type, and implicit assignment casts are allowed, then arguments which are not passed with that data type will be converted before the function is applied. For example, the LENGTH() function expects a STRING or VARBINARY, and INTEGER can be converted to STRING, therefore LENGTH(15) will return the length of '15', that is, 2. But implicit cast sometimes does NOT happen for parameters. Therefore ABS('5') will cause an error message after Issue#4159 is fixed. However, TRIM(5) will still be legal.

Although it is not a requirement of the SQL standard, implicit cast is supposed to help compatibility with other DBMSs. However, other DBMSs have different rules about what can be converted (for example they may allow assignment of 'inf' but disallow comparison with '1e5'). And, of course, it is not possible to be compatible with other DBMSs and at the same time support SCALAR, which other DBMSs do not have.

Limitations (Issue#3809): Result of concatenation, or out-of-bound result, may have wrong type. Parameter conversion behavior will change (Issue#4159). After issue#4159 is done, LENGTH(15) will be illegal.

Statements

A statement consists of SQL-language keywords and expressions that direct Tarantool to do something with a database. Statements begin with one of the words ALTER ANALYZE COMMIT CREATE DELETE DROP EXPLAIN INSERT PRAGMA RELEASE REPLACE ROLLBACK SAVEPOINT SELECT START TRUNCATE UPDATE VALUES WITH. Statements should end with ";" semicolon although this is not mandatory.

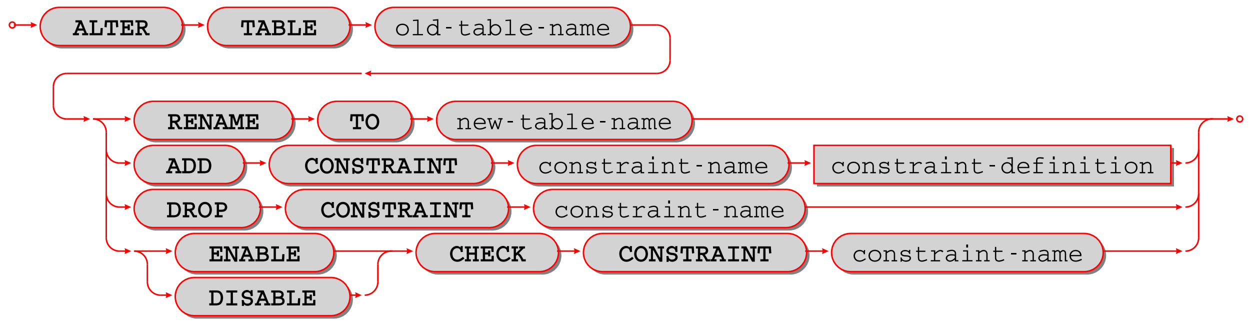
A client sends a statement to the Tarantool server. The Tarantool server parses the statement and executes it. If there is an error, Tarantool returns an error message.

5.1.3 SQL statements and clauses

ALTER TABLE

Syntax:

- ALTER TABLE table-name RENAME TO new-table-name;
- ALTER TABLE table-name ADD CONSTRAINT constraint-name constraint-definition;
- ALTER TABLE table-name DROP CONSTRAINT constraint-name;
- ALTER TABLE table-name ENABLE|DISABLE CHECK CONSTRAINT constraint-name;



ALTER is used to change a table's name or a table's constraints.

Examples:

For renaming a table with ALTER ... RENAME, the old-table must exist, the new-table must not exist. Example: -- renaming a table: ALTER TABLE t1 RENAME TO t2;

For adding a table constraint with ADD CONSTRAINT, the table must exist, the table must be empty, the constraint name must be unique within the table. Example with a foreign-key constraint definition: ALTER TABLE t1 ADD CONSTRAINT fk_s1_t1_1 FOREIGN KEY (s1) REFERENCES t1;

It is not possible to say CREATE TABLE table_a ... REFERENCES table_b ... if table b does not exist yet. This is a situation where ALTER TABLE is handy – users can CREATE TABLE table_a without the foreign key, then CREATE TABLE table_b, then ALTER TABLE table_a ... REFERENCES table_b ....

```
-- adding a primary-key constraint definition:
-- This is unusual because primary keys are created automatically
-- and it is illegal to have two primary keys for the same table.
-- However, it is possible to drop a primary-key index, and this
-- is a way to restore the primary key if that happens.
ALTER TABLE t1 ADD CONSTRAINT "pk_unnamed_T1_1" PRIMARY KEY (s1);

-- adding a unique-constraint definition:
-- Alternatively, you can say CREATE UNIQUE INDEX unique_key ON t1 (s1);
ALTER TABLE t1 ADD CONSTRAINT "unique_unnamed_T1_2" UNIQUE (s1);

-- Adding a check-constraint definition:
ALTER TABLE t1 ADD CONSTRAINT "ck_unnamed_T1_1" CHECK (s1 > 0);
```

For ALTER ... DROP CONSTRAINT, it is only legal to drop a named constraint, and Tarantool only looks for names of foreign-key constraints. (Tarantool generates the constraint names automatically if the user does not provide them.) To remove a unique constraint, use use DROP INDEX, which will drop the constraint as well.

```
-- dropping a constraint:
ALTER TABLE t1 DROP CONSTRAINT "fk_unnamed_JJ2_1";
```

For ALTER ... ENABLE|DISABLE CHECK CONSTRAINT, it is only legal to enable or disable a named constraint, and Tarantool only looks for names of check constraints. By default a constraint is enabled. If a constraint is disabled, then the check will not be performed.

```
-- disabling and re-enabling a constraint:
ALTER TABLE t1 DISABLE CHECK CONSTRAINT c;
ALTER TABLE t1 ENABLE CHECK CONSTRAINT c;
```

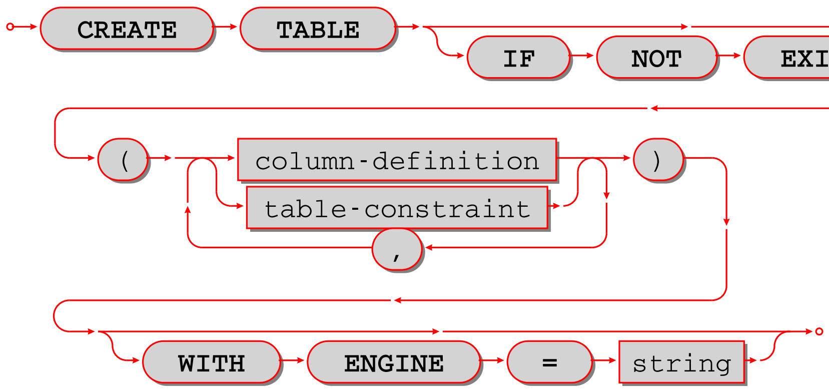
Limitations:

- It is not possible to add or drop a column.
- It is not possible to modify NOT NULL constraints or column properties DEFAULT and data type. However, it is possible to modify them with Tarantool/NOSQL, for example by calling space_object:format() with a different is_nullable value.

CREATE TABLE

Syntax:

CREATE TABLE [IF NOT EXISTS] table-name (column-definition or table-constraint list) [WITH ENGINE = string];



Create a new base table, usually called a "table".

Note: A table is a base table if it is created with CREATE TABLE and contains data in persistent storage.

A table is a viewed table, or just "view", if it is created with CREATE VIEW and gets its data from other views or from base tables.

The table-name must be an identifier which is valid according to the rules for identifiers, and must not be the name of an already existing base table or view.

The column-definition or table-constraint list is a comma-separated list of column definitions or table constraint definitions. Column definitions and table constraint definitions are sometimes called table elements.

Rules:

- A primary key is necessary; it can be specified with a table constraint PRIMARY KEY.
- There must be at least one column.
- When IF NOT EXISTS is specified, and there is already a table with the same name, the statement is ignored.
- When WITH ENGINE = string is specified, where string must be either 'memtx' or 'vinyl', the table is created with that storage engine. When this clause is not specified, the table is created with the default engine, which is ordinarily 'memtx' but may be changed by updating the box.space._session_settings system table..

Actions:

1. Tarantool evaluates each column definition and table-constraint, and returns an error if any of the rules is violated.
2. Tarantool makes a new definition in the schema.
3. Tarantool makes new indexes for PRIMARY KEY or UNIQUE constraints. A unique index name is created automatically.
4. Usually Tarantool effectively executes a COMMIT statement.

Examples:

```
-- the simplest form, with one column and one constraint:
CREATE TABLE t1 (s1 INTEGER, PRIMARY KEY (s1));

-- you can see the effect of the statement by querying
-- Tarantool system spaces:
```

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```
SELECT * FROM "_space" WHERE "name" = 'T1';
SELECT * FROM "_index" JOIN "_space" ON "_index"."id" = "_space"."id"
       WHERE "_space"."name" = 'T1';

-- variation of the simplest form, with delimited identifiers
-- and a bracketed comment:
CREATE TABLE "T1" ("S1" INT /* synonym of INTEGER */, PRIMARY KEY ("S1"));

-- two columns, one named constraint
CREATE TABLE t1 (s1 INTEGER, s2 STRING, CONSTRAINT pk_s1s2_t1_1 PRIMARY KEY (s1, s2));
```

Limitations:

- The maximum number of columns is 2000.
- The maximum length of a row depends on the memtx_max_tuple_size or vinyl_max_tuple_size configuration option.

Column definition

Syntax:

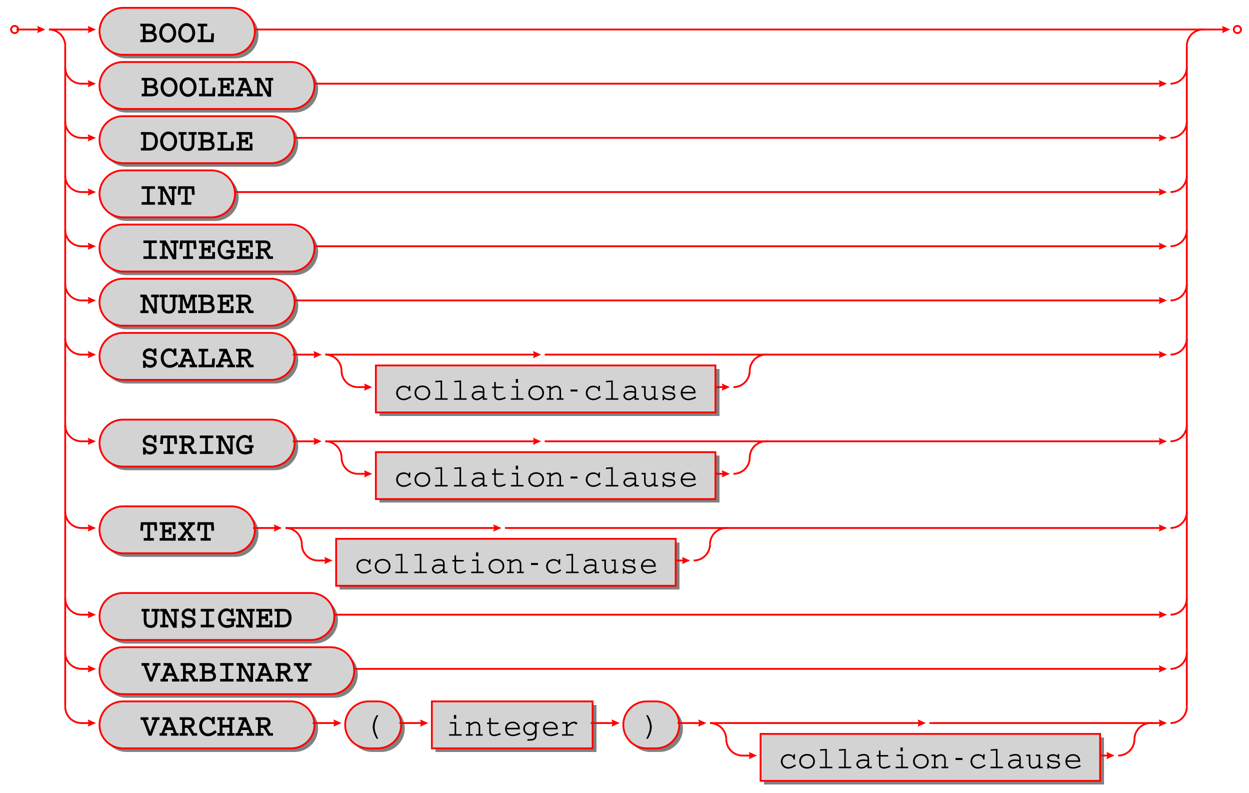
column-name data-type [, column-constraint]

Define a column, which is a table-element used in a CREATE TABLE statement.

The column-name must be an identifier which is valid according to the rules for identifiers.

Each column-name must be unique within a table.

Column definition – data type



Every column has a data type: BOOLEAN or DOUBLE or INTEGER or NUMBER or SCALAR or STRING or UNSIGNED or VARBINARY. The detailed description of data types is in the section Operands.

Column definition – the rules for the SCALAR data type

SCALAR is a "complex" data type, unlike all the other data types which are "primitive". Two column values in a SCALAR column can have two different primitive data types.

1. Any item defined as SCALAR has an underlying primitive type. For example, here:

   ```
   CREATE TABLE t (s1 SCALAR PRIMARY KEY);
   INSERT INTO t VALUES (55), ('41');
   ```

   the underlying primitive type of the item in the first row is INTEGER because literal 55 has data type INTEGER, and the underlying primitive type in the second row is STRING (the data type of a literal is always clear from its format).

   An item's primitive type is far more important than its defined type. Incidentally Tarantool might find the primitive type by looking at the way MsgPack stores it, but that is an implementation detail.

2. A SCALAR definition may not include a maximum length, as there is no suggested restriction.

3. A SCALAR definition may include a COLLATE clause, which affects any items whose primitive data type is STRING. The default collation is "binary".

4. Some assignments are illegal when data types differ, but legal when the target is a SCALAR item. For example UPDATE ... SET column1 = `'a'` is illegal if column1 is defined as INTEGER, but is legal if

column1 is defined as SCALAR – values which happen to be INTEGER will be changed so their data type is STRING.

5. There is no literal syntax which implies data type SCALAR.
6. TYPEOF(x) is never SCALAR, it is always the underlying data type. This is true even if x is NULL (in that case the data type is BOOLEAN). In fact there is no function that is guaranteed to return the defined data type. For example, TYPEOF(CAST(1 AS SCALAR)); returns INTEGER, not SCALAR.
7. For any operation that requires implicit casting from an item defined as SCALAR, the syntax is legal but the operation may fail at runtime. At runtime, Tarantool detects the underlying primitive data type and applies the rules for that. For example, if a definition is:

```
CREATE TABLE t (s1 SCALAR PRIMARY KEY, s2 INTEGER);
```

   and within any row s1 = `'a'`, that is, its underlying primitive type is STRING to indicate character strings, then UPDATE t SET s2 = s1; is illegal. Tarantool usually does not know that in advance.

8. For any dyadic operation that requires implicit casting for comparison, the syntax is legal and the operation will not fail at runtime. Take this situation: comparison with a primitive type VARBINARY and a primitive type STRING.

```
CREATE TABLE t (s1 SCALAR PRIMARY KEY);
INSERT INTO t VALUES (X'41');
SELECT * FROM t WHERE s1 > 'a';
```

   The comparison is valid, because Tarantool knows the ordering of X'41' and 'a' in Tarantool/NoSQL 'scalar'.

9. The result data type of min/max operation on a column defined as SCALAR is the data type of the minimum/maximum operand, unless the result value is NULL. For example:

```
CREATE TABLE t (s1 INTEGER, s2 SCALAR PRIMARY KEY);
INSERT INTO t VALUES (1, X'44'), (2, 11), (3, 1E4), (4, 'a');
SELECT min(s2), hex(max(s2)) FROM t;
```

   The result is: - - [11, `'44'`,]

   That is only possible with Tarantool/NoSQL scalar rules, but SELECT SUM(s2) would not be legal because addition would in this case require implicit casting from VARBINARY to a number, which is not sensible.

10. The result data type of a primitive combination is never SCALAR because we in effect use TYPEOF(item) not the defined data type. (Here we use the word "combination" in the way that the standard document uses it for section "Result of data type combinations".) Therefore for greatest(1E308, `'a'`, 0, X`'00'`) the result is X'00'.

Column definition – relation to NoSQL

All the SQL data types correspond to Tarantool/NoSQL types with the same name. For example an SQL STRING is stored in a NoSQL space as type = 'string'.

Therefore specifying an SQL data type X determines that the storage will be in a space with a format column saying that the NoSQL type is 'x'.

The rules for that NoSQL type are applicable to the SQL data type.

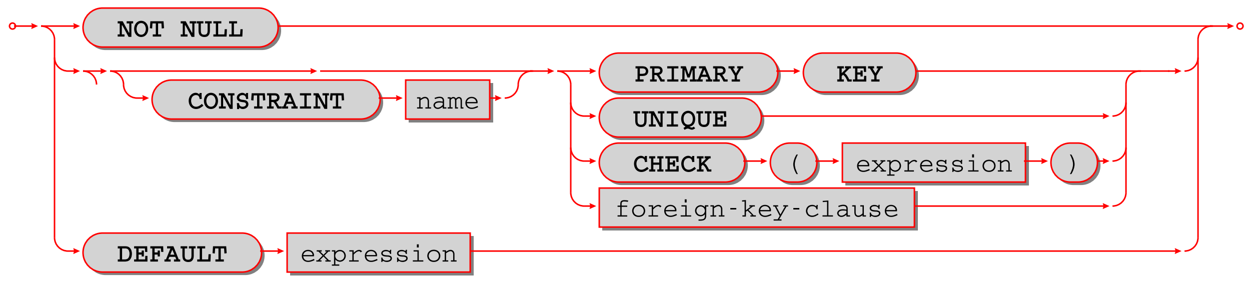
If two items have SQL data types that have the same underlying type, then they are compatible for all assignment or comparison purposes.

If two items have SQL data types that have different underlying types, then the rules for explicit casts, or implicit (assignment) casts, or implicit (comparison) casts, apply.

There is one floating-point value which is not handled by SQL: -nan is seen as NULL.

There are also some Tarantool/NoSQL data types which have no corresponding SQL data types. For example, SELECT "flags" FROM "_space"; will return a column whose data type is 'map'. Such columns can only be manipulated in SQL by invoking Lua functions.

Column definition – column-constraint or default clause



The column-constraint or default clause may be as follows:

Type	Comment
NOT NULL	means "it is illegal to assign a NULL to this column"
PRIMARY KEY	explained in the later section "Table Constraint Definition"
UNIQUE	explained in the later section "Table Constraint Definition"
CHECK (expression)	explained in the later section "Table Constraint Definition"
foreign-key-clause	explained in the later section "Table Constraint Definition for foreign keys"
DEFAULT expression	means "if INSERT does not assign to this column then assign expression result to this column" – if there is no DEFAULT clause then DEFAULT NULL is assumed.

If column-constraint is PRIMARY KEY, this is a shorthand for a separate table-constraint definition: "PRIMARY KEY (column-name)".

If column-constraint is UNIQUE, this is a shorthand for a separate table-constraint definition: "UNIQUE (column-name)".

If column-constraint is CHECK, this is a shorthand for a separate table-constraint definition: "CHECK (expression)".

Columns defined with PRIMARY KEY are automatically NOT NULL.

To enforce some restrictions that Tarantool does not enforce automatically, add CHECK clauses, like these:

```
CREATE TABLE t ("smallint" INTEGER PRIMARY KEY CHECK ("smallint" <= 32767 AND "smallint" >= -
↪32768));
CREATE TABLE t ("shorttext" STRING PRIMARY KEY CHECK (length("shorttext") <= 10));
```

but this may cause inserts or updates to be slow.

Column definition – examples

These are shown within CREATE TABLE statements. Data types may also appear in CAST functions.

```
-- the simple form with column-name and data-type
CREATE TABLE t (column1 INTEGER ...);
-- with column-name and data-type and column-constraint
CREATE TABLE t (column1 STRING PRIMARY KEY ...);
-- with column-name and data-type and collate-clause
CREATE TABLE t (column1 SCALAR COLLATE "unicode" ...);
```

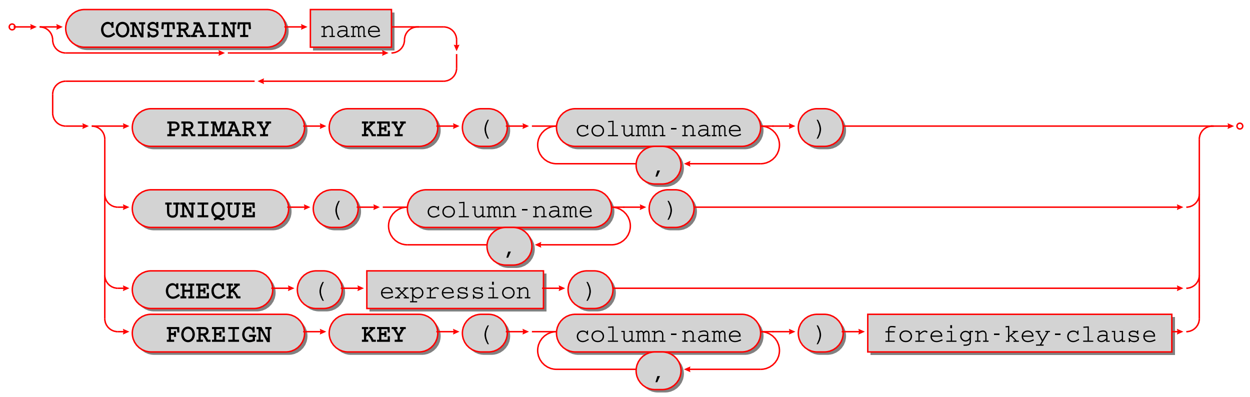
```
-- with all possible data types and aliases
CREATE TABLE t
(column1 BOOLEAN, column2 BOOL,
 column3 INT PRIMARY KEY, column4 INTEGER,
 column5 DOUBLE,
 column6 NUMBER,
 column7 STRING, column8 STRING COLLATE "unicode",
 column9 TEXT, columna TEXT COLLATE "unicode_sv_s1",
 columnb VARCHAR(0), columnc VARCHAR(100000) COLLATE "binary",
 columnd VARBINARY,
 columne SCALAR, columnf SCALAR COLLATE "unicode_uk_s2");
```

```
-- with all possible column constraints and a default clause
CREATE TABLE t
(column1 INTEGER NOT NULL,
 column2 INTEGER PRIMARY KEY,
 column3 INTEGER UNIQUE,
 column4 INTEGER CHECK (column3 > column2),
 column5 INTEGER REFERENCES t,
 column6 INTEGER DEFAULT NULL);
```

Table Constraint Definition

Syntax:

[CONSTRAINT constraint-name] primary-key-constraint | unique-constraint | check-constraint | foreign-key-constraint



Define a constraint, which is a table-element used in a CREATE TABLE statement.

The constraint-name must be an identifier which is valid according to the rules for identifiers. The constraint-name must be unique within the table.

PRIMARY KEY constraints look like this: PRIMARY KEY (column-name [, column-name...])

There is a shorthand: specifying PRIMARY KEY in a column definition.

Every table must have one and only one primary key. Primary-key columns are automatically NOT NULL. Primary-key columns are automatically indexed. Primary-key columns are unique, that is, it is illegal to have two rows which have the same values for the columns specified in the constraint.

Examples:

```
-- this is a table with a one-column primary-key constraint
CREATE TABLE t1 (s1 INTEGER, PRIMARY KEY (s1));
-- this is the column-definition shorthand for the same thing:
CREATE TABLE t1 (s1 INTEGER PRIMARY KEY);
-- this is a table with a two-column primary-key constraint
CREATE TABLE t2 (s1 INTEGER, s2 INTEGER, PRIMARY KEY (s1, s2));
-- this is an example of an attempted primary-key violation
-- (the third INSERT will fail because 55, 'a' is a duplicate)
CREATE TABLE t3 (s1 INTEGER, s2 STRING, PRIMARY KEY (s1, s2));
INSERT INTO t3 VALUES (55, 'a');
INSERT INTO t3 VALUES (55, 'b');
INSERT INTO t3 VALUES (55, 'a');
```

PRIMARY KEY plus AUTOINCREMENT modifier may be specified in one of two ways: - In a column definition after the words PRIMARY KEY, as in CREATE TABLE t (c INTEGER PRIMARY KEY AUTOINCREMENT); - In a PRIMARY KEY (column-list) after a column name, as in CREATE TABLE t (c INTEGER, PRIMARY KEY (c AUTOINCREMENT)); When AUTOINCREMENT is specified, the column must be a primary-key column and it must be INTEGER or UNSIGNED. Only one column in the table may be autoincrement. However, it is legal to say PRIMARY KEY (a, b, c AUTOINCREMENT) – in that case, there are three columns in the primary key but only the first column (a) is AUTOINCREMENT.

As the name suggests, values in an autoincrement column are automatically incremented. That is: if a user inserts NULL in the column, then the stored value will be the smallest non-negative integer that has not already been used. This occurs because autoincrement columns are associated with sequences.

UNIQUE constraints look like this: UNIQUE (column-name [, column-name...])

There is a shorthand: specifying UNIQUE in a column definition.

Unique constraints are similar to primary-key constraints, except that: a table may have any number of unique keys, and unique keys are not automatically NOT NULL. Unique columns are automatically indexed. Unique columns are unique, that is, it is illegal to have two rows with the same values in the unique-key columns.

Examples:

```
-- this is a table with a one-column primary-key constraint
-- and a one-column unique constraint
CREATE TABLE t1 (s1 INTEGER, s2 INTEGER, PRIMARY KEY (s1), UNIQUE (s2));
-- this is the column-definition shorthand for the same thing:
CREATE TABLE t1 (s1 INTEGER PRIMARY KEY, s2 INTEGER UNIQUE);
-- this is a table with a two-column unique constraint
CREATE TABLE t2 (s1 INTEGER PRIMARY KEY, s2 INTEGER, UNIQUE (s2, s1));
-- this is an example of an attempted unique-key violation
-- (the third INSERT will not fail because NULL is not a duplicate)
-- (the fourth INSERT will fail because 'a' is a duplicate)
CREATE TABLE t3 (s1 INTEGER PRIMARY KEY, s2 STRING, UNIQUE (s2));
```

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```
INSERT INTO t3 VALUES (1, 'a');
INSERT INTO t3 VALUES (2, NULL);
INSERT INTO t3 VALUES (3, NULL);
INSERT INTO t3 VALUES (4, 'a');
```

CHECK constraints look like this: CHECK (expression)

There is a shorthand: specifying CHECK in a column definition.

The expression may be anything that returns a BOOLEAN result = TRUE or FALSE or UNKNOWN. The expression may not contain a subquery. If the expression contains a column name, the column must exist in the table. If a CHECK constraint is specified, the table must not contain rows where the expression is FALSE. (The table may contain rows where the expression is either TRUE or UNKNOWN.) Constraint checking may be stopped with ALTER TABLE . . . DISABLE CHECK CONSTRAINT and restarted with ALTER TABLE . . . ENABLE CHECK CONSTRAINT.

Examples:

```
-- this is a table with a one-column primary-key constraint
-- and a check constraint
CREATE TABLE t1 (s1 INTEGER PRIMARY KEY, s2 INTEGER, CHECK (s2 <> s1));
-- this is an attempt to violate the constraint, it will fail
INSERT INTO t1 VALUES (1, 1);
-- this is okay because comparison with NULL will not return FALSE
INSERT INTO t1 VALUES (1, NULL);
-- a constraint that makes it difficult to insert lower case
CHECK (s1 = UPPER(s1))
```

Limitations: (Issue#3503): * CREATE TABLE t99 (s1 INTEGER, UNIQUE(s1, s1),PRIMARY KEY(s1)); causes no error message, although (s1, s1) is probably a user error.

Table Constraint Definition for foreign keys

FOREIGN KEY constraints look like this: FOREIGN KEY (referencing-column-name [, referencing-column-name...]) REFERENCES referenced-table-name [(referenced-column-name [, referenced-column-name...]]) [MATCH FULL] [update-or-delete-rules]

There is a shorthand: specifying REFERENCES in a column definition.

The referencing column names must be defined in the table that is being created. The referenced table name must refer to a table that already exists, or to the table that is being created. The referenced column names must be defined in the referenced table, and have similar data types. There must be a PRIMARY KEY or UNIQUE constraint or UNIQUE index on the referenced column names.

The words MATCH FULL are optional and have no effect.

If a foreign-key constraint exists, then the values in the referencing columns must equal values in the referenced columns of the referenced table, or at least one of the referencing columns must contain NULL.

Examples:

```
-- A foreign key referencing a primary key in the same table
CREATE TABLE t1 (s1 INTEGER PRIMARY KEY, s2 INTEGER, FOREIGN KEY (s2) REFERENCES t1␣
↪(s1));
-- The same thing with column shorthand
CREATE TABLE t1 (s1 INTEGER PRIMARY KEY, s2 INTEGER REFERENCES t1(s1));
-- An attempt to violate the constraint -- this will fail
```

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```
INSERT INTO t1 VALUES (1, 2);
-- A NULL in the referencing column -- this will succeed
INSERT INTO t1 VALUES (1, NULL);
-- A reference to a primary key that now exists -- this will succeed
INSERT INTO t1 VALUES (2, 1);
```

The optional update-or-delete rules look like this: ON {UPDATE|DELETE} { CASCADE | SET DEFAULT | SET NULL | RESTRICT | NO ACTION} and the idea is: if something changes the referenced key, then one of these possible "referential actions" takes place: CASCADE: the change that is applied for the referenced key is applied for the referencing key. SET DEFAULT: the referencing key is set to its default value. SET NULL: the referencing key is set to NULL. RESTRICT: the UPDATE or DELETE fails if a referencing key exists; checked immediately. NO ACTION: the UPDATE or DELETE fails if a referencing key exists; checked at statement end. The default is NO ACTION.

For example:

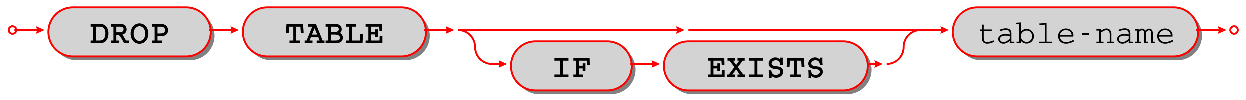
```
CREATE TABLE f1 (ordinal INTEGER PRIMARY KEY,
                 referenced_planet STRING UNIQUE NOT NULL);
CREATE TABLE f2 (
    ordinal INTEGER PRIMARY KEY,
    referring_planet STRING DEFAULT 'Earth',
    FOREIGN KEY (referring_planet) REFERENCES f1 (referenced_planet)
        ON UPDATE SET DEFAULT
        ON DELETE CASCADE);
INSERT INTO f1 VALUES (1, 'Mercury'), (2,' Venus'), (3, 'Earth');
INSERT INTO f2 VALUES (1, 'Mercury'), (2, 'Mercury');
UPDATE f1 SET referenced_planet = 'Mars'
    WHERE referenced_planet = 'Mercury';
SELECT * FROM f2;
DELETE FROM f1 WHERE referenced_planet = 'Earth';
SELECT * FROM f2;
... In this example, the UPDATE statement changes the referenced key,
    and the clause is ON UPDATE SET DEFAULT, therefore both of the
    rows in f2 have referring_planet set to their default value,
    which is 'Earth'. The DELETE statement deletes the row that
    has 'Earth', and the clause is ON DELETE CASCADE,
    therefore both of the rows in f2 are deleted.
```

Limitations: * Foreign keys can have a MATCH clause (Issue#3455).

DROP TABLE

Syntax:

DROP TABLE [IF EXISTS] table-name;



Drop a table.

The table-name must identify a table that was created earlier with the CREATE TABLE statement.

Rules:

- If there is a view that references the table, the drop will fail. Please drop the referencing view with DROP VIEW first.
- If there is a foreign key that references the table, the drop will fail. Please drop the referencing constraint with ALTER TABLE … DROP first.

Actions:

1. Tarantool returns an error if the table does not exist and there is no IF EXISTS clause.
2. The table and all its data are dropped.
3. All indexes for the table are dropped.
4. All triggers for the table are dropped.
5. Usually Tarantool effectively executes a COMMIT statement.

Examples:

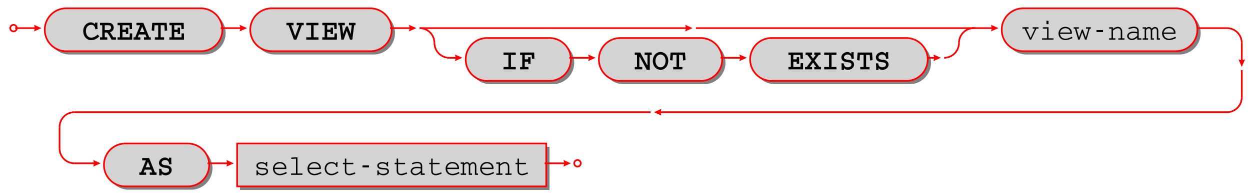
```
-- the simple case:
DROP TABLE t31;
-- with an IF EXISTS clause:
DROP TABLE IF EXISTS t31;
```

See also: DROP VIEW.

CREATE VIEW

Syntax:

CREATE VIEW [IF NOT EXISTS] view-name [(column-list)] AS subquery;



Create a new viewed table, usually called a "view".

The view-name must be valid according to the rules for identifiers.

The optional column-list must be a comma-separated list of names of columns in the view.

The syntax of the subquery must be the same as the syntax of a SELECT statement, or of a VALUES clause.

Rules:

- There must not already be a base table or view with the same name as view-name.
- If column-list is specified, the number of columns in column-list must be the same as the number of columns in the select list of the subquery.

Actions:

1. Tarantool will throw an error if a rule is violated.
2. Tarantool will create a new persistent object with column-names equal to the names in the column-list or the names in the subquery's select list.
3. Usually Tarantool effectively executes a COMMIT statement.

Examples:

```
-- the simple case:
CREATE VIEW v AS SELECT column1, column2 FROM t;
-- with a column-list:
CREATE VIEW v (a,b) AS SELECT column1, column2 FROM t;
```

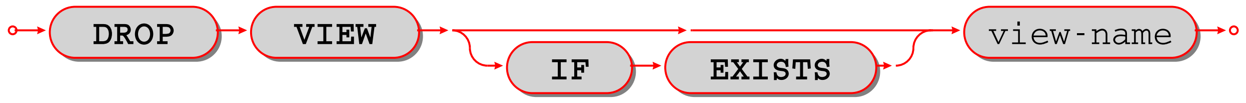
Limitations:

- It is not possible to insert or update or delete from a view, although sometimes a possible substitution is to create an INSTEAD OF trigger.

DROP VIEW

Syntax:

DROP VIEW [IF EXISTS] view-name;



Drop a view.

The view-name must identify a view that was created earlier with the CREATE VIEW statement.

Rules: none

Actions:

1. Tarantool returns an error if the view does not exist and there is no IF EXISTS clause.
2. The view is dropped.
3. All triggers for the view are dropped.
4. Usually Tarantool effectively executes a COMMIT statement.

Examples:

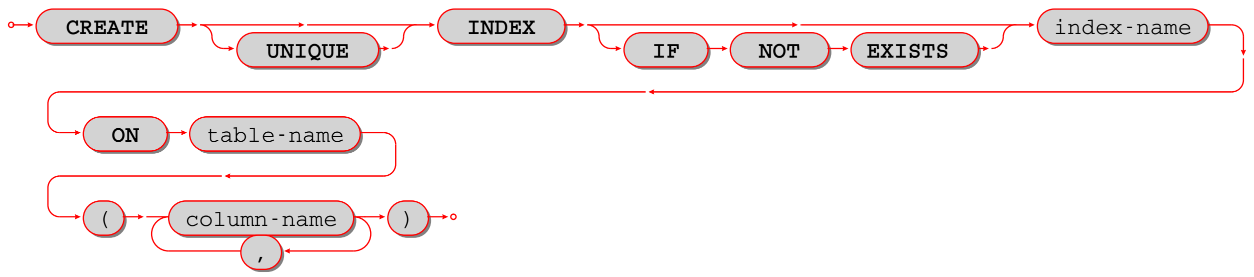
```
-- the simple case:
DROP VIEW v31;
-- with an IF EXISTS clause:
DROP VIEW IF EXISTS v31;
```

See also: DROP TABLE.

CREATE INDEX

Syntax:

CREATE [UNIQUE] INDEX [IF NOT EXISTS] index-name ON table-name (column-list);



Create an index.

The index-name must be valid according to the rules for identifiers.

The table-name must refer to an existing table.

The column-list must be a comma-separated list of names of columns in the table.

Rules:

- There must not already be, for the same table, an index with the same name as index-name. But there may already be, for a different table, an index with the same name as index-name.
- The maximum number of indexes per table is 128.

Actions:

1. Tarantool will throw an error if a rule is violated.
2. If the new index is UNIQUE, Tarantool will throw an error if any row exists with columns that have duplicate values.
3. Tarantool will create a new index.
4. Usually Tarantool effectively executes a COMMIT statement.

Automatic indexes:

Indexes may be created automatically for columns mentioned in the PRIMARY KEY or UNIQUE clauses of a CREATE TABLE statement. If an index was created automatically, then the index-name has four parts:

1. pk if this is for a PRIMARY KEY clause, unique if this is for a UNIQUE clause;
2. _unnamed_;
3. the name of the table;
4. _ and an ordinal number; the first index is 1, the second index is 2, and so on.

For example, after CREATE TABLE t (s1 INTEGER PRIMARY KEY, s2 INTEGER, UNIQUE (s2)); there are two indexes named pk_unnamed_T_1 and unique_unnamed_T_2. You can confirm this by saying SELECT * FROM "_index"; which will list all indexes on all tables. There is no need to say CREATE INDEX for columns that already have automatic indexes.

Examples:

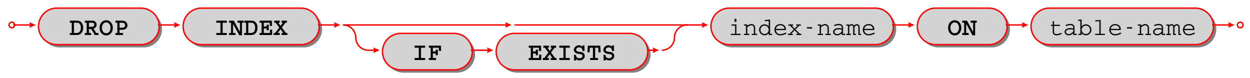
```
-- the simple case
CREATE INDEX idx_column1_t_1 ON t (column1);
-- with IF NOT EXISTS clause
CREATE INDEX IF NOT EXISTS idx_column1_t_1 ON t (column1);
-- with UNIQUE specifier and more than one column
CREATE UNIQUE INDEX idx_unnamed_t_1 ON t (column1, column2);
```

Dropping an automatic index created for a unique constraint will drop the unique constraint as well.

DROP INDEX

Syntax:

DROP INDEX [IF EXISTS] index-name ON table-name;



The index-name must be the name of an existing index, which was created with CREATE INDEX. Or, the index-name must be the name of an index that was created automatically due to a PRIMARY KEY or UNIQUE clause in the CREATE TABLE statement. To see what a table's indexes are, use PRAGMA index_list(table-name);.

Rules: none

Actions:

1. Tarantool throws an error if the index does not exist, or is an automatically created index.
2. Tarantool will drop the index.
3. Usually Tarantool effectively executes a COMMIT statement.

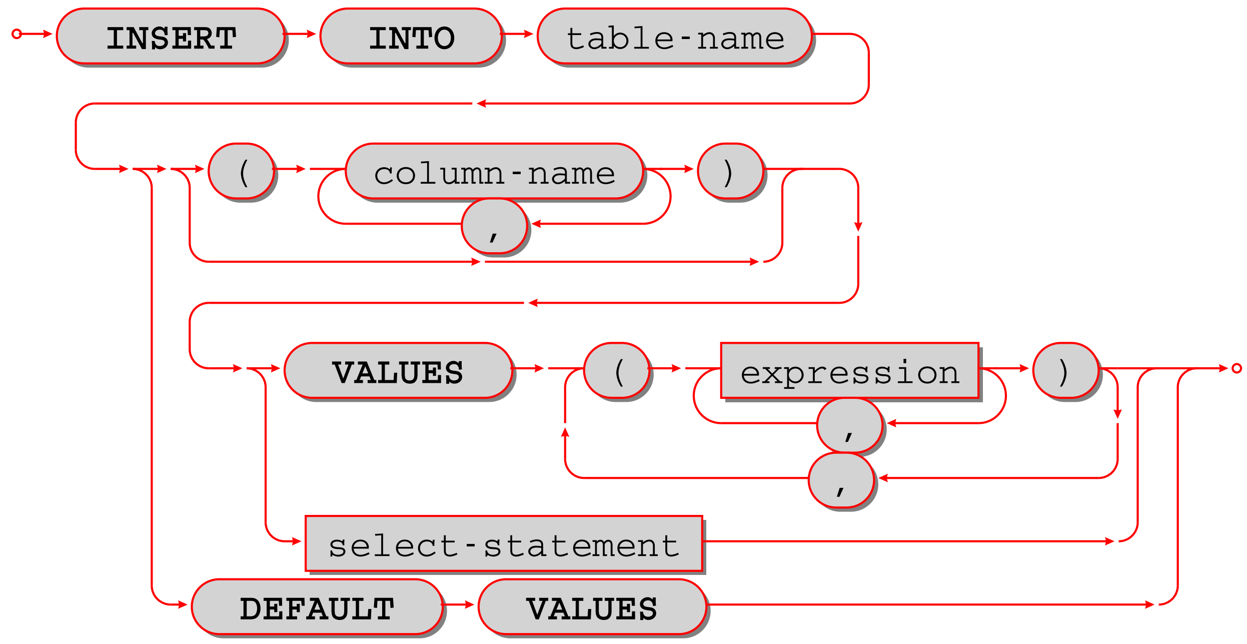
Example:

```
-- the simplest form:
DROP INDEX idx_unnamed_t_1 ON t;
```

INSERT

Syntax:

- INSERT INTO table-name [(column-list)] VALUES (expression-list) [, (expression-list)];
- INSERT INTO table-name [(column-list)] select-statement;
- INSERT INTO table-name DEFAULT VALUES;



Insert one or more new rows into a table.

The table-name must be a name of a table defined earlier with CREATE TABLE.

The optional column-list must be a comma-separated list of names of columns in the table.

The expression-list must be a comma-separated list of expressions; each expression may contain literals and operators and subqueries and function invocations.

Rules:

- The values in the expression-list are evaluated from left to right.
- The order of the values in the expression-list must correspond to the order of the columns in the table, or (if a column-list is specified) to the order of the columns in the column-list.
- The data type of the value should correspond to the data type of the column, that is, the data type that was specified with CREATE TABLE.
- If a column-list is not specified, then the number of expressions must be the same as the number of columns in the table.
- If a column-list is specified, then some columns may be omitted; omitted columns will get default values.
- The parenthesized expression-list may be repeated – (expression-list),(expression-list),... – for multiple rows.

Actions:

1. Tarantool evaluates each expression in expression-list, and returns an error if any of the rules is violated.
2. Tarantool creates zero or more new rows containing values based on the values in the VALUES list or based on the results of the select-expression or based on the default values.
3. Tarantool executes constraint checks and trigger actions and the actual insertion.

Examples:

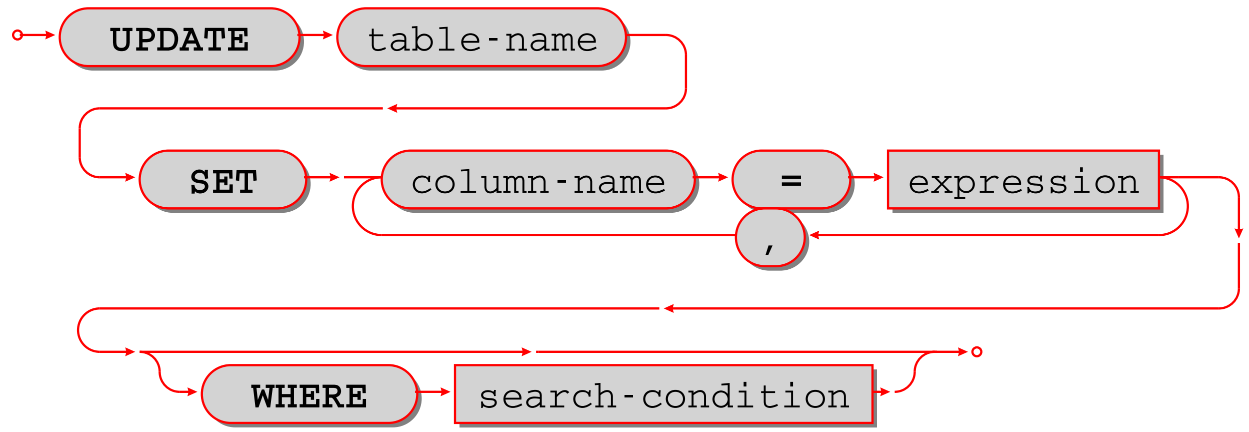
```
-- the simplest form:
INSERT INTO table1 VALUES (1, 'A');
-- with a column list:
INSERT INTO table1 (column1, column2) VALUES (2, 'B');
-- with an arithmetic operator in the first expression:
INSERT INTO table1 VALUES (2 + 1, 'C');
-- put two rows in the table:
INSERT INTO table1 VALUES (4, 'D'), (5, 'E');
```

See also: REPLACE statement.

UPDATE

Syntax:

UPDATE table-name SET column-name = expression [, column-name = expression ...] [WHERE search-condition];



Update zero or more existing rows in a table.

The table-name must be a name of a table defined earlier with CREATE TABLE or CREATE VIEW.

The column-name must be an updatable column in the table.

The expression may contain literals and operators and subqueries and function invocations and column names.

Rules:

- The values in the SET clause are evaluated from left to right.
- The data type of the value should correspond to the data type of the column, that is, the data type that was specified with CREATE TABLE.
- If a search-condition is not specified, then all rows in the table will be updated; otherwise only those rows which match the search-condition will be updated.

Actions:

1. Tarantool evaluates each expression in the SET clause, and returns an error if any of the rules is violated. For each row that is found by the WHERE clause, a temporary new row is formed based on the original contents and the modifications caused by the SET clause.
2. Tarantool executes constraint checks and trigger actions and the actual update.

Examples:

```
-- the simplest form:
UPDATE t SET column1 = 1;
-- with more than one assignment in the SET clause:
UPDATE t SET column1 = 1, column2 = 2;
-- with a WHERE clause:
UPDATE t SET column1 = 5 WHERE column2 = 6;
```

Special cases:

It is legal to say SET (list of columns) = (list of values). For example:

```
UPDATE t SET (column1, column2, column3) = (1, 2, 3);
```

It is not legal to assign to a column more than once. For example:

```
INSERT INTO t (column1) VALUES (0);
UPDATE t SET column1 = column1 + 1, column1 = column1 + 1;
```

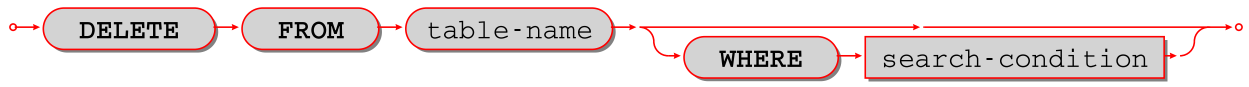
The result is an error: “duplicate column name”.

It is not legal to assign to a primary-key column.

DELETE

Syntax:

DELETE FROM table-name [WHERE search-condition];



Delete zero or more existing rows in a table.

The table-name must be a name of a table defined earlier with CREATE TABLE or CREATE VIEW.

The search-condition may contain literals and operators and subqueries and function invocations and column names.

Rules:

- If a search-condition is not specified, then all rows in the table will be deleted; otherwise only those rows which match the search-condition will be deleted.

Actions:

1. Tarantool evaluates each expression in the search-condition, and returns an error if any of the rules is violated.
2. Tarantool finds the set of rows that are to be deleted.
3. Tarantool executes constraint checks and trigger actions and the actual deletion.

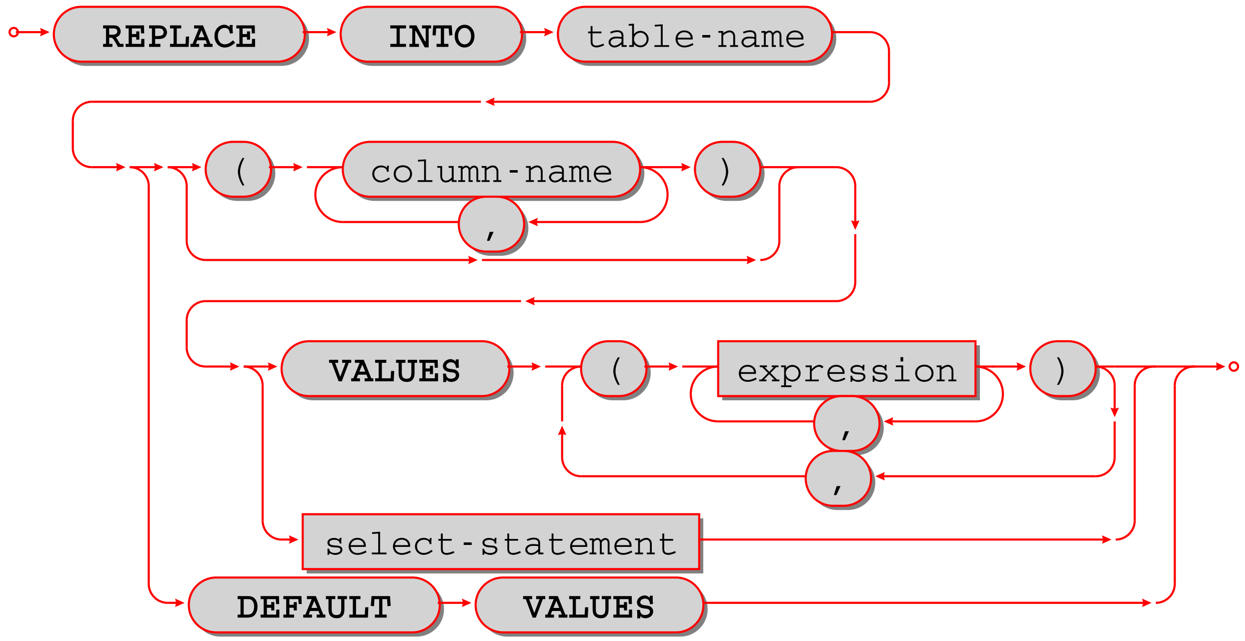
Examples:

```
-- the simplest form:
DELETE FROM t;
-- with a WHERE clause:
DELETE FROM t WHERE column2 = 6;
```

REPLACE

Syntax:

- REPLACE INTO table-name [(column-list)] VALUES (expression-list) [, (expression-list)];
- REPLACE INTO table-name [(column-list)] select-statement;
- REPLACE INTO table-name DEFAULT VALUES;



Insert one or more new rows into a table, or update existing rows.

If a row already exists (as determined by the primary key or any unique key), then the action is delete + insert, and the rules are the same as for a DELETE statement followed by an INSERT statement. Otherwise the action is insert, and the rules are the same as for the INSERT statement.

Examples:

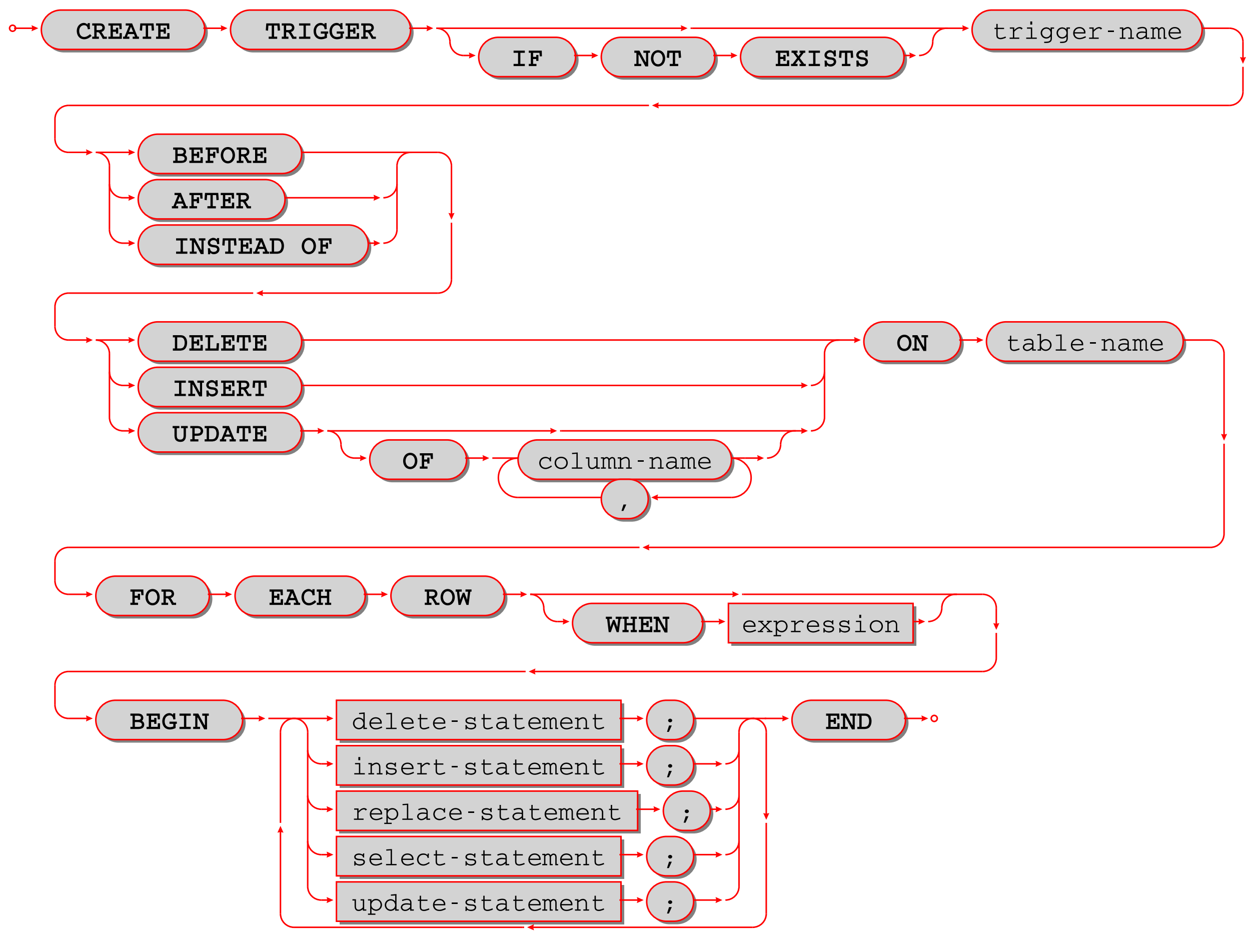
```
-- the simplest form:
REPLACE INTO table1 VALUES (1, 'A');
-- with a column list:
REPLACE INTO table1 (column1, column2) VALUES (2, 'B');
-- with an arithmetic operator in the first expression:
REPLACE INTO table1 VALUES (2 + 1, 'C');
-- put two rows in the table:
REPLACE INTO table1 VALUES (4, 'D'), (5, 'E');
```

See also: INSERT Statement, UPDATE Statement.

CREATE TRIGGER

Syntax:

CREATE TRIGGER [IF NOT EXISTS] trigger-name BEFORE|AFTER|INSTEAD OF DELETE|INSERT|UPDATE ON table-name FOR EACH ROW [WHEN search-condition] BEGIN delete-statement | insert-statement | replace-statement | select-statement | update-statement; [delete-statement | insert-statement | replace-statement | select-statement | update-statement; ...] END;



The trigger-name must be valid according to the rules for identifiers.

If the trigger action time is BEFORE or AFTER, then the table-name must refer to an existing base table.

If the trigger action time is INSTEAD OF, then the table-name must refer to an existing view.

Rules:

- There must not already be a trigger with the same name as trigger-name.
- Triggers on different tables or views share the same namespace.
- The statements between BEGIN and END should not refer to the table-name mentioned in the ON clause.
- The statements between BEGIN and END should not contain an INDEXED BY clause.

SQL triggers are not activated by Tarantool/NoSQL requests. This will change in a future version.

On a replica, effects of trigger execution are applied, and the SQL triggers themselves are not activated upon replication events.

NoSQL triggers are activated both on replica and master, thus if you have a NoSQL trigger on a replica, it is activated when applying effects of an SQL trigger.

Actions:

1. Tarantool will throw an error if a rule is violated.
2. Tarantool will create a new trigger.

3. Usually Tarantool effectively executes a COMMIT statement.

Examples:

```
-- the simple case:
CREATE TRIGGER stores_before_insert BEFORE INSERT ON stores FOR EACH ROW
  BEGIN DELETE FROM warehouses; END;
-- with IF NOT EXISTS clause:
CREATE TRIGGER IF NOT EXISTS stores_before_insert BEFORE INSERT ON stores FOR EACH ROW
  BEGIN DELETE FROM warehouses; END;
-- with FOR EACH ROW and WHEN clauses:
CREATE TRIGGER stores_before_insert BEFORE INSERT ON stores FOR EACH ROW WHEN a=5
  BEGIN DELETE FROM warehouses; END;
-- with multiple statements between BEGIN and END:
CREATE TRIGGER stores_before_insert BEFORE INSERT ON stores FOR EACH ROW
  BEGIN DELETE FROM warehouses; INSERT INTO inventories VALUES (1); END;
```

Trigger extra clauses

- UPDATE OF column-list

  After BEFORE|AFTER UPDATE it is optional to add OF column-list. If any of the columns in column-list is affected at the time the row is processed, then the trigger will be activated for that row. For example:

  ```
  CREATE TRIGGER table1_before_update
   BEFORE UPDATE  OF column1, column2 ON table1
   FOR EACH ROW
   BEGIN UPDATE table2 SET column1 = column1 + 1; END;
  UPDATE table1 SET column3 = column3 + 1; -- Trigger will not be activated
  UPDATE table1 SET column2 = column2 + 0; -- Trigger will be activated
  ```

- WHEN

  After table-name FOR EACH ROW it is optional to add [WHEN expression]. If the expression is true at the time the row is processed, only then will the trigger will be activated for that row. For example:

  ```
  CREATE TRIGGER table1_before_update BEFORE UPDATE ON table1 FOR EACH ROW
   WHEN (SELECT COUNT(*) FROM table1) > 1
   BEGIN UPDATE table2 SET column1 = column1 + 1; END;
  ```

  This trigger will not be activated unless there is more than one row in table1.

- OLD and NEW

  The keywords OLD and NEW have special meaning in the context of trigger action:

  - OLD.column-name refers to the value of column-name before the change.
  - NEW.column-name refers to the value of column-name after the change.

  For example:

  ```
  CREATE TABLE table1 (column1 STRING, column2 INTEGER PRIMARY KEY);
  CREATE TABLE table2 (column1 STRING, column2 STRING, column3 INTEGER PRIMARY KEY);
  INSERT INTO table1 VALUES ('old value', 1);
  INSERT INTO table2 VALUES ('', '', 1);
  CREATE TRIGGER table1_before_update BEFORE UPDATE ON table1 FOR EACH ROW
   BEGIN UPDATE table2 SET column1 = old.column1, column2 = new.column1; END;
  ```

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```
UPDATE table1 SET column1 = 'new value';
SELECT * FROM table2;
```

At the beginning of the UPDATE for the single row of table1, the value in column1 is 'old value' – so that is what is seen as old.column1.

At the end of the UPDATE for the single row of table1, the value in column1 is 'new value' – so that is what is seen as new.column1. (OLD and NEW are qualifiers for table1, not table2.)

Therefore, SELECT * FROM table2; returns ['old value', 'new value'].

OLD.column-name does not exist for an INSERT trigger.

NEW.column-name does not exist for a DELETE trigger.

OLD and NEW are read-only; you cannot change their values.

- Deprecated or illegal statements:

  It is illegal for the trigger action to include a qualified column reference other than OLD.column-name or NEW.column-name. For example, CREATE TRIGGER ... BEGIN UPDATE table1 SET table1.column1 = 5; END; is illegal.

  It is illegal for the trigger action to include statements that include a WITH clause, a DEFAULT VALUES clause, or an INDEXED BY clause.

  It is usually not a good idea to have a trigger on table1 which causes a change on table2, and at the same time have a trigger on table2 which causes a change on table1. For example:

```
CREATE TRIGGER table1_before_update
 BEFORE UPDATE ON table1
 FOR EACH ROW
 BEGIN UPDATE table2 SET column1 = column1 + 1; END;
CREATE TRIGGER table2_before_update
 BEFORE UPDATE ON table2
 FOR EACH ROW
 BEGIN UPDATE table1 SET column1 = column1 + 1; END;
```

  Luckily UPDATE table1 ... will not cause an infinite loop, because Tarantool recognizes when it has already updated so it will stop. However, not every DBMS acts this way.

Trigger activation

These are remarks concerning trigger activation.

Standard terminology:

- "trigger action time" = BEFORE or AFTER or INSTEAD OF
- "trigger event" = INSERT or DELETE or UPDATE
- "triggered statement" = BEGIN … DELETE|INSERT|REPLACE|SELECT|UPDATE … END
- "triggered when clause" = WHEN search-condition
- "activate" = execute a triggered statement
- some vendors use the word "fire" instead of "activate"

If there is more than one trigger for the same trigger event, Tarantool may execute the triggers in any order.

It is possible for a triggered statement to cause activation of another triggered statement. For example, this is legal:

```
CREATE TRIGGER t1_before_delete BEFORE DELETE ON t1 FOR EACH ROW BEGIN DELETE FROM␣
↪t2; END;
CREATE TRIGGER t2_before_delete BEFORE DELETE ON t2 FOR EACH ROW BEGIN DELETE FROM␣
↪t3; END;
```

Activation occurs FOR EACH ROW, not FOR EACH STATEMENT. Therefore, if no rows are candidates for insert or update or delete, then no triggers are activated.

The BEFORE trigger is activated even if the trigger event fails.

If an UPDATE trigger event does not make a change, the trigger is activated anyway. For example, if row 1 column1 contains `'a'`, and the trigger event is UPDATE ... SET column1 = `'a'`;, the trigger is activated.

The triggered statement may refer to a function: RAISE(FAIL, error-message). If a triggered statement invokes a RAISE(FAIL, error-message) function, or if a triggered statement causes an error, then statement execution stops immediately.

The triggered statement may refer to column values within the rows being changed. in this case:

- The row "as of before" the change is called the "old" row (which makes sense only for UPDATE and DELETE statements).
- The row "as of after" the change is called the "new" row (which makes sense only for UPDATE and INSERT statements).

This example shows how an INSERT can be done to a view by referring to the "new" row:

```
CREATE TABLE t (s1 INTEGER PRIMARY KEY, s2 INTEGER);
CREATE VIEW v AS SELECT s1, s2 FROM t;
CREATE TRIGGER v_instead_of INSTEAD OF INSERT ON v
  FOR EACH ROW
  BEGIN INSERT INTO t VALUES (new.s1, new.s2); END;
INSERT INTO v VALUES (1, 2);
```

Ordinarily saying INSERT INTO view_name ... is illegal in Tarantool, so this is a workaround.

It is possible to generalize this so that all data-change statements on views will change the base tables, provided that the view contains all the columns of the base table, and provided that the triggers refer to those columns when necessary, as in this example:

```
CREATE TABLE base_table (primary_key_column INTEGER PRIMARY KEY, value_column INTEGER);
CREATE VIEW viewed_table AS SELECT primary_key_column, value_column FROM base_table;
CREATE TRIGGER viewed_table_instead_of_insert INSTEAD OF INSERT ON viewed_table FOR EACH␣
↪ROW
  BEGIN
    INSERT INTO base_table VALUES (new.primary_key_column, new.value_column); END;
CREATE TRIGGER viewed_table_instead_of_update INSTEAD OF UPDATE ON viewed_table FOR EACH␣
↪ROW
  BEGIN
    UPDATE base_table
    SET primary_key_column = new.primary_key_column, value_column = new.value_column
    WHERE primary_key_column = old.primary_key_column; END;
CREATE TRIGGER viewed_table_instead_of_delete INSTEAD OF DELETE ON viewed_table FOR EACH␣
↪ROW
  BEGIN
    DELETE FROM base_table WHERE primary_key_column = old.primary_key_column; END;
```

When INSERT or UPDATE or DELETE occurs for table X, Tarantool usually operates in this order (a basic scheme):

```
For each row
  Perform constraint checks
  For each BEFORE trigger that refers to table X
    Check that the trigger's WHEN condition is true.
    Execute what is in the triggered statement.
  Insert or update or delete the row in table X.
  Perform more constraint checks
  For each AFTER trigger that refers to table X
    Check that the trigger's WHEN condition is true.
    Execute what is in the triggered statement.
```

However, Tarantool does not guarantee execution order when there are multiple constraints, or multiple triggers for the same event (including NoSQL on_replace triggers or SQL INSTEAD OF triggers that affect a view of table X).

The maximum number of trigger activations per statement is 32.

INSTEAD OF triggers

A trigger which is created with the clause INSTEAD OF INSERT|UPDATE|DELETE ON view-name is an INSTEAD OF trigger. For each affected row, the trigger action is performed “instead of” the INSERT or UPDATE or DELETE statement that causes trigger activation.

For example, ordinarily it is illegal to INSERT rows in a view, but it is legal to create a trigger which intercepts attempts to INSERT, and puts rows in the underlying base table:

```
CREATE TABLE t1 (column1 INTEGER PRIMARY KEY, column2 INTEGER);
CREATE VIEW v1 AS SELECT column1, column2 FROM t1;
CREATE TRIGGER v1_instead_of INSTEAD OF INSERT ON v1 FOR EACH ROW BEGIN
 INSERT INTO t1 VALUES (NEW.column1, NEW.column2); END;
INSERT INTO v1 VALUES (1, 1);
-- ... The result will be: table t1 will contain a new row.
```

INSTEAD OF triggers are only legal for views, while BEFORE or AFTER triggers are only legal for base tables.

It is legal to create INSTEAD OF triggers with triggered WHEN clauses.

Limitations:

- It is legal to create INSTEAD OF triggers with UPDATE OF column-list clauses, but they are not standard SQL.

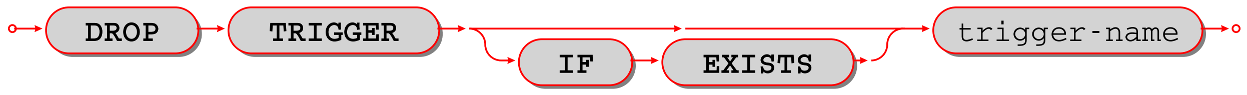
Example:

```
CREATE TRIGGER ev1_instead_of_update
  INSTEAD OF UPDATE OF column2,column1 ON ev1
  FOR EACH ROW BEGIN
  INSERT INTO et2 VALUES (NEW.column1, NEW.column2); END;
```

DROP TRIGGER

Syntax:

DROP TRIGGER [IF EXISTS] trigger-name;



Drop a trigger.

The trigger-name must identify a trigger that was created earlier with the CREATE TRIGGER statement.

Rules: none

Actions:

1. Tarantool returns an error if the trigger does not exist and there is no IF EXISTS clause.
2. The trigger is dropped.
3. Usually Tarantool effectively executes a COMMIT statement.

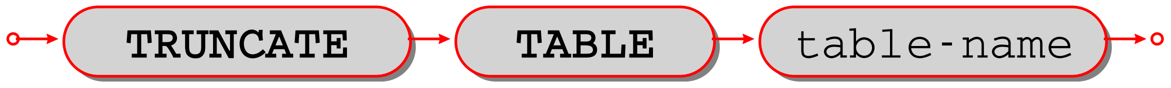
Examples:

```
-- the simple case:
DROP TRIGGER table1_before_insert;
-- with an IF EXISTS clause:
DROP TRIGGER IF EXISTS table1_before_insert;
```

TRUNCATE

Syntax:

TRUNCATE TABLE table-name;



Remove all rows in the table.

TRUNCATE is considered to be a schema-change rather than a data-change statement, so it does not work within transactions (it cannot be rolled back).

Rules:

- It is illegal to truncate a table which is referenced by a foreign key.
- It is illegal to truncate a table which is also a system space, such as _space.
- The table must be a base table rather than a view.

Actions:

1. All rows in the table are removed. Usually this is faster than DELETE FROM table-name;.
2. If the table has an autoincrement primary key, its sequence is not reset to zero, but that may occur in a future Tarantool version.
3. There is no effect for any triggers associated with the table.
4. There is no effect on the counts for the ROW_COUNT() function.
5. Only one action is written to the write-ahead log (with DELETE FROM table-name; there would be one action for each deleted row).

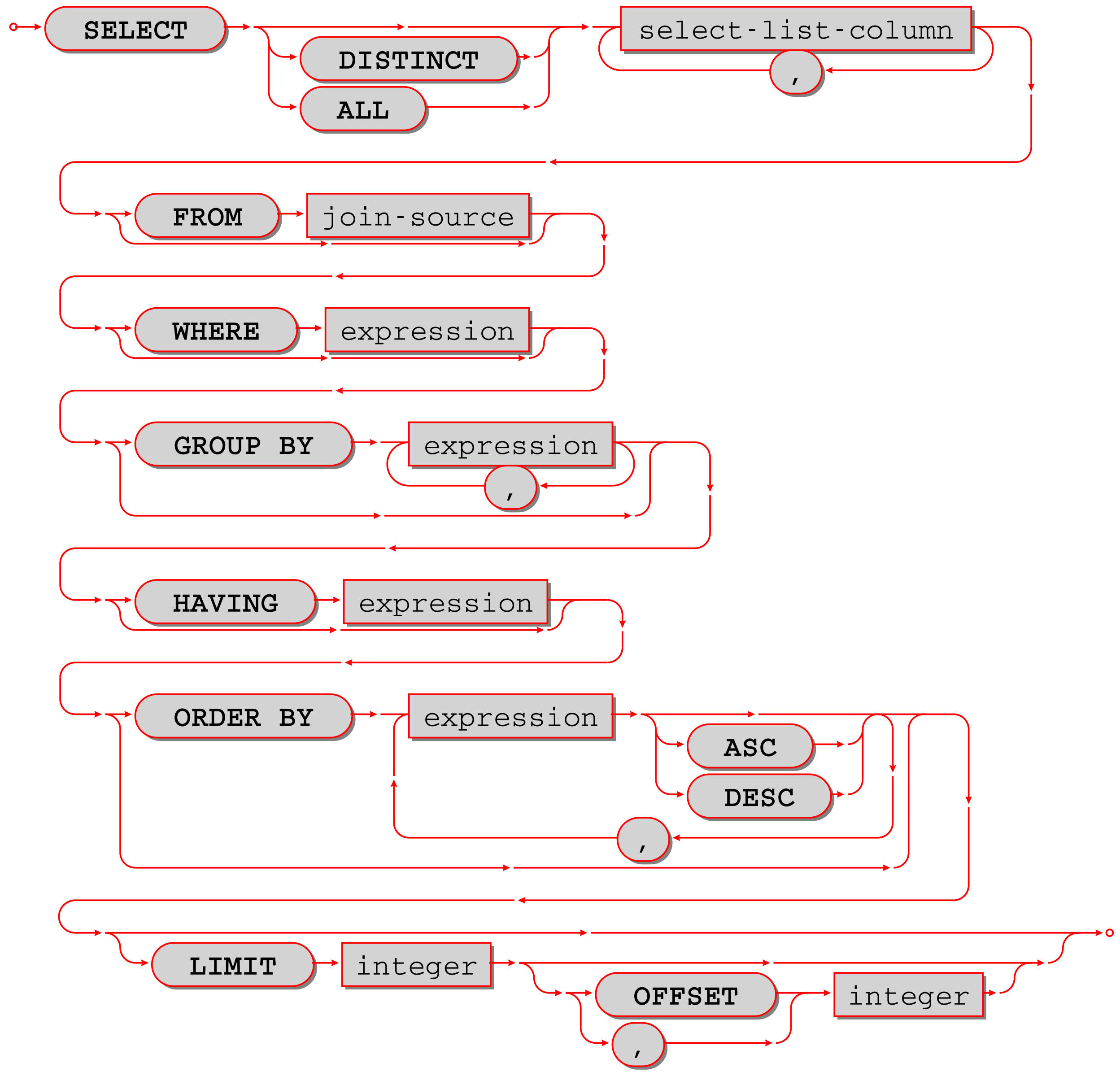
Example:

```
TRUNCATE TABLE t;
```

SELECT

Syntax:

SELECT [ALL|DISTINCT] select list [from clause] [where clause] [group-by clause] [having clause] [order-by clause];



Select zero or more rows.

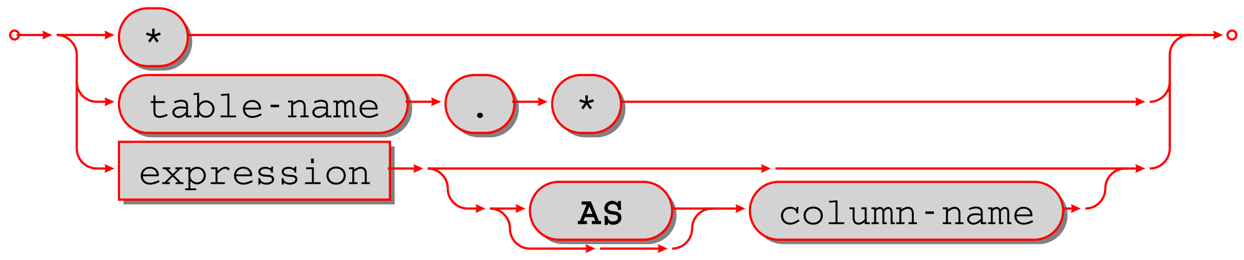
The clauses of the SELECT statement are discussed in the following five sections.

Select list

Syntax:

select-list-column [, select-list-column ...]

select-list-column:



Define what will be in a result set; this is a clause in a SELECT statement.

The select list is a comma-delimited list of expressions, or * (asterisk). An expression can have an alias provided with an [[AS] column-name] clause.

The * “asterisk” shorthand is valid if and only if the SELECT statement also contains a FROM clause which specifies the table or tables (details about the FROM clause are in the next section). The simple form is * which means “all columns” – for example, if the select is done for a table which contains three columns s1 s2 s3, then SELECT * ... is equivalent to SELECT s1, s2, s3 .... The qualified form is table-name.* which means “all columns in the specified table”, which again must be a result of the FROM clause – for example, if the table is named table1, then table1.* is equivalent to a list of the columns of table1.

The [[AS] column-name] clause determines the column name. The column name is useful for two reasons:

- in a tabular display, the column names are the headings
- if the results of the SELECT are used when creating a new table (such as a view), then the column names in the new table will be the column names in the select list.

If [[AS] column-name] is missing, Tarantool makes a name equal to the expression, for example SELECT 5 * 88 will cause the column name to be 5 * 88, but such names may be ambiguous or illegal in other contexts, so it is better to say, for example, SELECT 5 * 88 AS column1.

Examples:

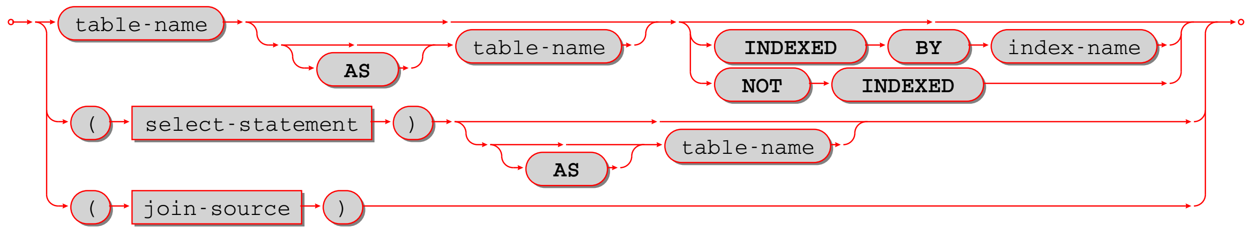
```
-- the simple form:
SELECT 5;
-- with multiple expressions including operators:
SELECT 1, 2 * 2, 'Three' || 'Four';
-- with [[AS] column-name] clause:
SELECT 5 AS column1;
-- * which must be eventually followed by a FROM clause:
SELECT * FROM table1;
-- as a list:
SELECT 1 AS a, 2 AS b, table1.* FROM table1;
```

Limitations: (Issue#3962) * Names for expressions will change in a future version.

FROM clause

Syntax:

FROM table-reference [, table-reference ...]



Specify the table or tables for the source of a SELECT statement.

The table-reference must be a name of an existing table, or a subquery, or a joined table.

A joined table looks like this:

table-reference-or-joined-table join-operator table-reference-or-joined-table [join-specification]

A join-operator must be any of the standard types:

- [NATURAL] LEFT [OUTER] JOIN,
- [NATURAL] INNER JOIN, or
- CROSS JOIN

A join-specification must be any of:

- ON expression, or
- USING (column-name [, column-name . . .])

Parentheses are allowed, and [[AS] correlation-name] is allowed.

The maximum number of joins in a FROM clause is 64.

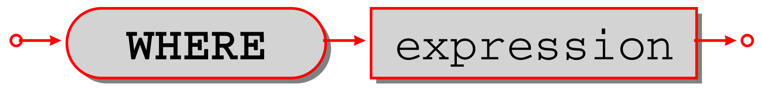
Examples:

```
-- the simplest form:
SELECT * FROM t;
-- with two tables, making a Cartesian join:
SELECT * FROM t1, t2;
-- with one table joined to itself, requiring correlation names:
SELECT a.*, b.* FROM t1 AS a, t1 AS b;
-- with a left outer join:
SELECT * FROM t1 LEFT JOIN t2;
```

WHERE clause

Syntax:

WHERE condition;



Specify the condition for filtering rows from a table; this is a clause in a SELECT or UPDATE or DELETE statement.

The condition may contain any expression that returns a BOOLEAN (TRUE or FALSE or UNKNOWN) value.

For each row in the table:

- if the condition is true, then the row is kept;
- if the condition is false or unknown, then the row is ignored.

In effect, WHERE condition takes a table with n rows and returns a table with n or fewer rows.

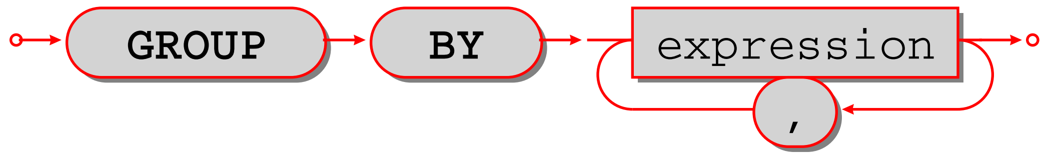
Examples:

```
-- with a simple condition:
SELECT 1 FROM t WHERE column1 = 5;
-- with a condition that contains AND and OR and parentheses:
SELECT 1 FROM t WHERE column1 = 5 AND (x > 1 OR y < 1);
```

GROUP BY clause

Syntax:

GROUP BY expression [, expression ...]



Make a grouped table; this is a clause in a SELECT statement.

The expressions should be column names in the table, and each column should be specified only once.

In effect, the GROUP BY clause takes a table with rows that may have matching values, combines rows that have matching values into single rows, and returns a table which, because it is the result of GROUP BY, is called a grouped table.

Thus, if the input is a table:

```
a    b      c
-    -      -
1    'a'   'b
1    'b'   'b'
2    'a'   'b'
3    'a'   'b'
1    'b'   'b'
```

then GROUP BY a, b will produce a grouped table:

```
a    b      c
-    -      -
1    'a'   'b'
1    'b'   'b'
2    'a'   'b'
3    'a'   'b'
```

The rows where column a and column b have the same value have been merged; column c has been preserved but its value should not be depended on – if the rows were not all 'b', Tarantool could pick any value.

It is useful to envisage a grouped table as having hidden extra columns for the aggregation of the values, for example:

```
a   b     c    COUNT(a) SUM(a) MIN(c)
-   -     -    -------- ------ ------
1   'a'   'b'       2     2    'b'
1   'b'   'b'       1     1    'b'
2   'a'   'b'       1     2    'b'
    'a'   'b'       1     3    'b'
```

These extra columns are what aggregate functions are for.

Examples:

```
-- with a single column:
SELECT 1 FROM t GROUP BY column1;
-- with two columns:
SELECT 1 FROM t GROUP BY column1, column2;
```

Limitations:

- SELECT s1, s2 FROM t GROUP BY s1; is legal.
- SELECT s1 AS q FROM t GROUP BY q; is legal.
- SELECT s1 FROM t GROUP by 1; is legal.

Aggregate functions

Syntax:

function-name (one or more expressions)

Apply a built-in aggregate function to one or more expressions and return a scalar value.

Aggregate functions are only legal in certain clauses of a SELECT statement for grouped tables. (A table is a grouped table if a GROUP BY clause is present.) Also, if an aggregate function is used in a select list and the GROUP BY clause is omitted, then Tarantool assumes SELECT ... GROUP BY [all columns];.

NULLs are ignored for all aggregate functions except COUNT(*).

AVG([DISTINCT] expression) Return the average value of expression.

Example: AVG(column1)

COUNT([DISTINCT] expression) Return the number of occurrences of expression.

Example: COUNT(column1)

COUNT(*) Return the number of occurrences of a row.

Example: COUNT(*)

GROUP_CONCAT(expression-1 [, expression-2]) or GROUP_CONCAT(DISTINCT expression-1)
Return a list of expression-1 values, separated by commas if expression-2 is omitted, or separated by the expression-2 value if expression-2 is not omitted.

Example: GROUP_CONCAT(column1)

MAX([DISTINCT] expression) Return the maximum value of expression.

Example: MAX(column1)

MIN([DISTINCT] expression) Return the minimum value of expression.

Example: MIN(column1)

SUM([DISTINCT] expression) Return the sum of values of expression.

Example: SUM(column1)

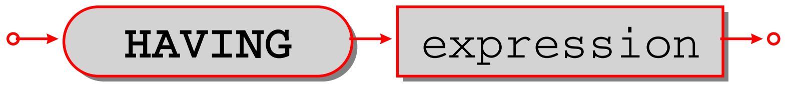
TOTAL([DISTINCT] expression) Return the sum of values of expression.

Example: TOTAL(column1)

HAVING clause

Syntax:

HAVING condition;



Specify the condition for filtering rows from a grouped table; this is a clause in a SELECT statement.

The clause preceding the HAVING clause may be a GROUP BY clause. HAVING operates on the table that the GROUP BY produces, which may contain grouped columns and aggregates.

If the preceding clause is not a GROUP BY clause, then there is only one group and the HAVING clause may only contain aggregate functions or literals.

For each row in the table:

- if the condition is true, then the row is kept;
- if the condition is false or unknown, then the row is ignored.

In effect, HAVING condition takes a table with n rows and returns a table with n or fewer rows.

Examples:

```
-- with a simple condition:
SELECT 1 FROM t GROUP BY column1 HAVING column2 > 5;
-- with a more complicated condition:
SELECT 1 FROM t GROUP BY column1 HAVING column2 > 5 OR column2 < 5;
-- with an aggregate:
SELECT x, SUM(y) FROM t GROUP BY x HAVING SUM(y) > 0;
-- with no GROUP BY and an aggregate:
SELECT SUM(y) FROM t GROUP BY x HAVING MIN(y) < MAX(y);
```

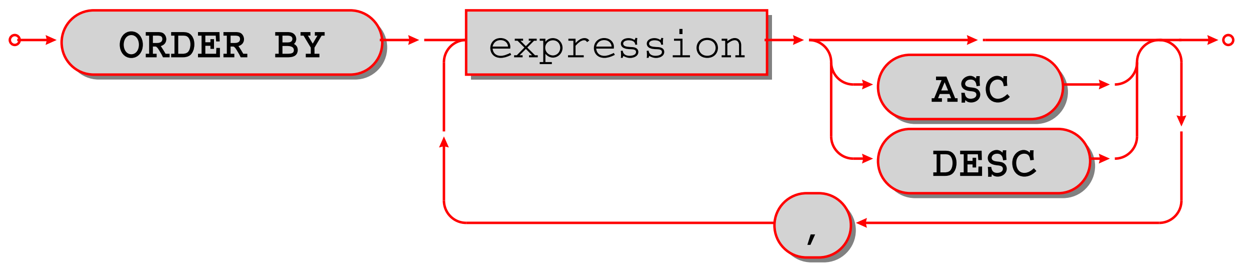
Limitations:

- HAVING without GROUP BY is not supported for multiple tables.

ORDER BY clause

Syntax:

ORDER BY expression [ASC|DESC] [, expression [ASC|DESC] ...]



Put rows in order; this is a clause in a SELECT statement.

An ORDER BY expression has one of three types which are checked in order:

1. Expression is a positive integer, representing the ordinal position of the column in the select list. For example, in the statement SELECT x, y, z FROM t ORDER BY 2; ORDER BY 2 means "order by the second column in the select list", which is y.
2. Expression is a name of a column in the select list, which is determined by an AS clause. For example, in the statement SELECT x, y AS x, z FROM t ORDER BY x; ORDER BY x means "order by the column explicitly named x in the select list", which is the second column.
3. Expression contains a name of a column in a table of the FROM clause. For example, in the statement SELECT x, y FROM t1 JOIN t2 ORDER BY z; ORDER BY z means "order by a column named z which is expected to be in table t1 or table t2".

If both tables contain a column named z, then Tarantool will choose the first column that it finds.

The expression may also contain operators and function names and literals. For example, in the statement SELECT x, y FROM t ORDER BY UPPER(z); ORDER BY UPPER(z) means "order by the uppercase form of column t.z", which may be similar to doing ordering in a case-insensitive manner.

Type 3 is illegal if the SELECT statement contains UNION or EXCEPT or INTERSECT.

If an ORDER BY clause contains multiple expressions, then expressions on the left are processed first and expressions on the right are processed only if necessary for tie-breaking. For example, in the statement SELECT x, y FROM t ORDER BY x, y; if there are two rows which both have the same values for column x, then an additional check is made to see which row has a greater value for column y.

In effect, ORDER BY clause takes a table with rows that may be out of order, and returns a table with rows in order.

Sorting order:

- The default order is ASC (ascending), the optional order is DESC (descending).
- NULLs come first, then BOOLEANs, then numbers, then STRINGs, then VARBINARYs.
- Within STRINGs, ordering is according to collation.
- Collation may be specified with a COLLATE clause within the ORDER BY column-list, or may be default.

Examples:

```
-- with a single column:
SELECT 1 FROM t ORDER BY column1;
-- with two columns:
SELECT 1 FROM t ORDER BY column1, column2;
-- with a variety of data:
CREATE TABLE h (s1 NUMBER PRIMARY KEY, s2 SCALAR);
INSERT INTO h VALUES (7, 'A'), (4, 'a'), (-4, 'AZ'), (17, 17), (23, NULL);
```

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```
INSERT INTO h VALUES (17.5, 'Д'), (1e+300, 'A'), (0, ''), (-1, '');
SELECT * FROM h ORDER BY s2 COLLATE "unicode_ci", s1;
-- The result of the above SELECT will be:
- - [23, null]
  - [17, 17]
  - [-1, '']
  - [0, '']
  - [4, 'a']
  - [7, 'A']
  - [1e+300, 'A']
  - [-4, 'AZ']
  - [17.5, 'Д']
...
```

Limitations:

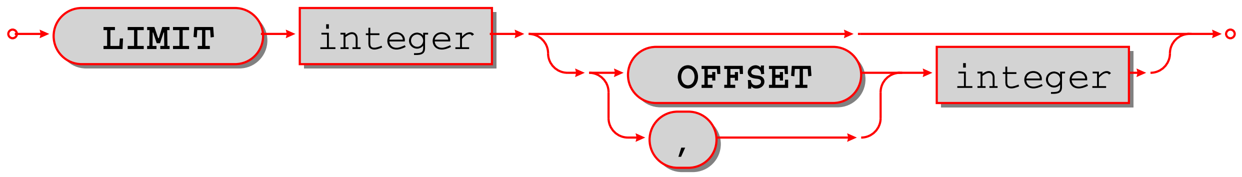
- ORDER BY 1 is legal. This is common but is not standard SQL nowadays.

LIMIT clause

Syntax:

- LIMIT limit-expression [OFFSET offset-expression]
- LIMIT offset-expression, limit-expression

Note: The above is not a typo: offset-expression and limit-expression are in reverse order if a comma is used.



Specify a maximum number of rows and a start row; this is a clause in a SELECT statement.

Expressions may contain integers and arithmetic operators or functions, for example ABS(-3 / 1). However, the result must be an integer value greater than or equal to zero.

Usually the LIMIT clause follows an ORDER BY clause, because otherwise Tarantool does not guarantee that rows are in order.

Examples:

```
-- simple case:
SELECT * FROM t LIMIT 3;
-- both limit and order:
SELECT * FROM t LIMIT 3 OFFSET 1;
-- applied to a UNIONed result (LIMIT clause must be the final clause):
SELECT column1 FROM table1 UNION SELECT column1 FROM table2 ORDER BY 1 LIMIT 1;
```

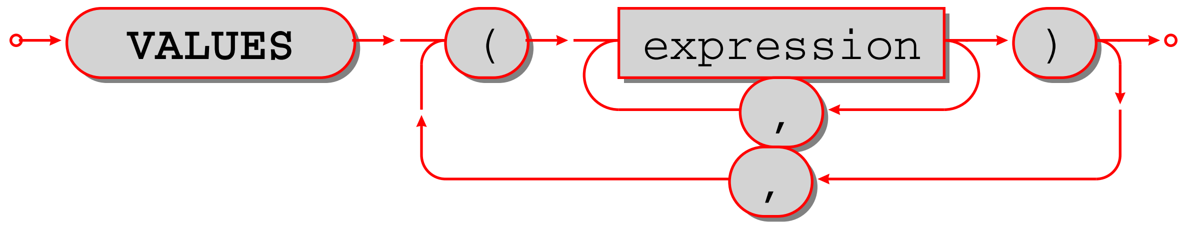
Limitations:

- If ORDER BY . . . LIMIT is used, then all order-by columns must be ASC or all must be DESC.

VALUES

Syntax:

VALUES (expression [, expression ...]) [, (expression [, expression ...])



Select one or more rows.

VALUES has the same effect as SELECT, that is, it returns a result set, but VALUES statements may not have FROM or GROUP or ORDER BY or LIMIT clauses.

VALUES may be used wherever SELECT may be used, for example in subqueries.

Examples:

```
-- simple case:
VALUES (1);
-- equivalent to SELECT 1, 2, 3:
VALUES (1, 2, 3);
-- two rows:
VALUES (1, 2, 3), (4, 5, 6);
```

Subquery

Syntax:

- SELECT-statement syntax
- VALUES-statement syntax

A subquery has the same syntax as a SELECT statement or VALUES statement embedded inside a main statement.

Note: The SELECT and VALUES statements are called "queries" because they return answers, in the form of result sets.

Subqueries may be the second part of INSERT statements. For example:

```
INSERT INTO t2 SELECT a, b, c FROM t1;
```

Subqueries may be in the FROM clause of SELECT statements.

Subqueries may be expressions, or be inside expressions. In this case they must be parenthesized, and usually the number of rows must be 1. For example:

```
SELECT 1, (SELECT 5), 3 FROM t WHERE c1 * (SELECT COUNT(*) FROM t2) > 5;
```

Subqueries may be expressions on the right side of certain comparison operators, and in this unusual case the number of rows may be greater than 1. The comparison operators are: [NOT] EXISTS and [NOT] IN. For example:

```
DELETE FROM t WHERE s1 NOT IN (SELECT s2 FROM t);
```

Subqueries may refer to values in the outer query. In this case, the subquery is called a "correlated subquery".

Subqueries may refer to rows which are being updated or deleted by the main query. In that case, the subquery finds the matching rows first, before starting to update or delete. For example, after:

```
CREATE TABLE t (s1 INTEGER PRIMARY KEY, s2 INTEGER);
INSERT INTO t VALUES (1, 3), (2, 1);
DELETE FROM t WHERE s2 NOT IN (SELECT s1 FROM t);
```

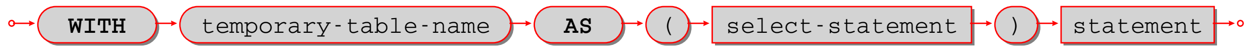
only one of the rows is deleted, not both rows.

WITH clause

WITH clause (common table expression)

Syntax:

WITH temporary-table-name AS (subquery) [, temporary-table-name AS (subquery)] SELECT statement | INSERT statement | DELETE statement | UPDATE statement | REPLACE statement;



```
WITH v AS (SELECT * FROM t) SELECT * FROM v;
```

is equivalent to creating a view and selecting from it:

```
CREATE VIEW v AS SELECT * FROM t;
SELECT * FROM v;
```

The difference is that a WITH-clause "view" is temporary and only useful within the same statement. No CREATE privilege is required.

The WITH-clause can also be thought of as a subquery that has a name. This is useful when the same subquery is being repeated. For example:

```
SELECT * FROM t WHERE a < (SELECT s1 FROM x) AND b < (SELECT s1 FROM x);
```

can be replaced with:

```
WITH s AS (SELECT s1 FROM x) SELECT * FROM t,s WHERE a < s.s1 AND b < s.s1;
```

This "factoring out" of a repeated expression is regarded as good practice.

Examples:

```
WITH cte AS (VALUES (7, '') INSERT INTO j SELECT * FROM cte;
WITH cte AS (SELECT s1 AS x FROM k) SELECT * FROM cte;
WITH cte AS (SELECT COUNT(*) FROM k WHERE s2 < 'x' GROUP BY s3)
  UPDATE j SET s2 = 5
  WHERE s1 = (SELECT s1 FROM cte) OR s3 = (SELECT s1 FROM cte);
```

WITH can only be used at the beginning of a statement, therefore it cannot be used at the beginning of a subquery or after a set operator or inside a CREATE statement.

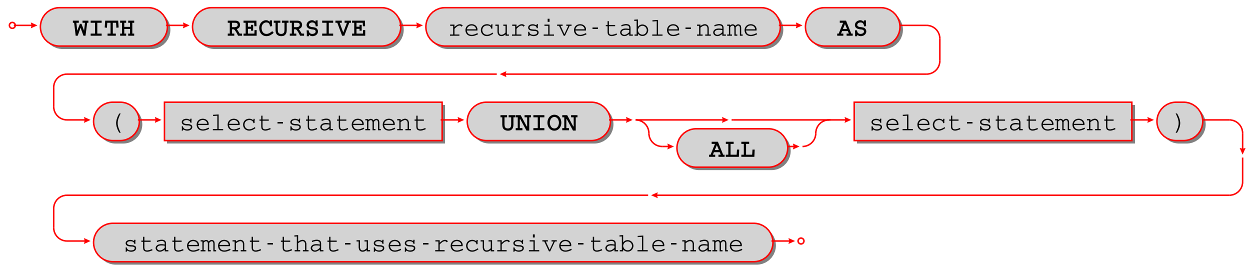
A WITH-clause "view" is read-only because Tarantool does not support updatable views.

WITH RECURSIVE

WITH RECURSIVE clause (iterative common table expression)

The real power of WITH lies in the WITH RECURSIVE clause, which is useful when it is combined with UNION or UNION ALL:

WITH RECURSIVE recursive-table-name AS (SELECT ... FROM non-recursive-table-name ... UNION [ALL] SELECT ... FROM recursive-table-name ...) statement-that-uses-recursive-table-name;



In non-SQL this can be read as: starting with a seed value from a non-recursive table, produce a recursive viewed table, UNION that with itself, UNION that with itself, UNION that with itself . . . forever, or until a condition in the WHERE clause says "stop".

For example:

```
CREATE TABLE ts (s1 INTEGER PRIMARY KEY);
INSERT INTO ts VALUES (1);
WITH RECURSIVE w AS (
  SELECT s1 FROM ts
  UNION ALL
  SELECT s1 + 1 FROM w WHERE s1 < 4)
SELECT * FROM w;
```

First, table w is seeded from t1, so it has one row: [1].

Then, UNION ALL (SELECT s1 + 1 FROM w) takes the row from w – which contains [1] – adds 1 because the select list says "s1+1", and so it has one row: [2].

Then, UNION ALL (SELECT s1 + 1 FROM w) takes the row from w – which contains [2] – adds 1 because the select list says "s1+1", and so it has one row: [3].

Then, UNION ALL (SELECT s1 + 1 FROM w) takes the row from w – which contains [3] – adds 1 because the select list says "s1+1", and so it has one row: [4].

Then, UNION ALL (SELECT s1 + 1 FROM w) takes the row from w – which contains [4] – and now the importance of the WHERE clause becomes evident, because "s1 < 4" is false for this row, and therefore we have reached the "stop" condition.

So, before the "stop", table w got 4 rows – [1], [2], [3], [4] – and the result of the statement looks like:

```
tarantool> WITH RECURSIVE w AS (
         >   SELECT s1 FROM ts
         >   UNION ALL
```

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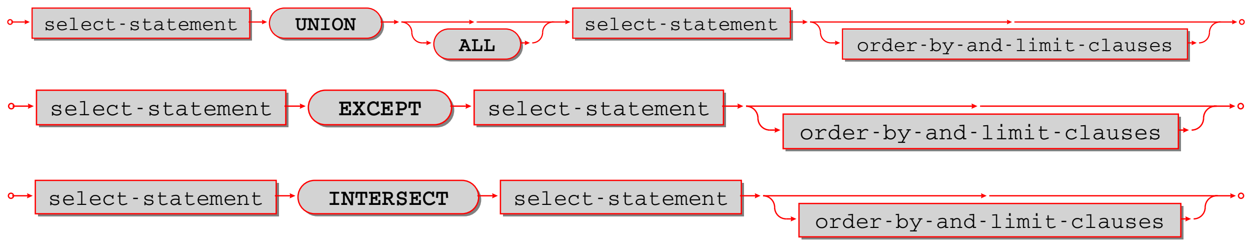
```
        >   SELECT s1 + 1 FROM w WHERE s1 < 4)
        > SELECT * FROM w;
---
- - [1]
  - [2]
  - [3]
  - [4]
...
```

In other words, this WITH RECURSIVE ... SELECT produces a table of auto-incrementing values.

UNION, EXCEPT, and INTERSECT clauses

Syntax:

- select-statement UNION [ALL] select-statement [ORDER BY clause] [LIMIT clause];
- select-statement EXCEPT select-statement [ORDER BY clause] [LIMIT clause];
- select-statement INTERSECT select-statement [ORDER BY clause] [LIMIT clause];



UNION, EXCEPT, and INTERSECT are collectively called "set operators" or "table operators". In particular:

- a UNION b means "take rows which occur in a OR b".
- a EXCEPT b means "take rows which occur in a AND NOT b".
- a INTERSECT b means "take rows which occur in a AND b".

Duplicate rows are eliminated unless ALL is specified.

The select-statements may be chained: SELECT ... SELECT ... SELECT ...;

Each select-statement must result in the same number of columns.

The select-statements may be replaced with VALUES statements.

The maximum number of set operations is 50.

Example:

```
CREATE TABLE t1 (s1 INTEGER PRIMARY KEY, s2 STRING);
CREATE TABLE t2 (s1 INTEGER PRIMARY KEY, s2 STRING);
INSERT INTO t1 VALUES (1, 'A'), (2, 'B'), (3, NULL);
INSERT INTO t2 VALUES (1, 'A'), (2, 'C'), (3,NULL);
SELECT s2 FROM t1 UNION SELECT s2 FROM t2;
SELECT s2 FROM t1 UNION ALL SELECT s2 FROM t2 ORDER BY s2;
SELECT s2 FROM t1 EXCEPT SELECT s2 FROM t2;
SELECT s2 FROM t1 INTERSECT SELECT s2 FROM t2;
```

In this example:

- The UNION query returns 4 rows: NULL, 'A', 'B', 'C'.
- The UNION ALL query returns 6 rows: NULL, NULL, 'A', 'A', 'B', 'C'.
- The EXCEPT query returns 1 row: 'B'.
- The INTERSECT query returns 2 rows: NULL, 'A'.

Limitations:

- Parentheses are not allowed.
- Evaluation is left to right, INTERSECT does not have precedence.

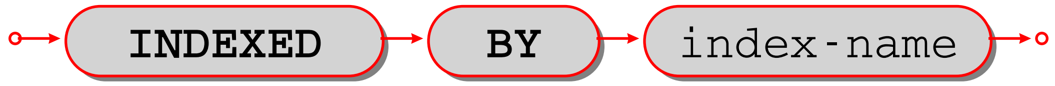
Example:

```
CREATE TABLE t01 (s1 INTEGER PRIMARY KEY, s2 STRING);
CREATE TABLE t02 (s1 INTEGER PRIMARY KEY, s2 STRING);
CREATE TABLE t03 (s1 INTEGER PRIMARY KEY, s2 STRING);
INSERT INTO t01 VALUES (1, 'A');
INSERT INTO t02 VALUES (1, 'B');
INSERT INTO t03 VALUES (1, 'A');
SELECT s2 FROM t01 INTERSECT SELECT s2 FROM t03 UNION SELECT s2 FROM t02;
SELECT s2 FROM t03 UNION SELECT s2 FROM t02 INTERSECT SELECT s2 FROM t03;
-- ... results are different.
```

INDEXED BY clause

Syntax:

INDEXED BY index-name



The INDEXED BY clause may be used in a SELECT, DELETE, or UPDATE statement, immediately after the table-name. For example:

```
DELETE FROM table7 INDEXED BY index7 WHERE column1 = 'a';
```

In this case the search for 'a' will take place within index7. For example:

```
SELECT * FROM table7 NOT INDEXED WHERE column1 = 'a';
```

In this case the search for 'a' will be done via a search of the whole table, what is sometimes called a "full table scan", even if there is an index for column1.

Ordinarily Tarantool chooses the appropriate index or lookup method depending on a complex set of "optimizer" rules; the INDEXED BY clause overrides the optimizer choice.

Example:

Suppose a table has two columns:

- The first column is the primary key and therefore it has an automatic index named pk_unnamed_T_1.
- The second column has an index created by the user.

The user selects with INDEXED BY the-index-on-column1, then selects with INDEXED BY the-index-on-column-2.

```
CREATE TABLE t (column1 INTEGER PRIMARY KEY, column2 INTEGER);
CREATE INDEX idx_column2_t_1 ON t (column2);
INSERT INTO t VALUES (1, 2), (2, 1);
SELECT * FROM t INDEXED BY "pk_unnamed_T_1";
SELECT * FROM t INDEXED BY idx_column2_t_1;
-- Result for the first select: (1, 2), (2, 1)
-- Result for the second select: (2, 1), (1, 2).
```

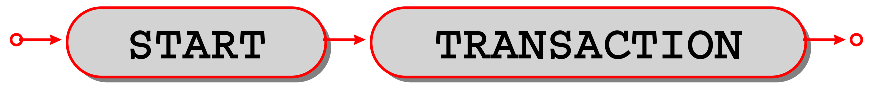
Limitations: Often INDEXED BY has no effect. Often INDEXED BY affects a choice of covering index, but not a WHERE clause.

Transactions

START TRANSACTION

Syntax:

START TRANSACTION;



Start a transaction. After START TRANSACTION;, a transaction is "active". If a transaction is already active, then START TRANSACTION; is illegal.

Transactions should be active for fairly short periods of time, to avoid concurrency issues. To end a transaction, say COMMIT; or ROLLBACK;.

Just as in NoSQL, transaction control statements are subject to limitations set by the storage engine involved:
* For the memtx storage engine, if a yield happens within an active transaction, the transaction is rolled back.
* For the vinyl engine, yields are allowed. Also, although CREATE AND DROP and ALTER statements are legal in transactions, there are a few exceptions. For example, CREATE INDEX ON table_name ... will fail within a multi-statement transaction if the table is not empty.

However,transaction control statements still may not work as you expect when run over a network connection: a transaction is associated with a fiber, not a network connection, and different transaction control statements sent via the same network connection may be executed by different fibers from the fiber pool.

In order to ensure that all statements are part of the intended transaction, put all of them between START TRANSACTION; and COMMIT; or ROLLBACK; then send as a single batch. For example:

- Enclose each separate SQL statement in a box.execute() function.
- Pass all the box.execute() functions to the server in a single message.

  If you are using a console, you can do this by writing everything on a single line.

  If you are using net.box, you can do this by putting all the function calls in a single string and calling eval(string).

Example:

```
START TRANSACTION;
```

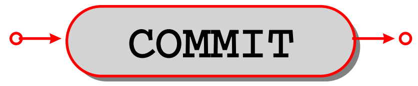
Example of a whole transaction sent to a server on localhost:3301 with eval(string):

```
net_box = require('net.box')
conn = net_box.new('localhost', 3301)
s = 'box.execute([[START TRANSACTION;]]) '
s = s .. 'box.execute([[INSERT INTO t VALUES (1);]]) '
s = s .. 'box.execute([[ROLLBACK;]]) '
conn:eval(s)
```

COMMIT

Syntax:

COMMIT;



Commit an active transaction, so all changes are made permanent and the transaction ends.

COMMIT is illegal unless a transaction is active. If a transaction is not active then SQL statements are committed automatically.

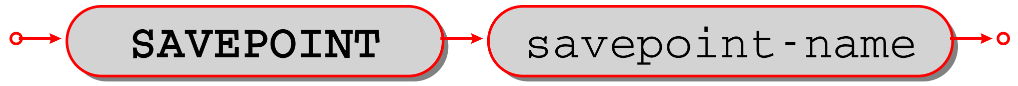
Example:

```
COMMIT;
```

SAVEPOINT

Syntax:

SAVEPOINT savepoint-name;



Set a savepoint, so that ROLLBACK TO savepoint-name is possible.

SAVEPOINT is illegal unless a transaction is active.

If a savepoint with the same name already exists, it is released before the new savepoint is set.

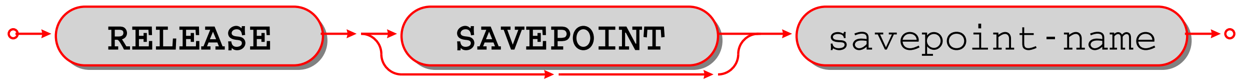
Example:

```
SAVEPOINT x;
```

RELEASE SAVEPOINT

Syntax:

RELEASE SAVEPOINT savepoint-name;



Release (destroy) a savepoint created by a SAVEPOINT statement.

RELEASE is illegal unless a transaction is active.

Savepoints are released automatically when a transaction ends.

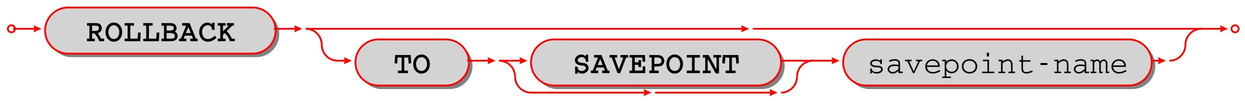
Example:

```
RELEASE SAVEPOINT x;
```

ROLLBACK

Syntax:

ROLLBACK [TO [SAVEPOINT] savepoint-name];



If ROLLBACK does not specify a savepoint-name, rollback an active transaction, so all changes since START TRANSACTION are cancelled, and the transaction ends.

If ROLLBACK does specify a savepoint-name, rollback an active transaction, so all changes since SAVEPOINT savepoint-name are cancelled, and the transaction does not end.

ROLLBACK is illegal unless a transaction is active.

Examples:

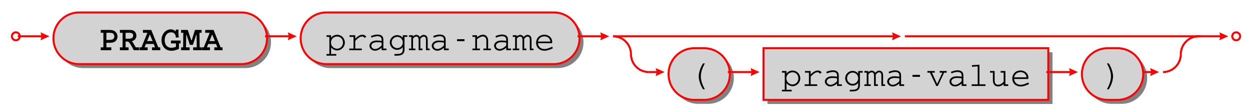
```
-- the simple form:
ROLLBACK;
-- the form so changes before a savepoint are not cancelled:
ROLLBACK TO SAVEPOINT x;
```

```
-- An example of a Lua function that will do a transaction
-- containing savepoint and rollback to savepoint.
function f()
box.execute([[DROP TABLE IF EXISTS t;]]) -- commits automatically
box.execute([[CREATE TABLE t (s1 STRING PRIMARY KEY);]]) -- commits automatically
box.execute([[START TRANSACTION;]]) -- after this succeeds, a transaction is active
box.execute([[INSERT INTO t VALUES ('Data change #1');]])
box.execute([[SAVEPOINT "1";]])
box.execute([[INSERT INTO t VALUES ('Data change #2');]])
box.execute([[ROLLBACK TO SAVEPOINT "1";]]) -- rollback Data change #2
box.execute([[ROLLBACK TO SAVEPOINt "1";]]) -- this is legal but does nothing
box.execute([[COMMIT;]]) -- make Data change #1 permanent, end the transaction
end
```

PRAGMA

Syntax:

- PRAGMA pragma-name (pragma-value);
- or PRAGMA pragma-name;



PRAGMA statements will give rudimentary information about database 'metadata' or server performance, although it is better to get metadata via system tables.

For PRAGMA statements that include (pragma-value), pragma values are strings and can be specified inside "" double quotes, or without quotes. When a string is used for searching, results must match according to a binary collation. If the object being searched has a lower-case name, use double quotes.

In an earlier version, there were some PRAGMA statements that determined behavior. Now that does not happen. Behavior change is done by updating the box.space._session_settings system table.

Pragma	Parameter	Effect
foreign_key_list	string table-name	Return a result set with one row for each foreign key of "table-name". Each row contains: (INTEGER) id – identification number (INTEGER) seq – sequential number (STRING) table – name of table (STRING) from – referencing key (STRING) to – referenced key (STRING) on_update – ON UPDATE clause (STRING) on_delete – ON DELETE clause (STRING) match – MATCH clause The system table is "_fk_constraint".
collation_list		Return a result set with one row for each supported collation. The first four collations are 'none' and 'unicode' and 'unicode_ci' and 'binary', then come about 270 predefined collations, the exact count may vary because users can add their own collations. The system table is "_collation".
index_info	string table-name . index-name	Return a result set with one row for each column in "table-name.index-name". Each row contains: (INTEGER) seqno – the column's ordinal position in the index (first column is 0) (INTEGER) cid – the column's ordinal position in the table (first column is 0) (STRING) name – name of the column (INTEGER) desc – 0 if ASC, 1 if DESC (STRING) collation name (STRING) type – data type
index_list	string table-name	Return a result set with one row for each index of "table-name". Each row contains: (INTEGER) seq – sequential number (STRING) name – index name (INTEGER) unique – whether the index is unique, 0 = false, 1 = true The system table is "_index".
stats		Return a result set with one row for each index of each table. Each row contains: (STRING) table – name of the table (STRING) index – name of the index (INTEGER) width – arbitrary information (INTEGER) height – arbitrary information
table_info	string table-name	Return a result set with one row for each column in "table-name". Each row contains: (INTEGER) cid – ordinal position in the table (first column number is 0) (STRING) name – column name (INTEGER) notnull – whether the column is NOT NULL. 0 is false, 1 is true. (STRING) dflt_value – default value (INTEGER) pk – whether the column is a PRIMARY KEY column. 0 is false, 1 is true.

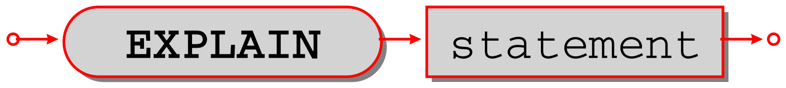
Example: (not showing result set metadata)

```
PRAGMA table_info('T');
---
- - [0, 's1', 'integer', 1, null, 1]
  - [1, 's2', 'integer', 0, null, 0]
...
```

EXPLAIN

Syntax:

- EXPLAIN explainable-statement;



EXPLAIN will show what steps Tarantool would take if it executed explainable-statement. This is primarily a debugging and optimization aid for the Tarantool team.

Example: EXPLAIN DELETE FROM m; returns:

```
- - [0, 'Init', 0, 3, 0, '', '00', 'Start at 3']
  - [1, 'Clear', 16416, 0, 0, '', '00', '']
  - [2, 'Halt', 0, 0, 0, '', '00', '']
  - [3, 'Transaction', 0, 1, 1, '0', '01', 'usesStmtJournal=0']
  - [4, 'Goto', 0, 1, 0, '', '00', '']
```

Variation: EXPLAIN QUERY PLAN statement; shows the steps of a search.

Functions

Syntax:

function-name (one or more expressions)

Apply a built-in function to one or more expressions and return a scalar value.

Tarantool supports 32 built-in functions.

The maximum number of operands for any function is 127.

The required privileges for built-in functions will likely change in a future version.

ABS

Syntax:

ABS(numeric-expression)

Return the absolute value of numeric-expression, which can be any numeric type.

Example: ABS(-1) is 1.

CAST

Syntax:

CAST(expression AS data-type)

Return the expression value after casting to the specified data type.

Examples: CAST('AB' AS VARBINARY), CAST(X'4142' AS STRING)

CHAR

Syntax:

CHAR([numeric-expression [,numeric-expression...])

Return the characters whose Unicode code point values are equal to the numeric expressions.

Short example:

The first 128 Unicode characters are the "ASCII" characters, so CHAR(65, 66, 67) is 'ABC'.

Long example:

For the current list of Unicode characters, in order by code point, see www.unicode.org/Public/UCD/latest/ucd/UnicodeData.txt. In that list, there is a line for a Linear B ideogram

100CC;LINEAR B IDEOGRAM B240 WHEELED CHARIOT ...

Therefore, for a string with a chariot in the middle, use the concatenation operator || and the CHAR function

`'start of string '` || CHAR(0X100CC) || `' end of string'`.

COALESCE

Syntax:

COALESCE(expression, expression [, expression ...])

Return the value of the first non-NULL expression, or, if all expression values are NULL, return NULL.

Example: COALESCE(NULL, 17, 32) is 17.

GREATEST

Syntax:

GREATEST(expression-1, expression-2, [expression-3 ...])

Return the greatest value of the supplied expressions, or, if any expression is NULL, return NULL. The reverse of GREATEST is LEAST.

Examples: GREATEST(7, 44, -1) is 44; GREATEST(1E308, `'a'`, 0, `X'00'`) is '0' = the nul character; GREATEST(3, NULL, 2) is NULL

HEX

Syntax:

HEX(expression)

Return the hexadecimal code for each byte in expression, which may be either a string or a byte sequence. For ASCII characters, this is straightforward because the encoding is the same as the code point value. For non-ASCII characters, since character strings are usually encoded in UTF-8, each character will require two or more bytes.

Examples:

- HEX(`'A'`) will return 41.

- HEX('Д') will return D094.

IFNULL

Syntax:

IFNULL(expression, expression)

Return the value of the first non-NULL expression, or, if both expression values are NULL, return NULL. Thus IFNULL(expression, expression) is the same as COALESCE(expression, expression).

Example: IFNULL(NULL, 17) is 17

LEAST

Syntax:

LEAST(expression-1, expression-2, [expression-3 ...])

Return the least value of the supplied expressions, or, if any expression is NULL, return NULL. The reverse of LEAST is GREATEST.

Examples: LEAST(7, 44, -1) is -1; LEAST(1E308, 'a', 0, X'00') is 0; LEAST(3, NULL, 2) is NULL.

LENGTH

Syntax:

LENGTH(expression)

Return the number of characters in the expression, or the number of bytes in the expression. It depends on the data type: strings with data type STRING are counted in characters, byte sequences with data type VARBINARY are counted in bytes and are not ended by the nul character. There are two aliases for LENGTH(expression) – CHAR_LENGTH(expression) and CHARACTER_LENGTH(expression) do the same thing.

Examples:

- LENGTH('ДД') is 2, the string has 2 characters.
- LENGTH(CAST('ДД' AS VARBINARY)) is 4, the string has 4 bytes.
- LENGTH(CHAR(0, 65)) is 2, '0' does not mean 'end of string'.
- LENGTH(X'410041') is 3, X'. . . ' byte sequences have type VARBINARY.

LIKELIHOOD

Syntax:

LIKELIHOOD(expression, number literal)

Return the result of the expression, provided that the number literal is between 0.0 and 1.0.

Example: LIKELIHOOD('a' = 'b', .0) is FALSE

LIKELY

Syntax:

LIKELY(expression)

Return TRUE if the expression is probably true.

Example: LIKELY(`'a'` <= `'b'`) is TRUE

LOWER

Syntax:

LOWER(string-expression)

Return the expression, with upper-case characters converted to lower case. The reverse of LOWER is UPPER.

Example: LOWER(`'ДА'`) is 'да'

NULLIF

Syntax:

NULLIF(expression-1, expression-2)

Return expression-1 if expression-1 <> expression-2, otherwise return NULL.

Examples:

- NULLIF(`'a'`, `'A'`) is 'a'.
- NULLIF(1.00, 1) is NULL.

POSITION

Syntax:

POSITION(expression-1, expression-2)

Return the position of expression-1 within expression-2, or return 0 if expression-1 does not appear within expression-2. The data types of the expressions must be either STRING or VARBINARY. If the expressions have data type STRING, then the result is the character position. If the expressions have data type VARBINARY, then the result is the byte position.

Short example: POSITION(`'C'`, `'ABC'`) is 3

Long example: The UTF-8 encoding for the Latin letter A is hexadecimal 41; the UTF-8 encoding for the Cyrillic letter Д is hexadecimal D094 – you can confirm this by saying SELECT HEX('ДА'); and seeing that the result is 'D09441'. If you now execute SELECT POSITION(`'A'`, `'ДА'`); the result will be 2, because 'A' is the second character in the string. However, if you now execute SELECT POSITION(X`'41'`, X`'D09441'`); the result will be 3, because X'41' is the third byte in the byte sequence.

PRINTF

Syntax:

PRINTF(string-expression [, expression ...])

Return a string formatted according to the rules of the C sprintf() function, where %d%s means the next two arguments are a number and a string, and so on.

If an argument is missing or is NULL, it becomes:

- '0' if the format requires an integer,
- '0.0' if the format requires a number with a decimal point,
- '' if the format requires a string.

Example: PRINTF(`'%da'`, 5) is '5a'.

QUOTE

Syntax:

QUOTE(string-literal)

Return a string with enclosing quotes if necessary, and with quotes inside the enclosing quotes if necessary. This function is useful for creating strings which are part of SQL statements, because of SQL's rules that string literals are enclosed by single quotes, and single quotes inside such strings are shown as two single quotes in a row.

Example: QUOTE(`'a'`) is `'a'`.

RAISE

Syntax:

RAISE(FAIL, error-message)

This may only be used within a triggered statement. See also Trigger Activation.

RANDOM

Syntax: RANDOM()

Return a 19-digit integer which is generated by a pseudo-random number generator,

Example: RANDOM() is 6832175749978026034, or it is any other integer

RANDOMBLOB

Syntax:

RANDOMBLOB(n)

Return a byte sequence, n bytes long, data type = VARBINARY, containing bytes generated by a pseudo-random byte generator. The result can be translated to hexadecimal. If n is less than 1 or is NULL or is infinity, then NULL is returned.

Example: HEX(RANDOMBLOB(3)) is '9EAAA8', or it is the hex value for any other three-byte string

REPLACE

Syntax:

REPLACE(expression-1, expression-2, expression-3)

Return expression-1, except that wherever expression-1 contains expression-2, replace expression-2 with expression-3. The expressions should all have data type STRING or VARBINARY.

Example: REPLACE('AAABCCCBD', 'B', '!') is 'AAA!CCC!D'

ROUND

Syntax:

ROUND(numeric-expression-1 [, numeric-expression-2])

Return the rounded value of numeric-expression-1, always rounding .5 upward for floating-point positive numbers or downward for negative numbers. If numeric-expression-2 is supplied then rounding is to the nearest numeric-expression-2 digits after the decimal point; if numeric-expression-2 is not supplied then rounding is to the nearest integer.

Example: ROUND(-1.5) is -2, ROUND(1.7766E1,2) is 17.77.

ROW_COUNT

ROW_COUNT()

Return the number of rows that were inserted / updated / deleted by the last INSERT or UPDATE or DELETE or REPLACE statement. Rows which were updated by an UPDATE statement are counted even if there was no change. Rows which were inserted / updated / deleted due to foreign-key action are not counted. Rows which were inserted / updated / deleted due to a view's INSTEAD OF triggers are not counted. After a CREATE or DROP statement, ROW_COUNT() is 1. After other statements, ROW_COUNT() is 0.

Example: ROW_COUNT() is 1 after a successful INSERT of a single row.

Special rule if there are BEFORE or AFTER triggers: In effect the ROW_COUNT() counter is pushed at the beginning of a series of triggered statements, and popped at the end. Therefore, after the following statements:

```
CREATE TABLE t1 (s1 INTEGER PRIMARY KEY);
CREATE TABLE t2 (s1 INTEGER, s2 STRING, s3 INTEGER, PRIMARY KEY (s1, s2, s3));
CREATE TRIGGER tt1 BEFORE DELETE ON t1 FOR EACH ROW BEGIN
  INSERT INTO t2 VALUES (old.s1, '#2 Triggered', ROW_COUNT());
  INSERT INTO t2 VALUES (old.s1, '#3 Triggered', ROW_COUNT());
  END;
INSERT INTO t1 VALUES (1),(2),(3);
DELETE FROM t1;
INSERT INTO t2 VALUES (4, '#4 Untriggered', ROW_COUNT());
SELECT * FROM t2;
```

The result is:

```
---
- - [1, '#2 Triggered', 3]
  - [1, '#3 Triggered', 1]
  - [2, '#2 Triggered', 3]
  - [2, '#3 Triggered', 1]
  - [3, '#2 Triggered', 3]
  - [3, '#3 Triggered', 1]
  - [4, '#4 Untriggered', 3]
...
```

SOUNDEX

Syntax:

SOUNDEX(string-expression)

Return a four-character string which represents the sound of string-expression. Often words and names which have different spellings will have the same Soundex representation if they are pronounced similarly, so it is possible to search by what they sound like. The algorithm works with characters in the Latin alphabet and works best with English words.

Example: SOUNDEX('Crater') and SOUNDEX('Creature') both return C636.

SUBSTR

Syntax:

SUBSTR(expression-1, numeric-expression-1 [, numeric-expression-2])

If expression-1 has data type STRING, then return the substring which begins at character position numeric-expression-1 and continues for numeric-expression-2 characters (if numeric-expression-2 is supplied), or continues till the end of string-expression-1 (if numeric-expression-2 is not supplied).

If expression-1 has data type VARBINARY rather than data type STRING, then positioning and counting is by bytes rather than by characters.

Example: SUBSTR('ABCDEFG', 3, 2) is 'CD'

TRIM

Syntax:

TRIM([[LEADING|TRAILING|BOTH] [expression-1] FROM] expression-2)

Return expression-2 after removing all leading and/or trailing characters or bytes. The expressions should have data type STRING or VARBINARY. If LEADING|TRAILING|BOTH is omitted, the default is BOTH. If expression-1 is omitted, the default is ' ' (space) for data type STRING or X'00' (nul) for data type VARBINARY.

Examples:

TRIM('a' FROM 'abaaaaa') is 'b' – all repetitions of 'a' are removed on both sides; TRIM(TRAILING '' FROM '') is '' – if all characters are Hebrew, TRAILING means "left"; TRIM(X'004400') is X'44' – the default byte sequence to trim is X'00' when data type is VARBINARY; TRIM(LEADING 'abc' FROM 'abcd') is 'd' – expression-1 can have more than 1 character.

TYPEOF

Syntax:

TYPEOF(expression)

Return the data type of the expression.

Examples:

TYPEOF('A') returns 'string'; TYPEOF(RANDOMBLOB(1)) returns 'varbinary'; TYPEOF(1e44) returns 'double' or 'number'; TYPEOF(-44) returns 'integer'; TYPEOF(NULL) returns 'boolean'

UNICODE

Syntax:

UNICODE(string-expression)

Return the Unicode code point value of the first character of string-expression. If string-expression is empty, the return is NULL. This is the reverse of CHAR(integer).

Example: UNICODE('Щ') is 1065 (hexadecimal 0429).

UNLIKELY

Syntax:

UNLIKELY(expression)

Return TRUE if the expression is probably false. Limitation: in fact UNLIKELY may return the same thing as LIKELY.

Example: UNLIKELY('a' <= 'b') is TRUE.

UPPER

Syntax:

UPPER(string-expression)

Return the expression, with lower-case characters converted to upper case. The reverse of UPPER is LOWER.

Example: UPPER('-4щl') is '-4ЩL'.

VERSION

Syntax:

VERSION()

Return the Tarantool version.

Example: for a December 2019 build VERSION() is 2.3.0-258-g960e9c0c7.

ZEROBLOB

Syntax:

ZEROBLOB(n)

Return a byte sequence, data type = VARBINARY, n bytes long.

COLLATE clause

COLLATE collation-name

The collation-name must identify an existing collation.

The COLLATE clause is allowed for STRING or SCALAR items: () in CREATE INDEX () in CREATE TABLE as part of column definition () in CREATE TABLE as part of UNIQUE definition () in string expressions

Examples:

```
-- In CREATE INDEX
CREATE INDEX idx_unicode_mb_1 ON mb (s1 COLLATE "unicode");
-- In CREATE TABLE
CREATE TABLE t1 (s1 INTEGER PRIMARY KEY, s2 STRING COLLATE "unicode_ci");
-- In CREATE TABLE ... UNIQUE
CREATE TABLE mb (a STRING, b STRING, PRIMARY KEY(a), UNIQUE(b COLLATE "unicode_ci"
↪DESC));
-- In string expressions
SELECT 'a' = 'b' COLLATE "unicode"
    FROM t
    WHERE s1 = 'b' COLLATE "unicode"
    ORDER BY s1 COLLATE "unicode";
```

The list of collations can be seen with: PRAGMA collation_list;

The collation rules comply completely with the Unicode Technical Standard #10 ("Unicode Collation Algorithm") and the default character order is as in the Default Unicode Collation Element Table (DUCET). There are many permanent collations; the commonly used ones include: "none" (not applicable) "unicode" (characters are in DUCET order with strength = 'tertiary') "unicode_ci" (characters are in DUCET order with strength = 'primary') "binary" (characters are in code point order) These identifiers must be quoted and in lower case because they are in lower case in Tarantool/NoSQL collations.

If one says COLLATE "binary", this is equivalent to asking for what is sometimes called "code point order" because, if the contents are in the UTF-8 character set, characters with larger code points will appear after characters with lower code points.

In an expression, COLLATE is an operator with higher precedence than anything except ~. This is fine because there are no other useful operators except || and comparison. After ||, collation is preserved.

In an expression with more than one COLLATE clause, if the collation names differ, there is an error: "Illegal mix of collations". In an expression with no COLLATE clauses, literals have collation "binary", columns have the collation specified by CREATE TABLE.

In other words, to pick a collation, we use: the first COLLATE clause in an expression if it was specified, else the the column's COLLATE clause if it was specified, else "binary".

However, for searches and sometimes for sorting, the collation may be an index's collation, so all non-index COLLATE clauses are ignored.

EXPLAIN will not show the name of what collation was used, but will show the collation's characteristics.

Example with Swedish collation: Knowing that “sv” is the two-letter code for Swedish, and knowing that “s1” means strength = 1, and seeing with PRAGMA collation_list; that there is a collation named unicode_sv_s1, check whether two strings are equal according to Swedish rules (yes they are): SELECT `'ÄÄ'` = `'ĘĘ'` COLLATE "unicode_sv_s1";

Example with Russian and Ukrainian and Kyrgyz collations: Knowing that Russian collation is practically the same as Unicode default, and knowing that the two-letter codes for Ukrainian and Kyrgyz are ‘uk’ and ‘ky’, and knowing that in Russian (but not Ukrainian) ‘Г’ = ‘Ґ’ with strength=primary, and knowing that in Russian (but not Kyrgyz) ‘Е’ = ‘Ё’ with strength=primary, the three SELECT statements here will return results in three different orders: CREATE TABLE things (remark STRING PRIMARY KEY); INSERT INTO things VALUES (`'Е2'`), (`'Ё1'`); INSERT INTO things VALUES (`'Г2'`), (`'Ґ1'`); SELECT remark FROM things ORDER BY remark COLLATE "unicode"; SELECT remark FROM things ORDER BY remark COLLATE "unicode_uk_s1"; SELECT remark FROM things ORDER BY remark COLLATE "unicode_ky_s1";

5.1.4 SQL PLUS LUA – Adding Tarantool/NoSQL to Tarantool/SQL

The Adding Tarantool/NoSQL To Tarantool/SQL Guide contains descriptions of NoSQL database objects that can be accessed from SQL, of SQL database objects that can be accessed from NoSQL, of the way to call SQL from Lua, and of the way to call Lua from SQL.

Lua Requests

A great deal of functionality is not specifically part of Tarantool’s SQL feature, but is part of the Tarantool Lua application server and DBMS. Here we will give examples so it is clear where to look in other sections of the Tarantool manual.

NoSQL “spaces” can be accessed as SQL "tables", and vice versa. For example, suppose a table has been created with CREATE TABLE things (id INTEGER PRIMARY KEY, remark SCALAR);

This is viewable from Tarantool’s NoSQL feature as a memtx space named THINGS with a primary-key TREE index . . .

```
tarantool> box.space.THINGS
---
- engine: memtx
  before_replace: 'function: 0x40bb4608'
  on_replace: 'function: 0x40bb45e0'
  ck_constraint: []
  field_count: 2
  temporary: false
  index:
    0: &0
      unique: true
      parts:
     - type: integer
        is_nullable: false
        fieldno: 1
      id: 0
      space_id: 520
      type: TREE
      name: pk_unnamed_THINGS_1
    pk_unnamed_THINGS_1: *0
  is_local: false
  enabled: true
```

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```
name: THINGS
id: 520
```

The NoSQL basic data operation requests select, insert, replace, upsert, update, delete will all work. Particularly interesting are the requests that come only via NoSQL.

To create an index on things (remark) with a non-default option for example a special id, say: box.space.THINGS:create_index('idx_100_things_2', {id=100, parts={2, 'scalar'}})

(If the SQL data type name is SCALAR, then the NoSQL type is 'scalar', as described earlier. See the chart in section Operands.)

To grant database-access privileges to user 'guest', say box.schema.user.grant('guest', 'execute', 'universe') To grant SELECT privileges on table things to user 'guest', say box.schema.user.grant('guest', 'read', 'space', 'THINGS') To grant UPDATE privileges on table things to user 'guest', say: box.schema.user.grant('guest', 'read,write', 'space', 'THINGS') To grant DELETE or INSERT privileges on table things if no reading is involved, say: box.schema.user.grant('guest', 'write', 'space', 'THINGS') To grant DELETE or INSERT privileges on table things if reading is involved, say: box.schema.user.grant('guest', 'read,write', 'space', 'THINGS') To grant CREATE TABLE privilege to user 'guest', say box.schema.user.grant('guest', 'read,write', 'space', '_schema') box.schema.user.grant('guest', 'read,write', 'space', '_space') box.schema.user.grant('guest', 'read,write', 'space', '_index') box.schema.user.grant('guest', 'create', 'space') To grant CREATE TRIGGER privilege to user 'guest', say box.schema.user.grant('guest', 'read', 'space', '_space') box.schema.user.grant('guest', 'read,write', 'space', '_trigger') To grant CREATE INDEX privilege to user 'guest', say box.schema.user.grant('guest', 'read,write', 'space', '_index') box.schema.user.grant('guest', 'create', 'space') To grant CREATE TABLE … INTEGER PRIMARY KEY AUTOINCREMENT to user 'guest', say box.schema.user.grant('guest', 'read,write', 'space', '_schema') box.schema.user.grant('guest', 'read,write', 'space', '_space') box.schema.user.grant('guest', 'read,write', 'space', '_index') box.schema.user.grant('guest', 'create', 'space') box.schema.user.grant('guest', 'read,write', 'space', '_space_sequence') box.schema.user.grant('guest', 'read,write', 'space', '_sequence') box.schema.user.grant('guest', 'create', 'sequence')

To write a stored procedure that inserts 5 rows in things, say function f() for i = 3, 7 do box.space.THINGS:insert{i, i} end end For client-side API functions, see section "Connectors".

To make spaces with field names that SQL can understand, use space_object:format(). (Exception: in Tarantool/NoSQL it is legal for tuples to have more fields than are described by a format clause, but in Tarantool/SQL such fields will be ignored.)

To handle replication and sharding of SQL data, see section Sharding.

To enhance performance of SQL statements by preparing them in advance, see section box.prepare().

To call SQL from Lua, see section box.execute([[…]]).

Limitations: (Issue#2368) * after box.schema.user.grant('guest','read,write,execute','universe'), user 'guest' can create tables. But this is a powerful set of privileges.

Limitations: (Issue#4659, Issue#4757, Issue#4758) SELECT with * or ORDER BY or GROUP BY from spaces that have map fields or array fields may cause errors. Any access to spaces that have hash indexes may cause severe errors.

System Tables

There is a way to get some information about the database objects, for example the names of all the tables and their indexes, using SELECT statements. This is done by looking at special read-only tables which Tarantool updates automatically whenever objects are created or dropped. See the submodule box.space overview section. Names of system tables are in lower case so always enclose them in "quotes".

For example, the _space system table has these fields which are seen in SQL as columns: id = numeric identifier owner = for example, 1 if the object was made by the 'admin' user name = the name that was used with CREATE TABLE engine = usually 'memtx' (the 'vinyl' engine can be used but is not default) field_count = sometimes 0, but usually a count of the table's columns flags = usually empty format = what a Lua format() function or an SQL CREATE statement produced Example selection: SELECT "id", "name" FROM "_space";

See also: Lua functions to make views of metadata.

Calling Lua routines from SQL

SQL statements can invoke functions that are written in Lua. This is Tarantool's equivalent for the "stored procedure" feature found in other SQL DBMSs. Tarantool server-side stored procedures are written in Lua rather than SQL/PSM dialect.

Functions can be invoked anywhere that the SQL syntax allows a literal or a column name for reading. Function parameters can include any number of SQL values. If a SELECT statement's result set has a million rows, and the select list invokes a non-deterministic function, then the function is called a million times.

To create a Lua function that you can call from SQL, use box.schema.func.create(func-name, {options-with-body}) with these additional options:

exports = {'LUA', 'SQL'} – This indicates what languages can call the function. The default is 'LUA'. Specify both: 'LUA', 'SQL'.

param_list = {list} – This is the list of parameters. Specify the Lua type names for each parameter of the function. Remember that a Lua type name is the same as an SQL data type name, in lower case. The Lua type should not be an array.

Also it is good to specify {deterministic = true} if possible, because that may allow Tarantool to generate more efficient SQL byte code.

For a useful example, here is a general function for decoding a single Lua 'map' field:

```
box.schema.func.create('_DECODE',
   {language = 'LUA',
    returns = 'string',
    body = [[function (field, part)
             __GLOBAL= field
             return dostring("return require('msgpack').decode(__GLOBAL,1)." .. part)
             end]],
    is_sandboxed = false,
    param_list = {'string', "string"},
    exports = {'LUA', 'SQL'},
    is_deterministic = true})
```

See it work with, say, the _trigger space. That space has a 'map' field named opts which has a part named sql. By selecting from the space and passing the field and the part name to _DECODE, you can get a list of all the trigger bodies.

```
__GLOBAL = ""
box.execute([[SELECT _decode("opts", 'sql') FROM "_trigger";]])
```

Remember that SQL converts regular identifiers to upper case, so this example works with a function named _DECODE. If the function had been named _decode, then the SELECT statement would have to be: box.execute([[SELECT "_decode"("opts", 'sql') FROM "_trigger";]])

Here is another example, which illustrates the way that Tarantool creates a view which includes the table_name and table_type columns in the same way that the standard-SQL information_schema.tables view contains them. The difficulty is that, in order to discover whether table_type should be 'BASE TABLE' or should be 'VIEW', we need to know the value of the "flags" field in the Tarantool/NoSQL "_space" or "_vspace" space. The "flags" field type is "map", which SQL does not understand well. If there were no Lua functions, we would have to treat it as a VARBINARY and look for POSITION(X'A476696577C3',"flags") > 0 (A4 is a MsgPack signal that a 4-byte string follows, 76696577 is UTF8 encoding for 'view', C3 is a MsgPack code meaning true). But we have a more sophisticated way, we can create a function that returns true if "flags".view is true. So our way of making the function looks like this:

```
box.schema.func.create('TABLES_IS_VIEW',
    {language = 'LUA',
     returns = 'boolean',
     body = [[function (flags)
        local view
        view = require('msgpack').decode(flags).view
        if view == nil then return false end
        return view
        end]],
    is_sandboxed = false,
    param_list = {'string'},
    exports = {'LUA', 'SQL'},
    is_deterministic = true})
```

And this creates the view:

```
box.execute([[
CREATE VIEW vtables AS SELECT
"name" AS table_name,
CASE WHEN tables_is_view("flags") == TRUE THEN 'VIEW'
    ELSE 'BASE TABLE' END AS table_type,
"id" AS id,
"engine" AS engine,
(SELECT "name" FROM "_vuser" x
 WHERE x."id" = y."owner") AS owner,
"field_count" AS field_count
FROM "_vspace" y;
]])
```

Remember that these Lua functions are persistent, so if the server has to be restarted then they do not have to be re-declared.

Executing Lua chunks

To execute Lua code without creating a function, use: LUA(Lua-code-string) where Lua-code-string is any amount of Lua code. The string should begin with 'return '.

For example this will show the number of seconds since the epoch: box.execute([[SELECT lua('return os.time()');]]) For example this will show a database configuration member: box.execute([[SELECT lua('return box.cfg.memtx_memory');]]) For example this will return FALSE because Lua nil and box.NULL are the same as SQL NULL: box.execute([[SELECT lua('return box.NULL') IS NOT NULL;]])

Warning: the SQL statement must not invoke a Lua function, or execute a Lua chunk, that accesses a space that underlies any SQL table that the SQL statement accesses. For example, if function f() contains a request "box.space.TEST:insert{0}", then the SQL statement "SELECT f() FROM test;" will try to access the same space in two ways. The results of such conflict may include a hang or an infinite loop.

Example Session – Create, Insert, Select

Assume that the task is to create two tables, put some rows in each table, create a view that is based on a join of the tables, then select from the view all rows where the second column values are not null, ordered by the first column.

That is, what we want is CREATE TABLE t1 (c1 INTEGER PRIMARY KEY, c2 STRING); CREATE TABLE t2 (c1 INTEGER PRIMARY KEY, x2 STRING); INSERT INTO t1 VALUES (1, 'A'), (2, 'B'), (3, 'C'); INSERT INTO t1 VALUES (4, 'D'), (5, 'E'), (6, 'F'); INSERT INTO t2 VALUES (1, 'C'), (4, 'A'), (6, NULL); CREATE VIEW v AS SELECT * FROM t1 NATURAL JOIN t2; SELECT * FROM v WHERE c2 IS NOT NULL ORDER BY c1;

So the session looks like this: box.cfg{} box.execute([[CREATE TABLE t1 (c1 INTEGER PRIMARY KEY, c2 STRING);]]) box.execute([[CREATE TABLE t2 (c1 INTEGER PRIMARY KEY, x2 STRING);]]) box.execute([[INSERT INTO t1 VALUES (1, 'A'), (2, 'B'), (3, 'C');]]) box.execute([[INSERT INTO t1 VALUES (4, 'D'), (5, 'E'), (6, 'F');]]) box.execute([[INSERT INTO t2 VALUES (1, 'C'), (4, 'A'), (6, NULL);]]) box.execute([[CREATE VIEW v AS SELECT * FROM t1 NATURAL JOIN t2;]]) box.execute([[SELECT * FROM v WHERE c2 IS NOT NULL ORDER BY c1;]])

If one executes the above requests with Tarantool as a client, provided the database objects do not already exist, the execution will be successful and the final display will be

```
tarantool> box.execute([[SELECT * FROM v WHERE c2 IS NOT NULL ORDER BY c1;]])
---
- - [1, 'A', 'C']
- [4, 'D', 'A']
- [6, 'F', null]
```

Example Session – Get a List of Columns

Here is a function which will create a table that contains a list of all the columns and their Lua types, for all tables. It is not a necessary function because one can create a _COLUMNS view instead. It merely shows, with simpler Lua code, how to make a base table instead of a view.

```
function create_information_schema_columns()
  box.execute([[DROP TABLE IF EXISTS information_schema_columns;]])
  box.execute([[CREATE TABLE information_schema_columns (
                    table_name STRING,
                    column_name STRING,
                    ordinal_position INTEGER,
                    data_type STRING,
                    PRIMARY KEY (table_name, column_name));]]);
  local space = box.space._vspace:select()
  local sqlstring = ''
  for i = 1, #space do
      for j = 1, #space[i][7] do
          sqlstring = "INSERT INTO information_schema_columns VALUES ("
                  .. "'" .. space[i][3] .. "'"
                  .. ","
                  .. "'" .. space[i][7][j].name .. "'"
                  .. ","
                  .. j
                  .. ","
                  .. "'" .. space[i][7][j].type .. "'"
                  .. ");"
          box.execute(sqlstring)
```

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```
    end
  end
  return
end
```

If you now execute the function by saying create_information_schema_columns() you will see that there is a table named information_schema_columns containing table_name and column_name and ordinal_position and data_type for everything that was accessible.

Example Session – Million-Row Insert

Here is a variation of the Lua tutorial "Insert one million tuples with a Lua stored procedure". The differences are: the creation is done with an SQL CREATE TABLE statement, and the inserting is done with an SQL INSERT statement. Otherwise, it is the same. It is the same because Lua and SQL are compatible, just as Lua and NoSQL are compatible.

```
box.execute([[CREATE TABLE tester (s1 INTEGER PRIMARY KEY, s2 STRING);]])

function string_function()
  local random_number
  local random_string
  random_string = ""
  for x = 1,10,1 do
    random_number = math.random(65, 90)
    random_string = random_string .. string.char(random_number)
  end
  return random_string
end

function main_function()
    local string_value, t, sql_statement
    for i = 1,1000000, 1 do
    string_value = string_function()
    sql_statement = "INSERT INTO tester VALUES (" .. i .. ",'" .. string_value .. "')"
    box.execute(sql_statement)
    end
end
start_time = os.clock()
main_function()
end_time = os.clock()
'insert done in ' .. end_time - start_time .. ' seconds'
```

Limitations: The function takes more time than the original (Tarantool/NoSQL).

Lua functions to make views of metadata

Tarantool does not include all the standard-SQL information_schema views, which are for looking at metadata, that is, "data about the data". But here is the Lua code and SQL code for creating equivalents: _TABLES nearly equivalent to INFORMATION_SCHEMA.TABLES _COLUMNS nearly equivalent to INFORMATION_SCHEMA.COLUMNS _VIEWS nearly equivalent to INFORMATION_SCHEMA.VIEWS _TRIGGERS nearly equivalent to INFORMATION_SCHEMA.TRIGGERS _REFERENTIAL_CONSTRAINTS nearly equivalent to INFORMATION_SCHEMA.REFERENTIAL_CONSTRAINTS _CHECK_CONSTRAINTS nearly equivalent to INFORMATION_SCHEMA.CHECK_CONSTRAINTS _TABLE_CONSTRAINTS nearly equivalent to

INFORMATION_SCHEMA.TABLE_CONSTRAINTS. For each view we show an example of a SELECT from the view, and the code. Users who want metadata can simply copy the code. Use this code only with Tarantool version 2.3.0 or later. With an earlier Tarantool version, a PRAGMA statement may be useful.

_TABLES view

Example:

```
tarantool>SELECT * FROM _tables WHERE id > 340 LIMIT 5;
OK 5 rows selected (0.0 seconds)
+---------------+--------------+----------------+------------+-----+--------+-------+-------------+
| TABLE_CATALOG | TABLE_SCHEMA | TABLE_NAME     | TABLE_TYPE | ID  | ENGINE | OWNER |␣
↪FIELD_COUNT |
+---------------+--------------+----------------+------------+-----+--------+-------+-------------+
| NULL          | NULL         | _fk_constraint | BASE TABLE | 356 | memtx  | admin |           0 |
| NULL          | NULL         | _ck_constraint | BASE TABLE | 364 | memtx  | admin |           0 |
| NULL          | NULL         | _func_index    | BASE TABLE | 372 | memtx  | admin |           0 |
| NULL          | NULL         | _COLUMNS       | VIEW       | 513 | memtx  | admin |           8 |
| NULL          | NULL         | _VIEWS         | VIEW       | 514 | memtx  | admin |           7 |
+---------------+--------------+----------------+------------+-----+--------+-------+-------------+
```

Definition of the function and the CREATE VIEW statement:

```
box.schema.func.drop('_TABLES_IS_VIEW',{if_exists = true})
box.schema.func.create('_TABLES_IS_VIEW',
     {language = 'LUA',
      returns = 'boolean',
      body = [[function (flags)
          local view
          view = require('msgpack').decode(flags).view
          if view == nil then return false end
          return view
          end]],
     is_sandboxed = false,
     param_list = {'string'},
     exports = {'LUA', 'SQL'},
     setuid = false,
     is_deterministic = true})
box.schema.role.grant('public', 'execute', 'function', '_TABLES_IS_VIEW')
pcall(function ()
    box.schema.role.revoke('public', 'read', 'space', '_TABLES', {if_exists = true})
    end)
box.execute([[DROP VIEW IF EXISTS _tables;]])
box.execute([[
CREATE VIEW _tables AS SELECT
    CAST(NULL AS STRING) AS table_catalog,
    CAST(NULL AS STRING) AS table_schema,
    "name" AS table_name,
    CASE
        WHEN _tables_is_view("flags") = TRUE THEN 'VIEW'
        ELSE 'BASE TABLE' END
        AS table_type,
    "id" AS id,
    "engine" AS engine,
    (SELECT "name" FROM "_vuser" x WHERE x."id" = y."owner") AS owner,
    "field_count" AS field_count
```

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```
FROM "_vspace" y;
]])
box.schema.role.grant('public', 'read', 'space', '_TABLES')
```

_COLUMNS view

This is also an example of how one can use recursive views to make temporary tables with multiple rows for each tuple in the original "_vtable" space. It requires a global variable, _G.box.FORMATS, as a temporary static variable.

Warning: Use this code only with Tarantool version 2.3.2 or later. Use with earlier versions will cause an assertion. See Issue#4504.

Example:

```
tarantool>SELECT * FROM _columns WHERE ordinal_position = 9;
OK 6 rows selected (0.0 seconds)
+--------------+-------------+-------------------------+--------------+------------------+-------------+-----------+-----+
| CATALOG_NAME | SCHEMA_NAME | TABLE_NAME              | COLUMN_NAME  | ORDINAL_
↪POSITION | IS_NULLABLE | DATA_TYPE | ID  |
+--------------+-------------+-------------------------+--------------+------------------+-------------+-----------+-----+
| NULL         | NULL        | _sequence               | cycle        |                9 | YES         | boolean   | 284 |
| NULL         | NULL        | _vsequence              | cycle        |                9 | YES         | boolean   | 286 |
| NULL         | NULL        | _func                   | returns      |                9   YES         string    | 296 |
| NULL         | NULL        | _fk_constraint          | parent_cols  |                9 | YES         | array     | 356 |
| NULL         | NULL        | _REFERENTIAL_CONSTRAINTS | MATCH_OPTION |                9 | YES         ␣
↪ | string    | 518 |
+--------------+-------------+-------------------------+--------------+------------------+-------------+-----------+-----+
```

Definition of the function and the CREATE VIEW statement:

```
box.schema.func.drop('_COLUMNS_FORMATS', {if_exists = true})
box.schema.func.create('_COLUMNS_FORMATS',
    {language = 'LUA',
     returns = 'scalar',
     body = [[
     function (row_number_, ordinal_position)
         if row_number_ == 0 then
             _G.box.FORMATS = {}
             local vspace = box.space._vspace:select()
             for i = 1, #vspace do
                 local format = vspace[i]["format"]
                 for j = 1, #format do
                     local is_nullable = 'YES'
                     if format[j].is_nullable == false then
                         is_nullable = 'NO'
                     end
                     table.insert(_G.box.FORMATS,
                                  {vspace[i].name, format[j].name, j,
                                   is_nullable, format[j].type, vspace[i].id})
                 end
             end
             return ''
         end
         if row_number_ > #_G.box.FORMATS then
```

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```
            _G.box.FORMATS = {}
            return ''
        end
        return _G.box.FORMATS[row_number_][ordinal_position]
    end
    ]],
    param_list = {'integer', 'integer'},
    exports = {'LUA', 'SQL'},
    is_sandboxed = false,
    setuid = false,
    is_deterministic = false})
box.schema.role.grant('public', 'execute', 'function', '_COLUMNS_FORMATS')

pcall(function ()
    box.schema.role.revoke('public', 'read', 'space', '_COLUMNS', {if_exists = true})
    end)
box.execute([[DROP VIEW IF EXISTS _columns;]])
box.execute([[
CREATE VIEW _columns AS
WITH RECURSIVE r_columns AS
(
SELECT 0 AS row_number_,
       '' AS table_name,
       '' AS column_name,
       0 AS ordinal_position,
       '' AS is_nullable,
       '' AS data_type,
       0 AS id
UNION ALL
SELECT row_number_ + 1 AS row_number_,
       _columns_formats(row_number_, 1) AS table_name,
       _columns_formats(row_number_, 2) AS column_name,
       _columns_formats(row_number_, 3) AS ordinal_position,
       _columns_formats(row_number_, 4) AS is_nullable,
       _columns_formats(row_number_, 5) AS data_type,
       _columns_formats(row_number_, 6) AS id
    FROM r_columns
    WHERE row_number_ == 0 OR row_number_ <= lua('return #_G.box.FORMATS + 1')
)
SELECT CAST(NULL AS STRING) AS catalog_name,
       CAST(NULL AS STRING) AS schema_name,
       table_name,
       column_name,
       ordinal_position,
       is_nullable,
       data_type,
       id
    FROM r_columns
    WHERE data_type <> '';
]])
box.schema.role.grant('public', 'read', 'space', '_COLUMNS')
```

_VIEWS view

Example:

```
tarantool>SELECT table_name, substr(view_definition,1,20), id, owner, field_count FROM _views LIMIT 5;
OK 5 rows selected (0.0 seconds)
+-------------------------+----------------------------+-----+-------+-------------+
| TABLE_NAME              | SUBSTR(VIEW_DEFINITION,1,20) | ID  | OWNER | FIELD_COUNT |
+-------------------------+----------------------------+-----+-------+-------------+
| _COLUMNS                | CREATE VIEW _columns       | 513 | admin |           8 |
| _TRIGGERS               | CREATE VIEW _trigger       | 515 | admin |           4 |
| _CHECK_CONSTRAINTS      | CREATE VIEW _check_c       | 517 | admin |           8 |
| _REFERENTIAL_CONSTRAINTS | CREATE VIEW _referen       | 518 | admin |          12 |
| _TABLE_CONSTRAINTS      | CREATE VIEW _table_c       | 519 | admin |          11 |
+-------------------------+----------------------------+-----+-------+-------------+
```

Definition of the function and the CREATE VIEW statement:

```
box.schema.func.drop('_VIEWS_DEFINITION',{if_exists = true})
box.schema.func.create('_VIEWS_DEFINITION',
    {language = 'LUA',
     returns = 'string',
     body = [[function (flags)
                 return require('msgpack').decode(flags).sql end]],
     param_list = {'string'},
     exports = {'LUA', 'SQL'},
     is_sandboxed = false,
     setuid = false,
     is_deterministic = false})
box.schema.role.grant('public', 'execute', 'function', '_VIEWS_DEFINITION')
pcall(function ()
    box.schema.role.revoke('public', 'read', 'space', '_VIEWS', {if_exists = true})
    end)
box.execute([[DROP VIEW IF EXISTS _views;]])
box.execute([[
CREATE VIEW _views AS SELECT
    CAST(NULL AS STRING) AS table_catalog,
    CAST(NULL AS STRING) AS table_schema,
    "name" AS table_name,
    CAST(_views_definition("flags") AS STRING) AS VIEW_DEFINITION,
    "id" AS id,
    (SELECT "name" FROM "_vuser" x WHERE x."id" = y."owner") AS owner,
    "field_count" AS field_count
    FROM "_vspace" y
    WHERE _tables_is_view("flags") = TRUE;
]])
box.schema.role.grant('public', 'read', 'space', '_VIEWS')
```

_TABLES_IS_VIEW() was described earlier, see _TABLES view.

_TRIGGERS view

Example:

```
tarantool>SELECT trigger_name, opts_sql FROM _triggers;
OK 2 rows selected (0.0 seconds)
+--------------+----------------------------------------------------------------------------------------------+
| TRIGGER_NAME | OPTS_SQL                                                                                     |
+--------------+----------------------------------------------------------------------------------------------+
| THINGS1_AD   | CREATE TRIGGER things1_ad AFTER DELETE ON things1 FOR EACH ROW BEGIN
↪DELETE FROM things2; END;  |
```

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```
| THINGS1_BI   | CREATE TRIGGER things1_bi BEFORE INSERT ON things1 FOR EACH ROW BEGIN␣
↪DELETE FROM things2; END; |
+--------------+----------------------------------------------------------------------------------------------+
```

Definition of the function and the CREATE VIEW statement:

```
box.schema.func.drop('_TRIGGERS_OPTS_SQL',{if_exists = true})
box.schema.func.create('_TRIGGERS_OPTS_SQL',
    {language = 'LUA',
     returns = 'string',
     body = [[function (opts)
                 return require('msgpack').decode(opts).sql end]],
     param_list = {'string'},
     exports = {'LUA', 'SQL'},
     is_sandboxed = false,
     setuid = false,
     is_deterministic = false})
box.schema.role.grant('public', 'execute', 'function', '_TRIGGERS_OPTS_SQL')
pcall(function ()
    box.schema.role.revoke('public', 'read', 'space', '_TRIGGERS', {if_exists = true})
    end)
box.execute([[DROP VIEW IF EXISTS _triggers;]])
box.execute([[
CREATE VIEW _triggers AS SELECT
    CAST(NULL AS STRING) AS trigger_catalog,
    CAST(NULL AS STRING) AS trigger_schema,
    "name" AS trigger_name,
    CAST(_triggers_opts_sql("opts") AS STRING) AS opts_sql,
    "space_id" AS space_id
    FROM "_trigger";
]])
box.schema.role.grant('public', 'read', 'space', '_TRIGGERS')
```

Users who select from this view will need 'read' privilege on the _trigger space.

_REFERENTIAL_CONSTRAINTS view

Example:

```
tarantool>SELECT constraint_name, update_rule, delete_rule, match_option,
> referencing, referenced
> FROM _referential_constraints;
OK 2 rows selected (0.0 seconds)
+--------------------+-------------+-------------+--------------+-------------+------------+
| CONSTRAINT_NAME    | UPDATE_RULE | DELETE_RULE | MATCH_OPTION | REFERENCING |␣
↪REFERENCED |
+--------------------+-------------+-------------+--------------+-------------+------------+
| fk_unnamed_THINGS2_1 | no_action   | no_action   | simple       | THINGS2     | THINGS1    |
| fk_unnamed_THINGS3_1 | no_action   | no_action   | simple       | THINGS3     | THINGS1    |
+--------------------+-------------+-------------+--------------+-------------+------------+
```

Definition of the CREATE VIEW statement:

```
pcall(function ()
    box.schema.role.revoke('public', 'read', 'space', '_REFERENTIAL_CONSTRAINTS', {if_exists = true})
```

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```
    end)
box.execute([[DROP VIEW IF EXISTS _referential_constraints;]])
box.execute([[
CREATE VIEW _referential_constraints AS SELECT
    CAST(NULL AS STRING) AS constraint_catalog,
    CAST(NULL AS STRING) AS constraint_schema,
    "name" AS constraint_name,
    CAST(NULL AS STRING) AS unique_constraint_catalog,
    CAST(NULL AS STRING) AS unique_constraint_schema,
    '' AS unique_constraint_name,
    "on_update" AS update_rule,
    "on_delete" AS delete_rule,
    "match" AS match_option,
    (SELECT "name" FROM "_vspace" x WHERE x."id" = y."child_id") AS referencing,
    (SELECT "name" FROM "_vspace" x WHERE x."id" = y."parent_id") AS referenced,
    "is_deferred" AS is_deferred,
    "child_id" AS child_id,
    "parent_id" AS parent_id
    FROM "_fk_constraint" y;
]])
box.schema.role.grant('public', 'read', 'space', '_REFERENTIAL_CONSTRAINTS')
```

We are not taking child_cols or parent_cols from the _fk_constraint space because in standard SQL those are in a separate table.

Users who select from this view will need ‘read’ privilege on the _fk_constraint space.

_CHECK_CONSTRAINTS view

Example:

```
tarantool>SELECT constraint_name, check_clause, space_name, language
> FROM _check_constraints;
OK 3 rows selected (0.0 seconds)
+------------------------+-------------------------+------------+----------+
| CONSTRAINT_NAME        | CHECK_CLAUSE            | SPACE_NAME | LANGUAGE |
+------------------------+-------------------------+------------+----------+
| ck_unnamed_Employees_1 | first_name LIKE 'Влад%' | Employees  | SQL      |
| ck_unnamed_Critics_1   | first_name LIKE 'Vlad%' | Critics    | SQL      |
| ck_unnamed_ACTORS_1    | salary > 0              | ACTORS     | SQL      |
+------------------------+-------------------------+------------+----------+
```

Definition of the CREATE VIEW statement:

```
pcall(function ()
    box.schema.role.revoke('public', 'read', 'space', '_CHECK_CONSTRAINTS', {if_exists = true})
    end)
box.execute([[DROP VIEW IF EXISTS _check_constraints;]])
box.execute([[
CREATE VIEW _check_constraints AS SELECT
    CAST(NULL AS STRING) AS constraint_catalog,
    CAST(NULL AS STRING) AS constraint_schema,
    "name" AS constraint_name,
    "code" AS check_clause,
    (SELECT "name" FROM "_vspace" x WHERE x."id" = y."space_id") AS space_name,
```

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```
    "language" AS language,
    "is_deferred" AS is_deferred,
    "space_id" AS space_id
    FROM "_ck_constraint" y;
]])
box.schema.role.grant('public', 'read', 'space', '_CHECK_CONSTRAINTS')
```

Users who select from this view will need 'read' privilege on the _ck_constraint space.

_TABLE_CONSTRAINTS view

This has only the constraints (primary-key and unique-key) that can be found by looking at the _index space. It is not a list of indexes, that is, it is not equivalent to INFORMATION_SCHEMA.STATISTICS. We do not take the columns of the index because in standard SQL they would be in a different table.

Example:

```
tarantool>SELECT constraint_name, constraint_type, table_name, id, iid, index_type
> FROM _table_constraints
> LIMIT 5;
OK 5 rows selected (0.0 seconds)
+-----------------+-----------------+------------+-----+-----+------------+
| CONSTRAINT_NAME | CONSTRAINT_TYPE | TABLE_NAME | ID  | IID | INDEX_TYPE |
+-----------------+-----------------+------------+-----+-----+------------+
| primary         | PRIMARY         | _schema    | 272 |   0 | tree       |
| primary         | PRIMARY         | _collation | 276 |   0 | tree       |
| name            | UNIQUE          | _collation | 276 |   1 | tree       |
| primary         | PRIMARY         | _vcollation| 277 |   0 | tree       |
| name            | UNIQUE          | _vcollation| 277 |   1 | tree       |
+-----------------+-----------------+------------+-----+-----+------------+
```

Definition of the function and the CREATE VIEW statement:

```
box.schema.func.drop('_TABLE_CONSTRAINTS_OPTS_UNIQUE',{if_exists = true})
function _TABLE_CONSTRAINTS_OPTS_UNIQUE (opts) return require('msgpack').decode(opts).unique end
box.schema.func.create('_TABLE_CONSTRAINTS_OPTS_UNIQUE',
    {language = 'LUA',
     returns = 'boolean',
     body = [[function (opts) return require('msgpack').decode(opts).unique end]],
     param_list = {'string'},
     exports = {'LUA', 'SQL'},
     is_sandboxed = false,
     setuid = false,
     is_deterministic = false})
box.schema.role.grant('public', 'execute', 'function', '_TABLE_CONSTRAINTS_OPTS_UNIQUE')
pcall(function ()
box.schema.role.revoke('public', 'read', 'space', '_TABLE_CONSTRAINTS', {if_exists = true})
end)
box.execute([[DROP VIEW IF EXISTS _table_constraints;]])
box.execute([[
CREATE VIEW _table_constraints AS SELECT
CAST(NULL AS STRING) AS constraint_catalog,
CAST(NULL AS STRING) AS constraint_schema,
"name" AS constraint_name,
(SELECT "name" FROM "_vspace" x WHERE x."id" = y."id") AS table_name,
```

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```
CASE WHEN "iid" = 0 THEN 'PRIMARY' ELSE 'UNIQUE' END AS constraint_type,
CAST(NULL AS STRING) AS initially_deferrable,
CAST(NULL AS STRING) AS deferred,
CAST(NULL AS STRING) AS enforced,
"id" AS id,
"iid" AS iid,
"type" AS index_type
FROM "_vindex" y
WHERE _table_constraints_opts_unique("opts") = TRUE;
]])
box.schema.role.grant('public', 'read', 'space', '_TABLE_CONSTRAINTS')
```

5.1.5 SQL features

In this section we will go through SQL:2016's "Feature taxonomy and definition for mandatory features".

For each feature in that list, we will come up with a simple example SQL statement. If Tarantool appears to handle the example, we will mark it "Okay", else we will mark it "Fail". Since this is rough and arbitrary, we believe that tests which are unfairly marked "Okay" will probably be balanced by tests which are unfairly marked "Fail".

Feature ID	Feature
E011	
E011-01	INTEGER and SMALLINT
E011-02	REAL, DOUBLE PRECISION, and FLOAT data types
E011-03	DECIMAL and NUMERIC data types
E011-04	Arithmetic operators
E011-05	Numeric comparisons
E011-06	Implicit casting among the numeric data types
E021	
E021-01	Character data type (including all its spellings)
E021-02	CHARACTER VARYING data type (including all its spellings)
E021-03	Character literals
E021-04	CHARACTER_LENGTH function
E021-05	OCTET_LENGTH
E021-06	SUBSTRING function.
E021-07	Character concatenation
E021-08	UPPER and LOWER functions
E021-09	TRIM function
E021-10	Implicit casting among the fixed-length and variable-length character string types
E021-11	POSITION function
E021-12	Character comparison
E031	Identifiers
E031-01	Delimited Identifiers
E031-02	Lower case identifiers
E031-03	Trailing underscore
E051	
E051-01	SELECT DISTINCT
E051-02	GROUP BY clause
E051-04	GROUP BY can contain columns not in select list

Feature ID	Feature
E051-05	Select list items can be renamed
E051-06	HAVING clause
E051-07	Qualified * in SELECT list
E051-08	Correlation names in the FROM clause
E051-09	Rename columns in the FROM clause
E061	
E061-01	Comparison predicate
E061-02	BETWEEN predicate
E061-03	IN predicate with list of values
E061-04	LIKE predicate
E061-05	LIKE predicate: ESCAPE clause
E061-06	NULL predicate
E061-07	Quantified comparison predicate
E061-08	EXISTS predicate
E061-09	Subqueries in comparison predicate
E061-11	Subqueries in IN predicate
E061-12	Subqueries in quantified comparison predicate
E061-13	Correlated subqueries
E061-14	Search condition
E071	
E071-01	UNION DISTINCT table operator
E071-02	UNION ALL table operator
E071-03	EXCEPT DISTINCT table operator
E071-05	Columns combined via table operators need not have exactly the same data type.
E071-06	Table operators in subqueries
E081	
E081-01	Select privilege at the table level
E081-02	DELETE privilege
E081-03	INSERT privilege at the table level
E081-04	UPDATE privilege at the table level
E081-05	UPDATE privilege at column level
E081-06	REFERENCES privilege at the table level
E081-07	REFERENCES privilege at column level
E081-08	WITH GRANT OPTION
E081-09	USAGE privilege
E081-10	EXECUTE privilege
E091	
E091-01	AVG
E091-02	COUNT
E091-03	MAX
E091-04	MIN
E091-05	SUM
E091-06	ALL quantifier
E091-07	DISTINCT quantifier
E101	
E101-01	INSERT statement
E101-03	Searched UPDATE statement
E101-04	Searched DELETE statement
E111	Single row SELECT statement

Feature ID	Feature
E121	
E121-01	DECLARE CURSOR
E121-02	ORDER BY columns need not be in select list
E121-03	Value expressions in select list
E121-04	OPEN statement
E121-06	Positioned UPDATE statement
E121-07	Positioned DELETE statement
E121-08	CLOSE statement
E121-10	FETCH statement implicit next
E121-17	WITH HOLD cursors
E131	Null value support (nulls in lieu of values)
E141	
E141-01	NOT NULL constraints
E141-02	UNIQUE constraints of NOT NULL columns
E141-03	PRIMARY KEY constraints
E141-04	Basic FOREIGN KEY constraint with the NO ACTION default for both referential delete actio
E141-06	CHECK constraints
E141-07	Column defaults
E141-08	NOT NULL inferred on primary key
E141-10	Names in a foreign key can be specified in any order
E151	
E151-01	COMMIT statement
E151-02	ROLLBACK statement
E152	
E152-01	SET TRANSACTION statement ISOLATION SERIALIZABLE clause
E152-02	SET TRANSACTION statement READ ONLY and READ WRITE clauses
E153	
E161	SQL comments using leading double minus
E171	SQLSTATE support
E182	Host language binding
F031	
F031-01	CREATE TABLE statement to create persistent base tables
F031-02	CREATE VIEW statement
F031-03	GRANT statement
F031-04	ALTER TABLE statement: add column
F031-13	DROP TABLE statement: RESTRICT clause
F031-16	DROP VIEW statement: RESTRICT clause
F031-19	REVOKE statement: RESTRICT clause
F041	
F041-01	Inner join but not necessarily the INNER keyword
F041-02	INNER keyword
F041-03	LEFT OUTER JOIN
F041-04	RIGHT OUTER JOIN
F041-05	Outer joins can be nested
F041-07	The inner table in a left or right outer join can also be used in an inner join
F041-08	All comparison operators are supported
F051-01	DATE data type (including support of DATE literal)
F051-02	TIME data type (including support of TIME literal)

Feature ID	Feature
F051-03	TIMESTAMP data type (including support of TIMESTAMP literal)
F051-04	Comparison predicate on DATE, TIME and TIMESTAMP data types
F051-05	Explicit CAST between date-time types and character string types
F051-06	CURRENT_DATE
F051-07	LOCALTIME
F051-08	LOCALTIMESTAMP
F081	UNION and EXCEPT in views
F131	
F131-01	WHERE, GROUP BY, and HAVING clauses supported in queries with grouped views
F131-02	Multiple tables supported in queries with grouped views
F131-03	Set functions supported in queries with grouped views
F131-04	Subqueries with GROUP BY and HAVING clauses and grouped views
F131-05	Single row SELECT with GROUP BY and HAVING clauses and grouped views
F181	Multiple module support
F201	CAST function
F221	Explicit defaults
F261	
F261-01	Simple CASE
F261-02	Searched CASE
F261-03	NULLIF
F261-04	COALESCE
F311	
F311-01	CREATE SCHEMA
F311-02	CREATE TABLE for persistent base tables
F311-03	CREATE VIEW
F311-04	CREATE VIEW: WITH CHECK OPTION
F311-05	GRANT statement
F471	Scalar subquery values
F481	Expanded NULL Predicate
F812	Basic flagging
S011	Distinct types
T321	
T321-01	User-defined functions with no overloading
T321-02	User-defined procedures with no overloading
T321-03	Function invocation
T321-04	CALL statement.
T321-05	RETURN statement.
T631	IN predicate with one list element
F021	Basic information schema

Total number of items marked "Fail": 68

Total number of items marked "Okay": 78

5.2 Built-in modules reference

This reference covers Tarantool's built-in Lua modules.

Note: Some functions in these modules are analogs to functions from standard Lua libraries. For better results, we recommend using functions from Tarantool's built-in modules.

5.2.1 Module box

As well as executing Lua chunks or defining your own functions, you can exploit Tarantool's storage functionality with the box module and its submodules.

Every submodule contains one or more Lua functions. A few submodules contain members as well as functions. The functions allow data definition (create alter drop), data manipulation (insert delete update upsert select replace), and introspection (inspecting contents of spaces, accessing server configuration).

To catch errors that functions in box submodules may throw, use pcall.

The contents of the box module can be inspected at runtime with box, with no arguments. The box module contains:

Submodule box.backup

The box.backup submodule contains two functions that are helpful for backup in certain situations.

backup.start([n])

Informs the server that activities related to the removal of outdated backups must be suspended.

To guarantee an opportunity to copy these files, Tarantool will not delete them. But there will be no read-only mode and checkpoints will continue by schedule as usual.

Parameters

- n (number) – optional argument starting with Tarantool 1.10.1 that indicates the checkpoint to use relative to the latest checkpoint. For example n = 0 means "backup will be based on the latest checkpoint", n = 1 means "backup will be based on the first checkpoint before the latest checkpoint (counting backwards)", and so on. The default value for n is zero.

Return: a table with the names of snapshot and vinyl files that should be copied

Example:

```
tarantool> box.backup.start()
---
- - ./00000000000000000015.snap
  - ./00000000000000000000.vylog
  - ./513/0/00000000000000000002.index
  - ./513/0/00000000000000000002.run
...
```

backup.stop()

informs the server that normal operations may resume.

Submodule box.cfg

The box.cfg submodule is used for specifying server configuration parameters.

To view the current configuration, say box.cfg without braces:

```
tarantool> box.cfg
---
- checkpoint_count: 2
  too_long_threshold: 0.5
  slab_alloc_factor: 1.1
  memtx_max_tuple_size: 1048576
  background: false
  <...>
...
```

To set particular parameters, use the following syntax: box.cfg{key = value [, key = value ...]} (further referred to as box.cfg{...} for short). For example:

```
tarantool> box.cfg{listen = 3301}
```

Parameters that are not specified in the box.cfg{...} call explicitly will be set to the default values.

If you say box.cfg{} with no parameters, Tarantool applies the following default settings to all the parameters:

```
tarantool> box.cfg{}
tarantool> box.cfg -- sorted in the alphabetic order
---
- background                   = false
  checkpoint_count             = 2
  checkpoint_interval          = 3600
  checkpoint_wal_threshold     = 1000000000000000000
  coredump                     = false
  custom_proc_title            = nil
  feedback_enabled             = true
  feedback_host                = 'https://feedback.tarantool.io'
  feedback_interval            = 3600
  force_recovery               = false
  hot_standby                  = false
  instance_uuid                = nil -- generated automatically
  io_collect_interval          = nil
  listen                       = nil
  log                          = nil
  log_format                   = plain
  log_level                    = 5
  log_nonblock                 = true
  memtx_dir                    = '.'
  memtx_max_tuple_size         = 1024 * 1024
  memtx_memory                 = 256 * 1024 *1024
  memtx_min_tuple_size         = 16
  net_msg_max                  = 768
  pid_file                     = nil
  readahead                    = 16320
  read_only                    = false
  replicaset_uuid              = nil -- generated automatically
  replication                  = nil
  replication_anon             = false
  replication_connect_quorum   = nil
  replication_connect_timeout  = 30
  replication_skip_conflict    = false
  replication_sync_lag         = 10
  replication_sync_timeout     = 300
  replication_timeout          = 1
```

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```
slab_alloc_factor            = 1.05
snap_io_rate_limit           = nil
sql_cache_size               = 5242880
strip_core                   = true
too_long_threshold           = 0.5
username                     = nil
vinyl_bloom_fpr              = 0.05
vinyl_cache                  = 128 * 1024 * 1024
vinyl_dir                    = '.'
vinyl_max_tuple_size         = 1024 * 1024* 1024 * 1024
vinyl_memory                 = 128 * 1024 * 1024
vinyl_page_size              = 8 * 1024
vinyl_range_size             = nil
vinyl_read_threads           = 1
vinyl_run_count_per_level    = 2
vinyl_run_size_ratio         = 3.5
vinyl_timeout                = 60
vinyl_write_threads          = 4
wal_dir                      = '.'
wal_dir_rescan_delay         = 2
wal_max_size                 = 256 * 1024 * 1024
wal_mode                     = 'write'
worker_pool_threads          = 4
work_dir                     = nil
```

The first call to box.cfg{...} (with or without parameters) initiates Tarantool's database module box. Before Tarantool 2.0, you needed to call box.cfg{...} prior to performing any database operations. Now you can start working with the database outright, without calling box.cfg{...}. In this case, Tarantool initiates the database module and applies default settings, as if you said box.cfg{} (without parameters).

box.cfg{...} is also the command that reloads persistent data files into RAM upon restart once we have data.

Submodule box.ctl

The box.ctl submodule contains two functions: wait_ro (wait until read-only) and wait_rw (wait until read-write). The functions are useful during initialization of a server.

A particular use is for box_once(). For example, when a replica is initializing, it may call a box.once() function while the server is still in read-only mode, and fail to make changes that are necessary only once before the replica is fully initialized. This could cause conflicts between a master and a replica if the master is in read-write mode and the replica is in read-only mode. Waiting until “read only mode = false” solves this problem.

To see whether a function is already in read-only or read-write mode, check box.info.ro.

box.ctl.wait_ro([timeout])

Wait until box.info.ro is true.

Parameters

- timeout (number) – maximum number of seconds to wait

Return nil, or error may be thrown due to timeout or fiber cancellation

Example:

```
tarantool> box.info().ro
---
- false
...

tarantool> n = box.ctl.wait_ro(0.1)
---
- error: timed out
...
```

box.ctl.wait_rw([timeout])

Wait until box.info.ro is false.

Parameters

- timeout (number) – maximum number of seconds to wait

Return nil, or error may be thrown due to timeout or fiber cancellation

Example:

```
tarantool> box.ctl.wait_rw(0.1)
---
...
```

The box.ctl submodule also contains two functions for the two server trigger definitions: on_shutdown and on_schema_init. Please, familiarize yourself with the mechanism of trigger functions before using them.

box.ctl.on_shutdown(trigger-function[, old-trigger-function])

Create a "shutdown trigger". The trigger-function will be executed whenever os.exit() happens, or when the server is shut down after receiving a SIGTERM or SIGINT or SIGHUP signal (but not after SIGSEGV or SIGABORT or any signal that causes immediate program termination).

Parameters

- trigger-function (function) – function which will become the trigger function
- old-trigger-function (function) – existing trigger function which will be replaced by trigger-function

Return nil or function pointer

If the parameters are (nil, old-trigger-function), then the old trigger is deleted.

Details about trigger characteristics are in the triggers section.

box.ctl.on_schema_init(trigger-function[, old-trigger-function])

Create a "schema_init trigger". The trigger-function will be executed when box.cfg{} happens for the first time. That is, the schema_init trigger is called before the server's configuration and recovery begins, and therefore box.ctl.on_schema_init must be called before box.cfg is called.

Parameters

- trigger-function (function) – function which will become the trigger function
- old-trigger-function (function) – existing trigger function which will be replaced by trigger-function

Return nil or function pointer

If the parameters are (nil, old-trigger-function), then the old trigger is deleted.

A common use is: make a schema_init trigger function which creates a before_replace trigger function on a system space. Thus, since system spaces are created when the server starts, the before_replace triggers will be activated for each tuple in each system space. For example, such a trigger could change the storage engine of a given space, or make a given space replica-local while a replica is being bootstrapped. Making such a change after box.cfg is not reliable because other connections might use the database before the change is made.

Details about trigger characteristics are in the triggers section.

Example:

Suppose that, before the server is fully up and ready for connections, you want to make sure that the engine of space space_name is vinyl. So you want to make a trigger that will be activated when a tuple is inserted in the _space system space. In this case you could end up with a master that has space-name with engine='memtx' and a replica that has space_name with engine='vinyl', with the same contents.

```
function function_for_before_replace(old, new)
  if old == nil and new ~= nil and new[3] == 'space_name' and new[4] ~= 'vinyl' then
    return new:update{{'=', 4, 'vinyl'}}
  end
end

box.ctl.on_schema_init(function()
  box.space._space:before_replace(function_for_before_replace)
end)

box.cfg{replication='master_uri', ...}
```

Submodule box.error

Overview

The box.error function is for raising an error. The difference between this function and Lua's built-in error function is that when the error reaches the client, its error code is preserved. In contrast, a Lua error would always be presented to the client as ER_PROC_LUA.

Index

Below is a list of all box.error functions.

Name	Use
box.error()	Throw an error
box.error.last()	Get a description of the last error
box.error.clear()	Clear the record of errors
box.error.new()	Create an error but do not throw

box.error(reason = string[, code = number])

When called with a Lua-table argument, the code and reason have any user-desired values. The result will be those values.

Parameters

- reason (string) – description of an error, defined by user

- code (integer) – numeric code for this error, defined by user

box.error()

When called without arguments, box.error() re-throws whatever the last error was.

box.error(code, errtext[, errtext ...])

Emulate a request error, with text based on one of the pre-defined Tarantool errors defined in the file errcode.h in the source tree. Lua constants which correspond to those Tarantool errors are defined as members of box.error, for example box.error.NO_SUCH_USER == 45.

Parameters

- code (number) – number of a pre-defined error
- errtext(s) (string) – part of the message which will accompany the error

For example:

the NO_SUCH_USER message is "User '%s' is not found" – it includes one "%s" component which will be replaced with errtext. Thus a call to box.error(box.error.NO_SUCH_USER, 'joe') or box.error(45, 'joe') will result in an error with the accompanying message "User 'joe' is not found".

Except whatever is specified in errcode-number.

Example:

```
tarantool> box.error{code = 555, reason = 'Arbitrary message'}
---
- error: Arbitrary message
...
tarantool> box.error()
---
- error: Arbitrary message
...
tarantool> box.error(box.error.FUNCTION_ACCESS_DENIED, 'A', 'B', 'C')
---
- error: A access denied for user 'B' to function 'C'
...
```

box.error.last()

Returns a description of the last error, as a Lua table with five members: "line" (number) Tarantool source file line number, "code" (number) error's number, "type", (string) error's C++ class, "message" (string) error's message, "file" (string) Tarantool source file. Additionally, if the error is a system error (for example due to a failure in socket or file io), there may be a sixth member: "errno" (number) C standard error number.

rtype: table

box.error.clear()

Clears the record of errors, so functions like box.error() or box.error.last() will have no effect.

Example:

```
tarantool> box.error{code = 555, reason = 'Arbitrary message'}
---
- error: Arbitrary message
...
tarantool> box.schema.space.create('#')
---
- error: Invalid identifier '#' (expected letters, digits or an underscore)
...
```

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```
tarantool> box.error.last()
---
- line: 278
  code: 70
  type: ClientError
  message: Invalid identifier '#' (expected letters, digits or an underscore)
  file: /tmp/buildd/tarantool-1.7.0.252.g1654e31~precise/src/box/key_def.cc
...
tarantool> box.error.clear()
---
...
tarantool> box.error.last()
---
- null
...
```

box.error.new(code, errtext[, errtext ...])

Create an error object, but do not throw. This is useful when error information should be saved for later retrieval. The parameters are the same as for box.error(), see the description there.

Parameters

- code (number) – number of a pre-defined error
- errtext(s) (string) – part of the message which will accompany the error

Example:

```
tarantool> e = box.error.new{code = 555, reason = 'Arbitrary message'}
---
...
tarantool> e:unpack()
---
- type: ClientError
  code: 555
  message: Arbitrary message
  trace:
  - file: '[string "e = box.error.new{code = 555, reason = ''Arbit..."]'
    line: 1
...
```

Submodule box.index

Overview

The box.index submodule provides read-only access for index definitions and index keys. Indexes are contained in box.space.space-name.index array within each space object. They provide an API for ordered iteration over tuples. This API is a direct binding to corresponding methods of index objects of type box.index in the storage engine.

Index

Below is a list of all box.index functions and members.

Name	Use
index_object.unique	Flag, true if an index is unique
index_object.type	Index type
index_object.parts	Array of index key fields
index_object:pairs()	Prepare for iterating
index_object:select()	Select one or more tuples via index
index_object:get()	Select a tuple via index
index_object:min()	Find the minimum value in index
index_object:max()	Find the maximum value in index
index_object:random()	Find a random value in index
index_object:count()	Count tuples matching key value
index_object:update()	Update a tuple
index_object:delete()	Delete a tuple by key
index_object:alter()	Alter an index
index_object:drop()	Drop an index
index_object:rename()	Rename an index
index_object:bsize()	Get count of bytes for an index
index_object:stat()	Get statistics for an index
index_object:compact()	Remove unused index space
index_object:user_defined()	Any function / method that any user wants to add

object index_object

index_object.unique
True if the index is unique, false if the index is not unique.

Rtype boolean

index_object.type
Index type, 'TREE' or 'HASH' or 'BITSET' or 'RTREE'.

index_object.parts
An array describing the index fields. To learn more about the index field types, refer to this table.

Rtype table

Example:

```
tarantool> box.space.tester.index.primary
---
- unique: true
  parts:
  - type: unsigned
    is_nullable: false
    fieldno: 1
  id: 0
  space_id: 513
  name: primary
  type: TREE
...
```

index_object:pairs([key[, {iterator = iterator-type}]])
Search for a tuple or a set of tuples via the given index, and allow iterating over one tuple at a time.

The key parameter specifies what must match within the index.

Note: key is only used to find the first match. Do not assume all matched tuples will contain the key.

The iterator parameter specifies the rule for matching and ordering. Different index types support different iterators. For example, a TREE index maintains a strict order of keys and can return all tuples in ascending or descending order, starting from the specified key. Other index types, however, do not support ordering.

To understand consistency of tuples returned by an iterator, it's essential to know the principles of the Tarantool transaction processing subsystem. An iterator in Tarantool does not own a consistent read view. Instead, each procedure is granted exclusive access to all tuples and spaces until there is a "context switch": which may happen due to the implicit yield rules, or by an explicit call to fiber.yield. When the execution flow returns to the yielded procedure, the data set could have changed significantly. Iteration, resumed after a yield point, does not preserve the read view, but continues with the new content of the database. The tutorial Indexed pattern search shows one way that iterators and yields can be used together.

For information about iterators' internal structures see the "Lua Functional library" documentation.

Parameters

- index_object (index_object) – an object reference.
- key (scalar/table) – value to be matched against the index key, which may be multi-part
- iterator – as defined in tables below. The default iterator type is 'EQ'

Return iterator which can be used in a for/end loop or with totable()

Possible errors:

- no such space; wrong type;
- selected iteration type is not supported for the index type;
- key is not supported for the iteration type.

Complexity factors: Index size, Index type; Number of tuples accessed.

A search-key-value can be a number (for example 1234), a string (for example `'abcd'`), or a table of numbers and strings (for example {1234, `'abcd'`}). Each part of a key will be compared to each part of an index key.

The returned tuples will be in order by index key value, or by the hash of the index key value if index type = 'hash'. If the index is non-unique, then duplicates will be secondarily in order by primary key value. The order will be reversed if the iterator type is 'LT' or 'LE' or 'REQ'.

Iterator types for TREE indexes

Iterator type	Arguments	Description
box.index.EQ or 'EQ'	search value	The comparison operator is '==' (equal to). If an index key is equal to a search value, it matches. Tuples are returned in ascending order by index key. This is the default.
box.index.REQ or 'REQ'	search value	Matching is the same as for box.index.EQ. Tuples are returned in descending order by index key.
box.index.GT or 'GT'	search value	The comparison operator is '>' (greater than). If an index key is greater than a search value, it matches. Tuples are returned in ascending order by index key.
box.index.GE or 'GE'	search value	The comparison operator is '>=' (greater than or equal to). If an index key is greater than or equal to a search value, it matches. Tuples are returned in ascending order by index key.
box.index.ALL or 'ALL'	search value	Same as box.index.GE.
box.index.LT or 'LT'	search value	The comparison operator is '<' (less than). If an index key is less than a search value, it matches. Tuples are returned in descending order by index key.
box.index.LE or 'LE'	search value	The comparison operator is '<=' (less than or equal to). If an index key is less than or equal to a search value, it matches. Tuples are returned in descending order by index key.

Informally, we can state that searches with TREE indexes are generally what users will find is intuitive, provided that there are no nils and no missing parts. Formally, the logic is as follows. A search key has zero or more parts, for example {}, {1,2,3},{1,nil,3}. An index key has one or more parts, for example {1}, {1,2,3},{1,2,3}. A search key may contain nil (but not msgpack.NULL, which is the wrong type). An index key may not contain nil or msgpack.NULL, although a later version of Tarantool will have different rules – the behavior of searches with nil is subject to change. Possible iterators are LT, LE, EQ, REQ, GE, GT. A search key is said to "match" an index key if the following statements, which are pseudocode for the comparison operation, return TRUE.

```
If (number-of-search-key-parts > number-of-index-key-parts) return ERROR
If (number-of-search-key-parts == 0) return TRUE
for (i = 1; ; ++i)
{
  if (i > number-of-search-key-parts) OR (search-key-part[i] is nil)
  {
    if (iterator is LT or GT) return FALSE
    return TRUE
  }
  if (type of search-key-part[i] is not compatible with type of index-key-part[i])
  {
    return ERROR
  }
  if (search-key-part[i] == index-key-part[i])
  {
    continue
  }
  if (search-key-part[i] > index-key-part[i])
  {
    if (iterator is EQ or REQ or LE or LT) return FALSE
```

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```
    return TRUE
  }
  if (search-key-part[i] < index-key-part[i])
  {
    if (iterator is EQ or REQ or GE or GT) return FALSE
    return TRUE
  }
}
```

Iterator types for HASH indexes

Type	Arguments	Description
box.index.ALL	none	All index keys match. Tuples are returned in ascending order by hash of index key, which will appear to be random.
box.index.EQ or 'EQ'	search value	The comparison operator is '==' (equal to). If an index key is equal to a search value, it matches. The number of returned tuples will be 0 or 1. This is the default.
box.index.GT or 'GT'	search value	The comparison operator is '>' (greater than). If a hash of an index key is greater than a hash of a search value, it matches. Tuples are returned in ascending order by hash of index key, which will appear to be random. Provided that the space is not being updated, one can retrieve all the tuples in a space, N tuples at a time, by using {iterator='GT', limit=N} in each search, and using the last returned value from the previous result as the start search value for the next search.

Iterator types for BITSET indexes

Type	Arguments	Description
box.index.ALL or 'ALL'	none	All index keys match. Tuples are returned in their order within the space.
box.index.EQ or 'EQ'	bitset value	If an index key is equal to a bitset value, it matches. Tuples are returned in their order within the space. This is the default.
box.index.BITS_ALL_SET	bitset value	If all of the bits which are 1 in the bitset value are 1 in the index key, it matches. Tuples are returned in their order within the space.
box.index.BITS_ANY_SET	bitset value	If any of the bits which are 1 in the bitset value are 1 in the index key, it matches. Tuples are returned in their order within the space.
box.index.BITS_ALL_NOT_SET	bitset value	If all of the bits which are 1 in the bitset value are 0 in the index key, it matches. Tuples are returned in their order within the space.

Iterator types for RTREE indexes

Type	Arguments	Description
box.index.ALL or 'ALL'	none	All keys match. Tuples are returned in their order within the space.
box.index.EQ or 'EQ'	search value	If all points of the rectangle-or-box defined by the search value are the same as the rectangle-or-box defined by the index key, it matches. Tuples are returned in their order within the space. "Rectangle-or-box" means "rectangle-or-box as explained in section about RTREE". This is the default.
box.index.GT or 'GT'	search value	If all points of the rectangle-or-box defined by the search value are within the rectangle-or-box defined by the index key, it matches. Tuples are returned in their order within the space.
box.index.GE or 'GE'	search value	If all points of the rectangle-or-box defined by the search value are within, or at the side of, the rectangle-or-box defined by the index key, it matches. Tuples are returned in their order within the space.
box.index.LT or 'LT'	search value	If all points of the rectangle-or-box defined by the index key are within the rectangle-or-box defined by the search key, it matches. Tuples are returned in their order within the space.
box.index.LE or 'LE'	search value	If all points of the rectangle-or-box defined by the index key are within, or at the side of, the rectangle-or-box defined by the search key, it matches. Tuples are returned in their order within the space.
box.index.OVERLAPS or 'OVERLAPS'	search value	If some points of the rectangle-or-box defined by the search value are within the rectangle-or-box defined by the index key, it matches. Tuples are returned in their order within the space.
box.index.NEIGHBOR or 'NEIGHBOR'	search value	If some points of the rectangle-or-box defined by the defined by the key are within, or at the side of, defined by the index key, it matches. Tuples are returned in order: nearest neighbor first.

First example of index pairs():

Default 'TREE' Index and pairs() function:

```
tarantool> s = box.schema.space.create('space17')
---
...
tarantool> s:create_index('primary', {
         >   parts = {1, 'string', 2, 'string'}
         > })
---
...
tarantool> s:insert{'C', 'C'}
```

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```
---
- ['C', 'C']
...
tarantool> s:insert{'B', 'A'}
---
- ['B', 'A']
...
tarantool> s:insert{'C', '!'}
---
- ['C', '!']
...
tarantool> s:insert{'A', 'C'}
---
- ['A', 'C']
...
tarantool> function example()
         >   for _, tuple in
         >     s.index.primary:pairs(nil, {
         >         iterator = box.index.ALL}) do
         >       print(tuple)
         >   end
         > end
---
...
tarantool> example()
['A', 'C']
['B', 'A']
['C', '!']
['C', 'C']
---
...
tarantool> s:drop()
---
...
```

Second example of index pairs():

This Lua code finds all the tuples whose primary key values begin with ‘XY’. The assumptions include that there is a one-part primary-key TREE index on the first field, which must be a string. The iterator loop ensures that the search will return tuples where the first value is greater than or equal to ‘XY’. The conditional statement within the loop ensures that the looping will stop when the first two letters are not ‘XY’.

```
for _, tuple in
box.space.t.index.primary:pairs("XY",{iterator = "GE"}) do
  if (string.sub(tuple[1], 1, 2) ~= "XY") then break end
  print(tuple)
end
```

Third example of index pairs():

This Lua code finds all the tuples whose primary key values are greater than or equal to 1000, and less than or equal to 1999 (this type of request is sometimes called a “range search” or a “between search”). The assumptions include that there is a one-part primary-key TREE index on the first field, which must be a number. The iterator loop ensures that the search will return tuples where the first value is greater than or equal to 1000. The conditional statement within the loop ensures that the looping will stop when the first value is greater than 1999.

```
for _, tuple in
box.space.t2.index.primary:pairs(1000,{iterator = "GE"}) do
  if (tuple[1] > 1999) then break end
  print(tuple)
end
```

index_object:select(search-key, options)

This is an alternative to box.space...select() which goes via a particular index and can make use of additional parameters that specify the iterator type, and the limit (that is, the maximum number of tuples to return) and the offset (that is, which tuple to start with in the list).

Parameters

- index_object (index_object) – an object reference.
- key (scalar/table) – values to be matched against the index key
- options (table/nil) – none, any, or all of the following parameters:
  - iterator – type of iterator
  - limit – maximum number of tuples
  - offset – start tuple number

Return the tuple or tuples that match the field values.

Rtype array of tuples

Example:

```
-- Create a space named tester.
tarantool> sp = box.schema.space.create('tester')
-- Create a unique index 'primary'
-- which won't be needed for this example.
tarantool> sp:create_index('primary', {parts = {1, 'unsigned' }})
-- Create a non-unique index 'secondary'
-- with an index on the second field.
tarantool> sp:create_index('secondary', {
         >   type = 'tree',
         >   unique = false,
         >   parts = {2, 'string'}
         > })
-- Insert three tuples, values in field[2]
-- equal to 'X', 'Y', and 'Z'.
tarantool> sp:insert{1, 'X', 'Row with field[2]=X'}
tarantool> sp:insert{2, 'Y', 'Row with field[2]=Y'}
tarantool> sp:insert{3, 'Z', 'Row with field[2]=Z'}
-- Select all tuples where the secondary index
-- keys are greater than 'X'.
tarantool> sp.index.secondary:select({'X'}, {
         >   iterator = 'GT',
         >   limit = 1000
         > })
```

The result will be a table of tuple and will look like this:

```
---
- - [2, 'Y', 'Row with field[2]=Y']
  - [3, 'Z', 'Row with field[2]=Z']
...
```

Note: The arguments are optional. If you call box.space.space-name:select{}, then every key in the index is considered to be a match, regardless of the iterator type. Therefore, for the example above, box.space.tester:select{} will select every tuple in the tester space via the first (primary-key) index.

Note: index.index-name is optional. If it is omitted, then the assumed index is the first (primary-key) index. Therefore, for the example above, box.space.tester:select({1}, {iterator = 'GT'}) would have returned the same two rows, via the 'primary' index.

Note: iterator = iterator-type is optional. If it is omitted, then iterator = 'EQ' is assumed.

Note: box.space.space-name.index.index-name:select(...)[1]. can be replaced by box.space.space-name.index.index-name:get(...). That is, get can be used as a convenient shorthand to get the first tuple in the tuple set that would be returned by select. However, if there is more than one tuple in the tuple set, then get throws an error.

Example with BITSET index:

The following script shows creation and search with a BITSET index. Notice: BITSET cannot be unique, so first a primary-key index is created. Notice: bit values are entered as hexadecimal literals for easier reading.

```
tarantool> s = box.schema.space.create('space_with_bitset')
tarantool> s:create_index('primary_index', {
         >   parts = {1, 'string'},
         >   unique = true,
         >   type = 'TREE'
         > })
tarantool> s:create_index('bitset_index', {
         >   parts = {2, 'unsigned'},
         >   unique = false,
         >   type = 'BITSET'
         > })
tarantool> s:insert{'Tuple with bit value = 01', 0x01}
tarantool> s:insert{'Tuple with bit value = 10', 0x02}
tarantool> s:insert{'Tuple with bit value = 11', 0x03}
tarantool> s.index.bitset_index:select(0x02, {
         >   iterator = box.index.EQ
         > })
---
- - ['Tuple with bit value = 10', 2]
...
tarantool> s.index.bitset_index:select(0x02, {
         >   iterator = box.index.BITS_ANY_SET
         > })
---
- - ['Tuple with bit value = 10', 2]
  - ['Tuple with bit value = 11', 3]
...
tarantool> s.index.bitset_index:select(0x02, {
```

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```
        >   iterator = box.index.BITS_ALL_SET
        > })
---
- - ['Tuple with bit value = 10', 2]
  - ['Tuple with bit value = 11', 3]
...
tarantool> s.index.bitset_index:select(0x02, {
        >   iterator = box.index.BITS_ALL_NOT_SET
        > })
---
- - ['Tuple with bit value = 01', 1]
...
```

index_object:get(key)

Search for a tuple via the given index, as described earlier.

Parameters

- index_object (index_object) – an object reference.
- key (scalar/table) – values to be matched against the index key

Return the tuple whose index-key fields are equal to the passed key values.

Rtype tuple

Possible errors:

- no such index;
- wrong type;
- more than one tuple matches.

Complexity factors: Index size, Index type. See also space_object:get().

Example:

```
tarantool> box.space.tester.index.primary:get(2)
---
- [2, 'Music']
...
```

index_object:min([key])

Find the minimum value in the specified index.

Parameters

- index_object (index_object) – an object reference.
- key (scalar/table) – values to be matched against the index key

Return the tuple for the first key in the index. If optional key value is supplied, returns the first key which is greater than or equal to key value. Starting with Tarantool version 2.0, index_object:min(key value) will return nothing if key value is not equal to a value in the index.

Rtype tuple

Possible errors: index is not of type 'TREE'.

Complexity factors: Index size, Index type.

Example:

```
tarantool> box.space.tester.index.primary:min()
---
- ['Alpha!', 55, 'This is the first tuple!']
...
```

index_object:max([key])

Find the maximum value in the specified index.

Parameters

- index_object (index_object) – an object reference.
- key (scalar/table) – values to be matched against the index key

Return the tuple for the last key in the index. If optional key value is supplied, returns the last key which is less than or equal to key value. Starting with Tarantool version 2.0, index_object:max(key value) will return nothing if key value is not equal to a value in the index.

Rtype tuple

Possible errors: index is not of type 'TREE'.

Complexity factors: Index size, Index type.

Example:

```
tarantool> box.space.tester.index.primary:max()
---
- ['Gamma!', 55, 'This is the third tuple!']
...
```

index_object:random(seed)

Find a random value in the specified index. This method is useful when it's important to get insight into data distribution in an index without having to iterate over the entire data set.

Parameters

- index_object (index_object) – an object reference.
- seed (number) – an arbitrary non-negative integer

Return the tuple for the random key in the index.

Rtype tuple

Complexity factors: Index size, Index type.

Note re storage engine: vinyl does not support random().

Example:

```
tarantool> box.space.tester.index.secondary:random(1)
---
- ['Beta!', 66, 'This is the second tuple!']
...
```

index_object:count([key][, iterator])

Iterate over an index, counting the number of tuples which match the key-value.

Parameters

- index_object (index_object) – an object reference.

- key (scalar/table) – values to be matched against the index key
- iterator – comparison method

Return the number of matching tuples.

Rtype number

Example:

```
tarantool> box.space.tester.index.primary:count(999)
---
- 0
...
tarantool> box.space.tester.index.primary:count('Alpha!', { iterator = 'LE' })
---
- 1
...
```

index_object:update(key, {{operator, field_identifier, value}, ...})

Update a tuple.

Same as box.space...update(), but key is searched in this index instead of primary key. This index should be unique.

Parameters

- index_object (index_object) – an object reference.
- key (scalar/table) – values to be matched against the index key
- operator (string) – operation type represented in string
- field_identifier (number-or-string) – what field the operation will apply to.
- value (lua_value) – what value will be applied

Return

- the updated tuple
- nil if the key is not found

Rtype tuple or nil

Since Tarantool 2.3 a tuple can also be updated via JSON paths.

index_object:delete(key)

Delete a tuple identified by a key.

Same as box.space...delete(), but key is searched in this index instead of in the primary-key index. This index ought to be unique.

Parameters

- index_object (index_object) – an object reference.
- key (scalar/table) – values to be matched against the index key

Return the deleted tuple.

Rtype tuple

Note re storage engine: vinyl will return nil, rather than the deleted tuple.

index_object:alter({options})

Alter an index. It is legal in some circumstances to change one or more of the index characteristics, for example its type, its sequence options, its parts, and whether it is unique. Usually this causes rebuilding of the space, except for the simple case where a part's is_nullable flag is changed from false to true.

Parameters

- index_object (index_object) – an object reference.
- options (table) – options list, same as the options list for create_index, see the chart named Options for space_object:create_index().

Return nil

Possible errors:

- index does not exist,
- the primary-key index cannot be changed to {unique = false}.

Note re storage engine: vinyl does not support alter() of a primary-key index unless the space is empty.

Example 1:

You can add and remove fields that make up a primary index:

```
tarantool> s = box.schema.create_space('test')
---
...
tarantool> i = s:create_index('i', {parts = {{field = 1, type = 'unsigned'}}})
---
...
tarantool> s:insert({1, 2})
---
- [1, 2]
...
tarantool> i:select()
---
- - [1, 2]
...
tarantool> i:alter({parts = {{field = 1, type = 'unsigned'}, {field = 2, type = 'unsigned'}}})
---
...
tarantool> s:insert({1, 't'})
---
- error: 'Tuple field 2 type does not match one required by operation: expected unsigned'
...
```

Example 2:

You can change index options for both memtx and vinyl spaces:

```
tarantool> box.space.space55.index.primary:alter({type = 'HASH'})
---
...

tarantool> box.space.vinyl_space.index.i:alter({page_size=4096})
---
...
```

index_object:drop()

Drop an index. Dropping a primary-key index has a side effect: all tuples are deleted.

Parameters

- index_object (index_object) – an object reference.

Return nil.

Possible errors:

- index does not exist,
- a primary-key index cannot be dropped while a secondary-key index exists.

Example:

```
tarantool> box.space.space55.index.primary:drop()
---
...
```

index_object:rename(index-name)

Rename an index.

Parameters

- index_object (index_object) – an object reference.
- index-name (string) – new name for index

Return nil

Possible errors: index_object does not exist.

Example:

```
tarantool> box.space.space55.index.primary:rename('secondary')
---
...
```

Complexity factors: Index size, Index type, Number of tuples accessed.

index_object:bsize()

Return the total number of bytes taken by the index.

Parameters

- index_object (index_object) – an object reference.

Return number of bytes

Rtype number

index_object:stat()

Return statistics about actions taken that affect the index.

This is for use with the vinyl engine.

Some detail items in the output from index_object:stat() are:

- index_object:stat().latency – timings subdivided by percentages;
- index_object:stat().bytes – the number of bytes total;
- index_object:stat().disk.rows – the approximate number of tuples in each range;
- index_object:stat().disk.statement – counts of inserts|updates|upserts|deletes;

- index_object:stat().disk.compaction – counts of compactions and their amounts;
- index_object:stat().disk.dump – counts of dumps and their amounts;
- index_object:stat().disk.iterator.bloom – counts of bloom filter hits|misses;
- index_object:stat().disk.pages – the size in pages;
- index_object:stat().disk.last_level – size of data in the last LSM tree level;
- index_object:stat().cache.evict – number of evictions from the cache;
- index_object:stat().range_size – maximum number of bytes in a range;
- index_object:stat().dumps_per_compaction – average number of dumps required to trigger major compaction in any range of the LSM tree.

Summary index statistics are also available via box.stat.vinyl().

Parameters

- index_object (index_object) – an object reference.

Return statistics

Rtype table

index_object:compact()

Remove unused index space. For the memtx storage engine this method does nothing; index_object:compact() is only for the vinyl storage engine. For example, with vinyl, if a tuple is deleted, the space is not immediately reclaimed. There is a scheduler for reclaiming space automatically based on factors such as lsm shape and amplification as discussed in the section Storing data with vinyl, so calling index_object:compact() manually is not always necessary.

Return nil (Tarantool returns without waiting for compaction to complete)

index_object:user_defined()

Users can define any functions they want, and associate them with indexes: in effect they can make their own index methods. They do this by:

(1) creating a Lua function,

(2) adding the function name to a predefined global variable which has type = table, and

(3) invoking the function any time thereafter, as long as the server is up, by saying index_object:function-name([parameters]).

There are three predefined global variables:

- Adding to box_schema.index_mt makes the method available for all indexes.
- Adding to box_schema.memtx_index_mt makes the method available for all memtx indexes.
- Adding to box_schema.vinyl_index_mt makes the method available for all vinyl indexes.

Alternatively, user-defined methods can be made available for only one index, by calling getmetatable(index_object) and then adding the function name to the meta table.

Parameters

- index_object (index_object) – an object reference.
- any-name (any-type) – whatever the user defines

Example:

```
-- Visible to any index of a memtx space, no parameters.
-- After these requests, the value of global_variable will be 6.
box.schema.space.create('t', {engine='memtx'})
box.space.t:create_index('i')
global_variable = 5
function f() global_variable = global_variable + 1 end
box.schema.memtx_index_mt.counter = f
box.space.t.index.i:counter()
```

Example:

```
-- Visible to index box.space.t.index.i only, 1 parameter.
-- After these requests, the value of X will be 1005.
box.schema.space.create('t', {engine='memtx', id = 1000})
box.space.t:create_index('i')
X = 0
i = box.space.t.index.i
function f(i_arg, param) X = X + param + i_arg.space_id end
box.schema.memtx_index_mt.counter = f
meta = getmetatable(i)
meta.counter = f
i:counter(5)
```

Example showing use of the box functions

This example will work with the sandbox configuration described in the preface. That is, there is a space named tester with a numeric primary key. The example function will:

- select a tuple whose key value is 1000;
- raise an error if the tuple already exists and already has 3 fields;
- Insert or replace the tuple with:
  - field[1] = 1000
  - field[2] = a uuid
  - field[3] = number of seconds since 1970-01-01;
- Get field[3] from what was replaced;
- Format the value from field[3] as yyyy-mm-dd hh:mm:ss.ffff;
- Return the formatted value.

The function uses Tarantool box functions box.space...select, box.space...replace, fiber.time, uuid.str. The function uses Lua functions os.date() and string.sub().

```
function example()
  local a, b, c, table_of_selected_tuples, d
  local replaced_tuple, time_field
  local formatted_time_field
  local fiber = require('fiber')
  table_of_selected_tuples = box.space.tester:select{1000}
  if table_of_selected_tuples ~= nil then
    if table_of_selected_tuples[1] ~= nil then
      if #table_of_selected_tuples[1] == 3 then
        box.error({code=1, reason='This tuple already has 3 fields'})
```

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```
      end
    end
  end
  replaced_tuple = box.space.tester:replace
    {1000,  require('uuid').str(), tostring(fiber.time())}
  time_field = tonumber(replaced_tuple[3])
  formatted_time_field = os.date("%Y-%m-%d %H:%M:%S", time_field)
  c = time_field % 1
  d = string.sub(c, 3, 6)
  formatted_time_field = formatted_time_field .. '.' .. d
  return formatted_time_field
end
```

. . . And here is what happens when one invokes the function:

```
tarantool> box.space.tester:delete(1000)
---
- [1000, '264ee2da03634f24972be76c43808254', '1391037015.6809']
...
tarantool> example(1000)
---
- 2014-01-29 16:11:51.1582
...
tarantool> example(1000)
---
- error: 'This tuple already has 3 fields'
...
```

Example showing a user-defined iterator

Here is an example that shows how to build one's own iterator. The paged_iter function is an "iterator function", which will only be understood by programmers who have read the Lua manual section Iterators and Closures. It does paginated retrievals, that is, it returns 10 tuples at a time from a table named "t", whose primary key was defined with create_index('primary',{parts={1,'string'}}).

```
function paged_iter(search_key, tuples_per_page)
  local iterator_string = "GE"
  return function ()
  local page = box.space.t.index[0]:select(search_key,
    {iterator = iterator_string, limit=tuples_per_page})
  if #page == 0 then return nil end
  search_key = page[#page][1]
  iterator_string = "GT"
  return page
  end
end
```

Programmers who use paged_iter do not need to know why it works, they only need to know that, if they call it within a loop, they will get 10 tuples at a time until there are no more tuples.

In this example the tuples are merely printed, a page at a time. But it should be simple to change the functionality, for example by yielding after each retrieval, or by breaking when the tuples fail to match some additional criteria.

```
for page in paged_iter("X", 10) do
  print("New Page. Number Of Tuples = " .. #page)
  for i = 1, #page, 1 do
    print(page[i])
  end
end
```

Submodule box.index with index type = RTREE for spatial searches

The box.index submodule may be used for spatial searches if the index type is RTREE. There are operations for searching rectangles (geometric objects with 4 corners and 4 sides) and boxes (geometric objects with more than 4 corners and more than 4 sides, sometimes called hyperrectangles). This manual uses the term rectangle-or-box for the whole class of objects that includes both rectangles and boxes. Only rectangles will be illustrated.

Rectangles are described according to their X-axis (horizontal axis) and Y-axis (vertical axis) coordinates in a grid of arbitrary size. Here is a picture of four rectangles on a grid with 11 horizontal points and 11 vertical points:

```
            X AXIS
            1   2   3   4   5   6   7   8   9   10   11
         1
         2  #-------+                                           <-Rectangle#1
Y AXIS   3  |       |
         4  +-------#
         5          #-----------------------+                   <-Rectangle#2
         6          |                       |
         7          |   #---+               |                   <-Rectangle#3
         8          |   |   |               |
         9          |   +---#               |
         10         +-----------------------#
         11                                     #               <-Rectangle#4
```

The rectangles are defined according to this scheme: {X-axis coordinate of top left, Y-axis coordinate of top left, X-axis coordinate of bottom right, Y-axis coordinate of bottom right} – or more succinctly: {x1,y1,x2,y2}. So in the picture … Rectangle#1 starts at position 1 on the X axis and position 2 on the Y axis, and ends at position 3 on the X axis and position 4 on the Y axis, so its coordinates are {1,2,3,4}. Rectangle#2's coordinates are {3,5,9,10}. Rectangle#3's coordinates are {4,7,5,9}. And finally Rectangle#4's coordinates are {10,11,10,11}. Rectangle#4 is actually a "point" since it has zero width and zero height, so it could have been described with only two digits: {10,11}.

Some relationships between the rectangles are: "Rectangle#1's nearest neighbor is Rectangle#2", and "Rectangle#3 is entirely inside Rectangle#2".

Now let us create a space and add an RTREE index.

```
tarantool> s = box.schema.space.create('rectangles')
tarantool> i = s:create_index('primary', {
         >   type = 'HASH',
         >   parts = {1, 'unsigned'}
         > })
tarantool> r = s:create_index('rtree', {
         >   type = 'RTREE',
         >   unique = false,
         >   parts = {2, 'ARRAY'}
         > })
```

Field#1 doesn't matter, we just make it because we need a primary-key index. (RTREE indexes cannot be unique and therefore cannot be primary-key indexes.) The second field must be an "array", which means its values must represent {x,y} points or {x1,y1,x2,y2} rectangles. Now let us populate the table by inserting two tuples, containing the coordinates of Rectangle#2 and Rectangle#4.

```
tarantool> s:insert{1, {3, 5, 9, 10}}
tarantool> s:insert{2, {10, 11}}
```

And now, following the description of RTREE iterator types, we can search the rectangles with these requests:

```
tarantool> r:select({10, 11, 10, 11}, {iterator = 'EQ'})
---
- - [2, [10, 11]]
...
tarantool> r:select({4, 7, 5, 9}, {iterator = 'GT'})
---
- - [1, [3, 5, 9, 10]]
...
tarantool> r:select({1, 2, 3, 4}, {iterator = 'NEIGHBOR'})
---
- - [1, [3, 5, 9, 10]]
  - [2, [10, 11]]
...
```

Request#1 returns 1 tuple because the point {10,11} is the same as the rectangle {10,11,10,11} ("Rectangle#4" in the picture). Request#2 returns 1 tuple because the rectangle {4,7,5,9}, which was "Rectangle#3" in the picture, is entirely within{3,5,9,10} which was Rectangle#2. Request#3 returns 2 tuples, because the NEIGHBOR iterator always returns all tuples, and the first returned tuple will be {3,5,9,10} ("Rectangle#2" in the picture) because it is the closest neighbor of {1,2,3,4} ("Rectangle#1" in the picture).

Now let us create a space and index for cuboids, which are rectangle-or-boxes that have 6 corners and 6 sides.

```
tarantool> s = box.schema.space.create('R')
tarantool> i = s:create_index('primary', {parts = {1, 'unsigned'}})
tarantool> r = s:create_index('S', {
         >   type = 'RTREE',
         >   unique = false,
         >   dimension = 3,
         >   parts = {2, 'ARRAY'}
         > })
```

The additional option here is dimension=3. The default dimension is 2, which is why it didn't need to be specified for the examples of rectangle. The maximum dimension is 20. Now for insertions and selections there will usually be 6 coordinates. For example:

```
tarantool> s:insert{1, {0, 3, 0, 3, 0, 3}}
tarantool> r:select({1, 2, 1, 2, 1, 2}, {iterator = box.index.GT})
```

Now let us create a space and index for Manhattan-style spatial objects, which are rectangle-or-boxes that have a different way to calculate neighbors.

```
tarantool> s = box.schema.space.create('R')
tarantool> i = s:create_index('primary', {parts = {1, 'unsigned'}})
tarantool> r = s:create_index('S', {
         >   type = 'RTREE',
         >   unique = false,
```

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```
        >   distance = 'manhattan',
        >   parts = {2, 'ARRAY'}
        > })
```

The additional option here is distance='manhattan'. The default distance calculator is 'euclid', which is the straightforward as-the-crow-flies method. The optional distance calculator is 'manhattan', which can be a more appropriate method if one is following the lines of a grid rather than traveling in a straight line.

```
tarantool> s:insert{1, {0, 3, 0, 3}}
tarantool> r:select({1, 2, 1, 2}, {iterator = box.index.NEIGHBOR})
```

More examples of spatial searching are online in the file R tree index quick start and usage.

Submodule box.info

The box.info submodule provides access to information about server instance variables.

- cluster.uuid is the UUID of the replica set. Every instance in a replica set will have the same cluster.uuid value. This value is also stored in box.space._schema system space.
- gc() returns the state of the Tarantool garbage collector including the checkpoints and their consumers (users); see details below.
- id corresponds to replication.id (see below).
- lsn corresponds to replication.lsn (see below).
- memory() returns the statistics about memory (see below).
- pid is the process ID. This value is also shown by tarantool module and by the Linux command ps -A.
- ro is true if the instance is in "read-only" mode (same as read_only in box.cfg{}), or if status is 'orphan'.
- signature is the sum of all lsn values from the vector clocks (vclock) of all instances in the replica set.
- sql().cache.size is the number of bytes in the SQL prepared statement cache.
- sql().cache.stmt_count is the number of statements in the SQL prepared statement cache.
- status is the current state of the instance. It can be:
  - running – the instance is loaded,
  - loading – the instance is either recovering xlogs/snapshots or bootstrapping,
  - orphan – the instance has not (yet) succeeded in joining the required number of masters (see orphan status),
  - hot_standby – the instance is standing by another instance.
- uptime is the number of seconds since the instance started. This value can also be retrieved with tarantool.uptime().
- uuid corresponds to replication.uuid (see below).
- vclock corresponds to replication.downstream.vclock (see below).
- version is the Tarantool version. This value is also shown by tarantool -V.
- vinyl() returns runtime statistics for the vinyl storage engine. This function is deprecated, use box.stat.vinyl() instead.

box.info.memory()

The memory function of box.info gives the admin user a picture of the whole Tarantool instance.

Note: To get a picture of the vinyl subsystem, use box.stat.vinyl() instead.

- memory().cache – number of bytes used for caching user data. The memtx storage engine does not require a cache, so in fact this is the number of bytes in the cache for the tuples stored for the vinyl storage engine.
- memory().data – number of bytes used for storing user data (the tuples) with the memtx engine and with level 0 of the vinyl engine, without taking memory fragmentation into account.
- memory().index – number of bytes used for indexing user data, including memtx and vinyl memory tree extents, the vinyl page index, and the vinyl bloom filters.
- memory().lua – number of bytes used for Lua runtime.
- memory().net – number of bytes used for network input/output buffers.
- memory().tx – number of bytes in use by active transactions. For the vinyl storage engine, this is the total size of all allocated objects (struct txv, struct vy_tx, struct vy_read_interval) and tuples pinned for those objects.

An example with a minimum allocation while only the memtx storage engine is in use:

```
tarantool> box.info.memory()
---
- cache: 0
  data: 6552
  tx: 0
  lua: 1315567
  net: 98304
  index: 1196032
...
```

box.info.gc()

The gc function of box.info gives the admin user a picture of the factors that affect the Tarantool garbage collector. The garbage collector compares vclock (vector clock) values of users and checkpoints, so a look at box.info.gc() may show why the garbage collector has not removed old WAL files, or show what it may soon remove.

- gc().consumers – a list of users whose requests might affect the garbage collector.
- gc().checkpoints – a list of preserved checkpoints.
- gc().checkpoints[n].references – a list of references to a checkpoint.
- gc().checkpoints[n].vclock – a checkpoint's vclock value.
- gc().checkpoints[n].signature – a sum of a checkpoint's vclock's components.
- gc().checkpoint_is_in_progress – true if a checkpoint is in progress, otherwise false
- gc().vclock – the garbage collector's vclock.
- gc().signature – the sum of the garbage collector's checkpoint's components.

box.info.replication

The replication section of box.info() is a table array with statistics for all instances in the replica set that the current instance belongs to (see also "Monitoring a replica set"):

In the following, n is the index number of one table item, for example replication[1], which has data about server instance number 1, which may or may not be the same as the current instance (the "current instance" is what is responding to box.info).

- replication[n].id is a short numeric identifier of instance n within the replica set. This value is stored in the box.space._cluster system space.
- replication[n].uuid is a globally unique identifier of instance n. This value is stored in the box.space._cluster system space.
- replication[n].lsn is the log sequence number (LSN) for the latest entry in instance n's write ahead log (WAL).
- replication[n].upstream appears (is not nil) if the current instance is following or intending to follow instance n, which ordinarily means replication[n].upstream.status = follow, replication[n].upstream.peer = url of instance n which is being followed, replication[n].lag and idle = the instance's speed, described later. Another way to say this is: replication[n].upstream will appear when replication[n].upstream.peer is not of the current instance, and is not read-only, and was specified in box.cfg{replication={...}}, so it is shown in box.cfg.replication.
- replication[n].upstream.status is the replication status of the connection with instance n:
  - auth means that authentication is happening.
  - connecting means that connection is happening.
  - disconnected means that it is not connected to the replica set (due to network problems, not replication errors).
  - follow means that the current instance's role is "replica" (read-only, or not read-only but acting as a replica for this remote peer in a master-master configuration), and is receiving or able to receive data from instance n's (upstream) master.
  - stopped means that replication was stopped due to a replication error (for example duplicate key).
  - sync means that the master and replica are synchronizing to have the same data.
- replication[n].upstream.idle is the time (in seconds) since the last event was received. This is the primary indicator of replication health. See more in Monitoring a replica set.
- replication[n].upstream.peer contains instance n's URI for example 127.0.0.1:3302. See more in Monitoring a replica set.
- replication[n].upstream.lag is the time difference between the local time of instance n, recorded when the event was received, and the local time at another master recorded when the event was written to the write ahead log on that master. See more in Monitoring a replica set.
- replication[n].upstream.message contains an error message in case of a degraded state, otherwise it is nil.
- replication[n].downstream appears (is not nil) with data about an instance that is following instance n or is intending to follow it, which ordinarily means replication[n].downstream.status = follow,
- replication[n].downstream.vclock contains the vector clock, which is a table of 'id, lsn' pairs, for example vclock: {1: 3054773, 4: 8938827, 3: 285902018}. (Notice that the table may have multiple pairs although vclock is a singular name).

Even if instance n is removed, its values will still appear here; however, its values will be overridden if an instance joins later with the same UUID. Vector clock pairs will only appear if lsn > 0.

replication[n].downstream.vclock may be the same as the current instance's vclock (box.info.vclock) because this is for all known vclock values of the cluster. A master will know what is in a replica's copy of vclock because, when the master makes a data change, it sends the change information to the replica (including the master's vector clock), and the replica replies with what is in its entire vector clock table.

Also the replica sends its entire vector clock table in response to a master's heartbeat message, see the heartbeat-message examples in section Binary protocol – replication.

- replication[n].downstream.idle is the time (in seconds) since the last time that instance n sent events through the downstream replication.
- replication[n].downstream.status is the replication status for downstream replications:
  - stopped means that downstream replication has stopped,
  - follow means that downstream replication is in progress (instance n is ready to accept data from the master or is currently doing so).
- replication[n].downstream.message and replication[n].downstream.system_message will be nil unless a problem occurs with the connection. For example, if instance n goes down, then one may see status = `'stopped'`, message = `'unexpected EOF when reading from socket'`, and system_message = `'Broken pipe'`. See also degraded state.

box.info()

Since box.info contents are dynamic, it's not possible to iterate over keys with the Lua pairs() function. For this purpose, box.info() builds and returns a Lua table with all keys and values provided in the submodule.

Return keys and values in the submodule

Rtype table

Example:

This example is for a master-replica set that contains one master instance and one replica instance. The request was issued at the replica instance.

```
tarantool> box.info()
---
- vinyl: []
  version: 2.2.0-482-g8c84932ad
  id: 2
  ro: true
  status: running
  vclock: {1: 9}
  uptime: 356
  lsn: 0
  memory: []
  cluster:
    uuid: e261a5bc-6303-4de3-9873-556f311255e0
  pid: 160
  gc: []
  signature: 9
  replication:
    1:
      id: 1
```

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```
      uuid: fce71bb3-0e99-40ec-ab7e-5159487e18d1
      lsn: 9
      upstream:
        status: follow
        idle: 0.035709699994186
        peer: replicator@127.0.0.1:3401
        lag: 0.00016164779663086
      downstream:
        status: follow
        idle: 0.59840899999836
        vclock: {1: 9}
    2:
      id: 2
      uuid: bc4629ce-ea31-4f75-b805-a4807bcacc93
      lsn: 0
  uuid: bc4629ce-ea31-4f75-b805-a4807bcacc93
...
```

Function box.once

box.once(key, function[, ...])

Execute a function, provided it has not been executed before. A passed value is checked to see whether the function has already been executed. If it has been executed before, nothing happens. If it has not been executed before, the function is invoked.

See an example of using box.once() while bootstrapping a replica set.

Warning: If an error occurs inside box.once() when initializing a database, you can re-execute the failed box.once() block without stopping the database. The solution is to delete the once object from the system space _schema. Say box.space._schema:select{}, find your once object there and delete it. For example, re-executing a block with key='hello' :

When box.once() is used for initialization, it may be useful to wait until the database is in an appropriate state (read-only or read-write). In that case, see the functions in the box.ctl submodule.

```
tarantool> box.space._schema:select{}
---
- - ['cluster', 'b4e15788-d962-4442-892e-d6c1dd5d13f2']
  - ['max_id', 512]
  - ['oncebye']
  - ['oncehello']
  - ['version', 1, 7, 2]
...

tarantool> box.space._schema:delete('oncehello')
---
- ['oncehello']
...

tarantool> box.once('hello', function() end)
---
...
```

Parameters

- key (string) – a value that will be checked

- function (function) – a function
- ... – arguments that must be passed to function

Note: The parameter key will be stored in the _schema system space after box.once() is called in order to prevent a double run. These keys are global per replica set. So a simultaneous call of box.once() with the same key on two instances of the same replica set may succeed on both of them, but it'll lead to a transaction conflict.

Constant box.NULL

There are some major problems with using Lua nil values in tables. For example: you can't correctly assess the length of a table that is not a sequence.

Example:

```
tarantool> t = {0, nil, 1, 2, nil}
---
...

tarantool> t
---
- - 0
  - null
  - 1
  - 2
...

tarantool> #t
---
- 4
...
```

The console output of t processes nil values in the middle and at the end of the table differently. This is due to undefined behavior.

Note: Trying to find the length for sparse arrays in LuaJIT leads to another scenario of undefined behavior.

To avoid this problem, use Tarantool's box.NULL constant instead of nil. box.NULL is a placeholder for a nil value in tables to preserve a key without a value.

Using box.NULL

box.NULL is a value of the cdata type representing a NULL pointer. It is similar to msgpack.NULL, json.NULL and yaml.NULL. So it is some not nil value, even if it is a pointer to NULL.

Use box.NULL only with capitalized NULL (box.null is incorrect).

Note: Technically speaking, box.NULL equals to ffi.cast('void *', 0).

Example:

```
tarantool> t = {0, box.NULL, 1, 2, box.NULL}
---
...

tarantool> t
---
- - 0
  - null # cdata
  - 1
  - 2
  - null # cdata
...

tarantool> #t
---
- 5
...
```

Note: Notice that t[2] shows the same null output in both examples. However in this example t[2] and t[5] are of the cdata type, while in the previous example their type was nil.

Important: Avoid using implicit comparisons with nullable values when using box.NULL. Due to Lua behavior, returning anything except false or nil from a condition expression is considered as true. And, as it was mentioned earlier, box.NULL is a pointer by design.

That is why the expression box.NULL will always be considered true in case it is used as a condition in a comparison. This means that the code

if box.NULL then func() end

will always execute the function func() (because the condition box.NULL will always be neither false nor nil).

Distinction of nil and box.NULL

Use the expression if x == nil to check if the x is either a nil or a box.NULL.

To check whether x is a nil but not a box.NULL, use the following condition expression:

```
type(x) == 'nil'
```

If it's true, then x is a nil, but not a box.NULL.

You can use the following for box.NULL:

```
x == nil and type(x) == 'cdata'
```

If the expression above is true, then x is a box.NULL.

Note: By converting data to different formats (JSON, YAML, msgpack), you shall expect that it is possible that nil in sparse arrays will be converted to box.NULL. And it is worth mentioning that such conversion might be unexpected (for example: by sending data via net.box or by obtaining data from spaces etc.).

```
tarantool> type(({1, nil, 2})[2])
---
- nil
...

tarantool> type(json.decode(json.encode({1, nil, 2}))[2])
---
- cdata
...
```

You must anticipate such behavior and use a proper condition expression. Use the explicit comparison x == nil for checking for NULL in nullable values. It will detect both nil and box.NULL.

Submodule box.schema

Overview

The box.schema submodule has data-definition functions for spaces, users, roles, function tuples, and sequences.

Index

Below is a list of all box.schema functions.

Name	Use
box.schema.space.create() or box.schema.create_space()	Create a space
box.schema.upgrade	Upgrade a database
box.schema.user.create()	Create a user
box.schema.user.drop()	Drop a user
box.schema.user.exists()	Check if a user exists
box.schema.user.grant()	Grant privileges to a user or a role
box.schema.user.revoke()	Revoke privileges from a user or a role
box.schema.user.password()	Get a hash of a user's password
box.schema.user.passwd()	Associate a password with a user
box.schema.user.info()	Get a description of a user's privileges
box.schema.role.create()	Create a role
box.schema.role.drop()	Drop a role
box.schema.role.exists()	Check if a role exists
box.schema.role.grant()	Grant privileges to a role
box.schema.role.revoke()	Revoke privileges from a role
box.schema.role.info()	Get a description of a role's privileges
box.schema.func.create()	Create a function tuple
box.schema.func.drop()	Drop a function tuple
box.schema.func.exists()	Check if a function tuple exists
box.schema.sequence.create()	Create a new sequence generator
sequence_object:next()	Generate and return the next value
sequence_object:alter()	Change sequence options
sequence_object:reset()	Reset sequence state
sequence_object:set()	Set the new value
sequence_object:drop()	Drop the sequence
space_object:create_index()	Create an index

box.schema.space.create(space-name[, {options}])

box.schema.create_space(space-name[, {options}])

Create a space.

Parameters

- space-name (string) – name of space, which should conform to the rules for object names
- options (table) – see "Options for box.schema.space.create" chart, below

Return space object

Rtype userdata

You can use either syntax. For example, s = box.schema.space.create('tester') has the same effect as s = box.schema.create_space('tester').

Options for box.schema.space.create

Name	Effect	Type	Default
engine	'memtx' or 'vinyl'	string	'memtx'
field_count	fixed count of fields: for example if field_count=5, it is illegal to insert a tuple with fewer than or more than 5 fields	number	0 i.e. not fixed
format	field names and types: See the illustrations of format clauses in the space_object:format() description and in the box.space._space example. Optional and usually not specified.	table	(blank)
id	unique identifier: users can refer to spaces with the id instead of the name	number	last space's id, +1
if_not_exists	create space only if a space with the same name does not exist already, otherwise do nothing but do not cause an error	boolean	false
is_local	space contents are replication-local: changes are stored in the write-ahead log of the local node but there is no replication.	boolean	false
temporary	space contents are temporary: changes are not stored in the write-ahead log and there is no replication. Note re storage engine: vinyl does not support temporary spaces.	boolean	false
user	name of the user who is considered to be the space's owner for authorization purposes	string	current user's name

There are three syntax variations for object references targeting space objects, for example box.schema.space.drop(space-id) will drop a space. However, the common approach is to use functions attached to the space objects, for example space_object:drop().

Example

```
tarantool> s = box.schema.space.create('space55')
---
...
tarantool> s = box.schema.space.create('space55', {
         >   id = 555,
         >   temporary = false
         > })
---
- error: Space 'space55' already exists
...
tarantool> s = box.schema.space.create('space55', {
         >   if_not_exists = true
         > })
---
...
```

After a space is created, usually the next step is to create an index for it, and then it is available for insert, select, and all the other box.space functions.

box.schema.user.create(user-name[, {options}])

Create a user. For explanation of how Tarantool maintains user data, see section Users and reference on _user space.

The possible options are:

- if_not_exists = true|false (default = false) - boolean; true means there should be no error if the user already exists,
- password (default = '') - string; the password = password specification is good because in a URI (Uniform Resource Identifier) it is usually illegal to include a user-name without a password.

Note: The maximum number of users is 32.

Parameters

- user-name (string) – name of user, which should conform to the rules for object names
- options (table) – if_not_exists, password

Return nil

Examples:

```
box.schema.user.create('Lena')
box.schema.user.create('Lena', {password = 'X'})
box.schema.user.create('Lena', {if_not_exists = false})
```

box.schema.user.drop(user-name[, {options}])

Drop a user. For explanation of how Tarantool maintains user data, see section Users and reference on _user space.

Parameters

- user-name (string) – the name of the user
- options (table) – if_exists = true|false (default = false) - boolean; true means there should be no error if the user does not exist.

Examples:

```
box.schema.user.drop('Lena')
box.schema.user.drop('Lena',{if_exists=false})
```

box.schema.user.exists(user-name)

Return true if a user exists; return false if a user does not exist. For explanation of how Tarantool maintains user data, see section Users and reference on _user space.

Parameters

- user-name (string) – the name of the user

Rtype bool

Example:

```
box.schema.user.exists('Lena')
```

box.schema.user.grant(user-name, privileges, object-type, object-name[, {options}])

box.schema.user.grant(user-name, privileges, 'universe'[, nil, {options}])
box.schema.user.grant(user-name, role-name[, nil, nil, {options}])

Grant privileges to a user or to another role.

Parameters

- user-name (string) – the name of the user.
- privileges (string) – 'read' or 'write' or 'execute' or 'create' or 'alter' or 'drop' or a combination.
- object-type (string) – 'space' or 'function' or 'sequence' or 'role'.
- object-name (string) – name of object to grant permissions for.
- role-name (string) – name of role to grant to user.
- options (table) – grantor, if_not_exists.

If `'function','object-name'` is specified, then a _func tuple with that object-name must exist.

Variation: instead of object-type, object-name say 'universe' which means 'all object-types and all objects'. In this case, object name is omitted.

Variation: instead of privilege, object-type, object-name say role-name (see section Roles).

Variation: instead of box.schema.user.grant('user-name','usage,session','universe',nil, {if_not_exists=true}) say box.schema.user.enable('user-name').

The possible options are:

- grantor = grantor_name_or_id – string or number, for custom grantor,
- if_not_exists = true|false (default = false) - boolean; true means there should be no error if the user already has the privilege.

Example:

```
box.schema.user.grant('Lena', 'read', 'space', 'tester')
box.schema.user.grant('Lena', 'execute', 'function', 'f')
box.schema.user.grant('Lena', 'read,write', 'universe')
box.schema.user.grant('Lena', 'Accountant')
box.schema.user.grant('Lena', 'read,write,execute', 'universe')
box.schema.user.grant('X', 'read', 'universe', nil, {if_not_exists=true}))
```

box.schema.user.revoke(user-name, privileges, object-type, object-name[, {options}])
box.schema.user.revoke(user-name, privileges, 'universe'[, nil, {options}])

Revoke privileges from a user or from another role.

Parameters

- user-name (string) – the name of the user.
- privilege (string) – 'read' or 'write' or 'execute' or 'create' or 'alter' or 'drop' or a combination.
- object-type (string) – 'space' or 'function' or 'sequence'.
- object-name (string) – the name of a function or space or sequence.
- options (table) – if_exists.

The user must exist, and the object must exist, but if the option setting is {if_exists=true} then it is not an error if the user does not have the privilege.

Variation: instead of object-type, object-name say 'universe' which means 'all object-types and all objects'.

Variation: instead of privilege, object-type, object-name say role-name (see section Roles).

Variation: instead of box.schema.user.revoke('user-name','usage,session','universe',nil, {if_exists=true}) say box.schema.user.disable('user-name').

Example:

```
box.schema.user.revoke('Lena', 'read', 'space', 'tester')
box.schema.user.revoke('Lena', 'execute', 'function', 'f')
box.schema.user.revoke('Lena', 'read,write', 'universe')
box.schema.user.revoke('Lena', 'Accountant')
```

box.schema.user.password(password)

Return a hash of a user's password. For explanation of how Tarantool maintains passwords, see section Passwords and reference on _user space.

Note:

- If a non-'guest' user has no password, it's impossible to connect to Tarantool using this user. The user is regarded as "internal" only, not usable from a remote connection. Such users can be useful if they have defined some procedures with the SETUID option, on which privileges are granted to externally-connectable users. This way, external users cannot create/drop objects, they can only invoke procedures.
- For the 'guest' user, it's impossible to set a password: that would be misleading, since 'guest' is the default user on a newly-established connection over a binary port, and Tarantool does not require a password to establish a binary connection. It is, however, possible to change the current user to 'guest' by providing the AUTH packet with no password at all or an empty password. This feature is useful for connection pools, which want to reuse a connection for a different user without re-establishing it.

Parameters

- password (string) – password to be hashed

Rtype string

Example:

```
box.schema.user.password('ЛЕНА')
```

box.schema.user.passwd([user-name], password)

Associate a password with the user who is currently logged in, or with the user specified by user-name. The user must exist and must not be 'guest'.

Users who wish to change their own passwords should use box.schema.user.passwd(password) syntax.

Administrators who wish to change passwords of other users should use box.schema.user.passwd(user-name, password) syntax.

Parameters

- user-name (string) – user-name
- password (string) – password

Example:

```
box.schema.user.passwd('ЛЕНА')
box.schema.user.passwd('Lena', 'ЛЕНА')
```

box.schema.user.info([user-name])
Return a description of a user's privileges.

box.schema.role.create(role-name[, {options}])
Create a role. For explanation of how Tarantool maintains role data, see section Roles.

Parameters

- role-name (string) – name of role, which should conform to the rules for object names
- options (table) – if_not_exists = true|false (default = false) - boolean; true means there should be no error if the role already exists

Return nil

Example:

```
box.schema.role.create('Accountant')
box.schema.role.create('Accountant', {if_not_exists = false})
```

box.schema.role.drop(role-name[, {options}])
Drop a role. For explanation of how Tarantool maintains role data, see section Roles.

Parameters

- role-name (string) – the name of the role
- options (table) – if_exists = true|false (default = false) - boolean; true means there should be no error if the role does not exist.

Example:

```
box.schema.role.drop('Accountant')
```

box.schema.role.exists(role-name)
Return true if a role exists; return false if a role does not exist.

Parameters

- role-name (string) – the name of the role

Rtype bool

Example:

```
box.schema.role.exists('Accountant')
```

box.schema.role.grant(role-name, privilege, object-type, object-name[, option])
box.schema.role.grant(role-name, privilege, 'universe'[, nil, option])
box.schema.role.grant(role-name, role-name[, nil, nil, option])
Grant privileges to a role.

Parameters

- role-name (string) – the name of the role.
- privilege (string) – 'read' or 'write' or 'execute' or 'create' or 'alter' or 'drop' or a combination.
- object-type (string) – 'space' or 'function' or 'sequence' or 'role'.

- object-name (string) – the name of a function or space or sequence or role.
- option (table) – if_not_exists = true|false (default = false) - boolean; true means there should be no error if the role already has the privilege.

The role must exist, and the object must exist.

Variation: instead of object-type, object-name say 'universe' which means 'all object-types and all objects'. In this case, object name is omitted.

Variation: instead of privilege, object-type, object-name say role-name – to grant a role to a role.

Example:

```
box.schema.role.grant('Accountant', 'read', 'space', 'tester')
box.schema.role.grant('Accountant', 'execute', 'function', 'f')
box.schema.role.grant('Accountant', 'read,write', 'universe')
box.schema.role.grant('public', 'Accountant')
box.schema.role.grant('role1', 'role2', nil, nil, {if_not_exists=false})
```

box.schema.role.revoke(role-name, privilege, object-type, object-name)
Revoke privileges from a role.

Parameters

- role-name (string) – the name of the role.
- privilege (string) – 'read' or 'write' or 'execute' or 'create' or 'alter' or 'drop' or a combination.
- object-type (string) – 'space' or 'function' or 'sequence' or 'role'.
- object-name (string) – the name of a function or space or sequence or role.

The role must exist, and the object must exist, but it is not an error if the role does not have the privilege.

Variation: instead of object-type, object-name say 'universe' which means 'all object-types and all objects'.

Variation: instead of privilege, object-type, object-name say role-name.

Example:

```
box.schema.role.revoke('Accountant', 'read', 'space', 'tester')
box.schema.role.revoke('Accountant', 'execute', 'function', 'f')
box.schema.role.revoke('Accountant', 'read,write', 'universe')
box.schema.role.revoke('public', 'Accountant')
```

box.schema.role.info(role-name)
Return a description of a role's privileges.

Parameters

- role-name (string) – the name of the role.

Example:

```
box.schema.role.info('Accountant')
```

box.schema.func.create(func-name[, {options-without-body}])
Create a function tuple. without including the body option. (For functions created with the body option, see box.schema.func.create(func-name [, {options-with-body}]).

This is called a "not persistent" function because functions without bodies are not persistent. This does not create the function itself – that is done with Lua – but if it is necessary to grant privileges for a function, box.schema.func.create must be done first. For explanation of how Tarantool maintains function data, see the reference for the box.space._func space.

The possible options are:

- if_not_exists = true|false (default = false) - boolean; true means there should be no error if the _func tuple already exists.
- setuid = true|false (default = false) - boolean; true means that Tarantool should treat the function's caller as the function's owner, with owner privileges. setuid works only over binary ports, setuid does not work if the function is invoked via an admin console or inside a Lua script.
- language = 'LUA'|'C' (default = 'LUA') - string.

Parameters

- func-name (string) – name of function, which should conform to the rules for object names
- options (table) – if_not_exists, setuid, language.

Return nil

These functions can be called with function-object:call(arguments); however, unlike the case with ordinary functions, array arguments will not be correctly recognized unless they are enclosed in braces.

Example:

```
box.schema.func.create('calculate')
box.schema.func.create('calculate', {if_not_exists = false})
box.schema.func.create('calculate', {setuid = false})
box.schema.func.create('calculate', {language = 'LUA'})
```

box.schema.func.create(func-name[, {options-with-body}])

Create a function tuple. including the body option. (For functions created without the body option, see box.schema.func.create(func-name [, {options-without-body}]).

This is called a "persistent" function because only functions with bodies are persistent. This does create the function itself, the body is a function definition. For explanation of how Tarantool maintains function data, see the reference for the box.space._func space.

The possible options are:

- if_not_exists = true|false (default = false) - boolean; same as for box.schema.func.create(func-name [, {options-without-body}]).
- setuid = true|false (default = false) - boolean; same as for box.schema.func.create(func-name [, {options-without-body}]).
- language = 'LUA'|'C' (default = 'LUA') - string. same as for box.schema.func.create(func-name [, {options-without-body}]).
- is_sandboxed = true|false (default = false) - boolean; whether the function should be executed in a sandbox.
- is_deterministic = true|false (default = false) - boolean; true means that the function should be deterministic, false means that the function may or may not be deterministic.
- body = function definition (default = nil) - string; the function definition.
- Additional options for SQL = See Calling Lua routines from SQL.

Parameters

- func-name (string) – name of function, which should conform to the rules for object names
- options (table) – if_not_exists, setuid, language, is_sandboxed, is_deterministic, body.

Return nil

C functions are imported from .so files, Lua functions can be defined within body. We will only describe Lua functions in this section.

A function tuple with a body is "persistent" because the tuple is stored in a snapshot and is recoverable if the server restarts. All of the option values described in this section are visible in the box.space._func system space.

If is_sandboxed is true, then the function will be executed in an isolated environment: any operation that accesses the world outside the sandbox will be forbidden or will have no effect. Therefore a sandboxed function can only use modules and functions which cannot affect isolation: assert, error, ipairs, math.*, next, pairs, pcall, print, select, string.*, table.*, tonumber, tostring, type, unpack, utf8.*, xpcall. Also a sandboxed function cannot refer to global variables – they will be treated as local variables because the sandbox is established with setfenv. So a sandboxed function will happen to be stateless and deterministic.

If is_deterministic is true, there is no immediate effect. Tarantool plans to use the is_deterministic value in a future version. A function is deterministic if it always returns the same outputs given the same inputs. It is the function creator's responsibility to ensure that a function is truly deterministic.

Using a persistent Lua function

After a persistent Lua function is created, it can be found in the box.space._func system space, and it can be shown with box.func.func-name and it can be invoked by any user with authorization to 'execute' it. The syntax for invoking is: box.func.func-name:call([parameters]) or, if the connection is remote, the syntax is as in net_box:call().

Example:

```
tarantool> lua_code = [[function(a, b) return a + b end]]
tarantool> box.schema.func.create('sum', {body = lua_code})

tarantool> box.func.sum
---
- is_sandboxed: false
  is_deterministic: false
  id: 2
  setuid: false
  body: function(a, b) return a + b end
  name: sum
  language: LUA
...

tarantool> box.func.sum:call({1, 2})
---
- 3
...
```

box.schema.func.drop(func-name[, {options}])
Drop a function tuple. For explanation of how Tarantool maintains function data, see reference on _func space.

Parameters

- func-name (string) – the name of the function
- options (table) – if_exists = true|false (default = false) - boolean; true means there should be no error if the _func tuple does not exist.

Example:

```
box.schema.func.drop('calculate')
```

box.schema.func.exists(func-name)

Return true if a function tuple exists; return false if a function tuple does not exist.

Parameters

- func-name (string) – the name of the function

Rtype bool

Example:

```
box.schema.func.exists('calculate')
```

box.schema.func.reload([name])

Reload a C module with all its functions without restarting the server.

Under the hood, Tarantool loads a new copy of the module (*.so shared library) and starts routing all new request to the new version. The previous version remains active until all started calls are finished. All shared libraries are loaded with RTLD_LOCAL (see “man 3 dlopen”), therefore multiple copies can co-exist without any problems.

Note: Reload will fail if a module was loaded from Lua script with ffi.load().

Parameters

- name (string) – the name of the module to reload

Example:

```
-- reload the entire module contents
box.schema.func.reload('module')
```

Sequences

An introduction to sequences is in the Sequences section of the “Data model” chapter. Here are the details for each function and option.

All functions related to sequences require appropriate privileges.

box.schema.sequence.create(name[, options])

Create a new sequence generator.

Parameters

- name (string) – the name of the sequence

- options (table) – see a quick overview in the "Options for box.schema.sequence.create()" chart (in the Sequences section of the "Data model" chapter), and see more details below.

Return a reference to a new sequence object.

Options:

- start – the STARTS WITH value. Type = integer, Default = 1.
- min – the MINIMUM value. Type = integer, Default = 1.
- max - the MAXIMUM value. Type = integer, Default = 9223372036854775807.

  There is a rule: min <= start <= max. For example it is illegal to say {start=0} because then the specified start value (0) would be less than the default min value (1).

  There is a rule: min <= next-value <= max. For example, if the next generated value would be 1000, but the maximum value is 999, then that would be considered "overflow".

  There is a rule: start and min and max must all be <= 9223372036854775807 which is 2^63 - 1 (not 2^64).
- cycle – the CYCLE value. Type = bool. Default = false.

  If the sequence generator's next value is an overflow number, it causes an error return – unless cycle == true.

  But if cycle == true, the count is started again, at the MINIMUM value or at the MAXIMUM value (not the STARTS WITH value).
- cache – the CACHE value. Type = unsigned integer. Default = 0.

  Currently Tarantool ignores this value, it is reserved for future use.
- step – the INCREMENT BY value. Type = integer. Default = 1.

  Ordinarily this is what is added to the previous value.

sequence_object:next()
Generate the next value and return it.

The generation algorithm is simple:

- If this is the first time, then return the STARTS WITH value.
- If the previous value plus the INCREMENT value is less than the MINIMUM value or greater than the MAXIMUM value, that is "overflow", so either raise an error (if cycle = false) or return the MAXIMUM value (if cycle = true and step < 0) or return the MINIMUM value (if cycle = true and step > 0).

If there was no error, then save the returned result, it is now the "previous value".

For example, suppose sequence 'S' has:

- min == -6,
- max == -1,
- step == -3,
- start = -2,
- cycle = true,
- previous value = -2.

Then box.sequence.S:next() returns -5 because -2 + (-3) == -5.

Then box.sequence.S:next() again returns -1 because -5 + (-3) < -6, which is overflow, causing cycle, and max == -1.

This function requires a 'write' privilege on the sequence.

Note: This function should not be used in "cross-engine" transactions (transactions which use both the memtx and the vinyl storage engines).

To see what the previous value was, without changing it, you can select from the _sequence_data system space.

---

sequence_object:alter(options)
The alter() function can be used to change any of the sequence's options. Requirements and restrictions are the same as for box.schema.sequence.create().

sequence_object:reset()
Set the sequence back to its original state. The effect is that a subsequent next() will return the start value. This function requires a 'write' privilege on the sequence.

sequence_object:set(new-previous-value)
Set the "previous value" to new-previous-value. This function requires a 'write' privilege on the sequence.

sequence_object:drop()
Drop an existing sequence.

Example:

Here is an example showing all sequence options and operations:

```
s = box.schema.sequence.create(
               'S2',
               {start=100,
               min=100,
               max=tonumber64('9223372036854775807'),
               cache=100000,
               cycle=false,
               step=100
               })
s:alter({step=6})
s:next()
s:reset()
s:set(150)
s:drop()
```

space_object:create_index(... [sequence='...' option] ...)
You can use the sequence option when creating or altering a primary-key index. The sequence becomes associated with the index, so that the next insert() will put the next generated number into the primary-key field, if the field value would otherwise be nil.

The syntax may be any of: sequence = sequence identifier or sequence = {id = sequence identifier } or sequence = {field = field number } or sequence = {id = sequence identifier , field = field number } or sequence = true or sequence = {}. The sequence identifier may be either a number (the sequence id) or a string (the sequence name). The field number may be the ordinal number of any field in the index; default = 1. Examples of all possibilities: sequence = 1 or sequence = 'sequence_name' or sequence = {id = 1} or sequence = {id = 'sequence_name'} or sequence = {id = 1, field = 1} or sequence = {id = 'sequence_name', field = 1} or sequence = {field = 1} or sequence = true or sequence =

{}. Notice that the sequence identifier can be omitted, if it is omitted then a new sequence is created automatically with default name = space-name_seq. Notice that the field number does not have to be 1, that is, the sequence can be associated with any field in the primary-key index.

For example, if 'Q' is a sequence and 'T' is a new space, then this will work:

```
tarantool> box.space.T:create_index('Q',{sequence='Q'})
---
- unique: true
  parts:
  - type: unsigned
    is_nullable: false
    fieldno: 1
  sequence_id: 8
  id: 0
  space_id: 514
  name: Q
  type: TREE
...
```

(Notice that the index now has a sequence_id field.)

And this will work:

```
tarantool> box.space.T:insert{box.NULL,0}
---
- [1, 0]
...
```

Note: The index key type may be either 'integer' or 'unsigned'. If any of the sequence options is a negative number, then the index key type should be 'integer'.

Users should not insert a value greater than 9223372036854775807, which is 2^63 - 1, in the indexed field. The sequence generator will ignore it.

A sequence cannot be dropped if it is associated with an index. However, index_object:alter() can be used to say that a sequence is not associated with an index, for example box.space.T.index.I:alter({sequence=false}).

If a sequence was created automatically because the sequence identifier was omitted, then it will be dropped automatically if the index is altered so that sequence=false, or if the index is dropped.

index_object:alter() can also be used to associate a sequence with an existing index, with the same syntax for options.

When a sequence is used with an index based on a JSON path, inserted tuples must have all components of the path preceding the autoincrement field, and the autoincrement field. To achieve that use box.NULL rather than nil. Example:

```
s = box.schema.space.create('test')
s:create_index('pk', {parts = {{'[1].a.b[1]', 'unsigned'}}, sequence = true})
s:replace{} -- error
s:replace{{c = {}}} -- error
s:replace{{a = {c = {}}}} -- error
s:replace{{a = {b = {}}}} -- error
s:replace{{a = {b = {nil}}}} -- error
s:replace{{a = {b = {box.NULL}}}} -- ok
```

Submodule box.session

Overview

The box.session submodule allows querying the session state, writing to a session-specific temporary Lua table, or sending out-of-band messages, or setting up triggers which will fire when a session starts or ends.

A session is an object associated with each client connection.

Index

Below is a list of all box.session functions and members.

Name	Use
box.session.id()	Get the current session's ID
box.session.exists()	Check if a session exists
box.session.peer()	Get the session peer's host address and port
box.session.sync()	Get the sync integer constant
box.session.user()	Get the current user's name
box.session.type()	Get the connection type or cause of action
box.session.su()	Change the current user
box.session.uid()	Get the current user's ID
box.session.euid()	Get the current effective user's ID
box.session.storage	Table with session-specific names and values
box.session.on_connect()	Define a connect trigger
box.session.on_disconnect()	Define a disconnect trigger
box.session.on_auth()	Define an authentication trigger
box.session.push()	Send an out-of-band message

box.session.id()

Return the unique identifier (ID) for the current session. The result can be 0 or -1 meaning there is no session.

Rtype number

box.session.exists(id)

Return true if the session exists, false if the session does not exist.

Rtype boolean

box.session.peer(id)

This function works only if there is a peer, that is, if a connection has been made to a separate Tarantool instance.

Return The host address and port of the session peer, for example "127.0.0.1:55457". If the session exists but there is no connection to a separate instance, the return is null. The command is executed on the server instance, so the "local name" is the server instance's host and port, and the "peer name" is the client's host and port.

Rtype string

Possible errors: 'session.peer(): session does not exist'

box.session.sync()

Return the value of the sync integer constant used in the binary protocol. This value becomes invalid when the session is disconnected.

Rtype number

This function is local for the request, i.e. not global for the session. If the connection behind the session is multiplexed, this function can be safely used inside the request processor.

box.session.user()

Return the name of the current user

Rtype string

box.session.type()

Return the type of connection or cause of action.

Rtype string

Possible return values are:

- 'binary' if the connection was done via the binary protocol, for example to a target made with box.cfg{listen=...};
- 'console' if the connection was done via the administrative console, for example to a target made with console.listen;
- 'repl' if the connection was done directly, for example when using Tarantool as a client;
- 'applier' if the action is due to replication, regardless of how the connection was done;
- 'background' if the action is in a background fiber, regardless of whether the Tarantool server was started in the background.

box.session.type() is useful for an on_replace() trigger on a replica – the value will be 'applier' if and only if the trigger was activated because of a request that was done on the master.

box.session.su(user-name[, function-to-execute])

Change Tarantool's current user – this is analogous to the Unix command su.

Or, if function-to-execute is specified, change Tarantool's current user temporarily while executing the function – this is analogous to the Unix command sudo.

Parameters

- user-name (string) – name of a target user
- function-to-execute – name of a function, or definition of a function. Additional parameters may be passed to box.session.su, they will be interpreted as parameters of function-to-execute.

Example

```
tarantool> function f(a) return box.session.user() .. a end
---
...

tarantool> box.session.su('guest', f, '-xxx')
---
- guest-xxx
...

tarantool> box.session.su('guest',function(...) return ... end,1,2)
```

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```
---
- 1
- 2
...
```

box.session.uid()

Return the user ID of the current user.

Rtype number

Every user has a unique name (seen with box.session.user()) and a unique ID (seen with box.session.uid()). The values are stored together in the _user space.

box.session.euid()

Return the effective user ID of the current user.

This is the same as box.session.uid(), except in two cases:

- The first case: if the call to box.session.euid() is within a function invoked by box.session.su(user-name, function-to-execute) – in that case, box.session.euid() returns the ID of the changed user (the user who is specified by the user-name parameter of the su function) but box.session.uid() returns the ID of the original user (the user who is calling the su function).
- The second case: if the call to box.session.euid() is within a function specified with box.schema.func.create(function-name, {setuid= true}) and the binary protocol is in use – in that case, box.session.euid() returns the ID of the user who created "function-name" but box.session.uid() returns the ID of the the user who is calling "function-name".

Rtype number

Example

```
tarantool> box.session.su('admin')
---
...
tarantool> box.session.uid(), box.session.euid()
---
- 1
- 1
...
tarantool> function f() return {box.session.uid(),box.session.euid()} end
---
...
tarantool> box.session.su('guest', f)
---
- - 1
  - 0
...
```

box.session.storage

A Lua table that can hold arbitrary unordered session-specific names and values, which will last until the session ends. For example, this table could be useful to store current tasks when working with a Tarantool queue manager.

Example

```
tarantool> box.session.peer(box.session.id())
---
- 127.0.0.1:45129
...
tarantool> box.session.storage.random_memorandum = "Don't forget the eggs"
---
...
tarantool> box.session.storage.radius_of_mars = 3396
---
...
tarantool> m = ''
---
...
tarantool> for k, v in pairs(box.session.storage) do
         >   m = m .. k .. '='.. v .. ' '
         > end
---
...
tarantool> m
---
- 'radius_of_mars=3396 random_memorandum=Don't forget the eggs. '
...
```

box.session.on_connect([trigger-function[, old-trigger-function]])

Define a trigger for execution when a new session is created due to an event such as console.connect. The trigger function will be the first thing executed after a new session is created. If the trigger execution fails and raises an error, the error is sent to the client and the connection is closed.

Parameters

- trigger-function (function) – function which will become the trigger function
- old-trigger-function (function) – existing trigger function which will be replaced by trigger-function

Return nil or function pointer

If the parameters are (nil, old-trigger-function), then the old trigger is deleted.

If both parameters are omitted, then the response is a list of existing trigger functions.

Details about trigger characteristics are in the triggers section.

Example

```
tarantool> function f ()
         >   x = x + 1
         > end
tarantool> box.session.on_connect(f)
```

Warning: If a trigger always results in an error, it may become impossible to connect to a server to reset it.

box.session.on_disconnect([trigger-function[, old-trigger-function]])

Define a trigger for execution after a client has disconnected. If the trigger function causes an error, the error is logged but otherwise is ignored. The trigger is invoked while the session associated with the client still exists and can access session properties, such as box.session.id().

Since version 1.10, the trigger function is invoked immediately after the disconnect, even if requests that were made during the session have not finished.

Parameters

- trigger-function (function) – function which will become the trigger function
- old-trigger-function (function) – existing trigger function which will be replaced by trigger-function

Return nil or function pointer

If the parameters are (nil, old-trigger-function), then the old trigger is deleted.

If both parameters are omitted, then the response is a list of existing trigger functions.

Details about trigger characteristics are in the triggers section.

Example #1

```
tarantool> function f ()
         >   x = x + 1
         > end
tarantool> box.session.on_disconnect(f)
```

Example #2

After the following series of requests, a Tarantool instance will write a message using the log module whenever any user connects or disconnects.

```
function log_connect ()
  local log = require('log')
  local m = 'Connection. user=' .. box.session.user() .. ' id=' .. box.session.id()
  log.info(m)
end

function log_disconnect ()
  local log = require('log')
  local m = 'Disconnection. user=' .. box.session.user() .. ' id=' .. box.session.id()
  log.info(m)
end

box.session.on_connect(log_connect)
box.session.on_disconnect(log_disconnect)
```

Here is what might appear in the log file in a typical installation:

```
2014-12-15 13:21:34.444 [11360] main/103/iproto I>
    Connection. user=guest id=3
2014-12-15 13:22:19.289 [11360] main/103/iproto I>
    Disconnection. user=guest id=3
```

box.session.on_auth([trigger-function[, old-trigger-function]])

Define a trigger for execution during authentication.

The on_auth trigger function is invoked in these circumstances:

(1) The console.connect function includes an authentication check for all users except 'guest'. For this case, the on_auth trigger function is invoked after the on_connect trigger function, if and only if the connection has succeeded so far.

(2) The binary protocol has a separate authentication packet. For this case, connection and authentication are considered to be separate steps.

Unlike other trigger types, on_auth trigger functions are invoked before the event. Therefore a trigger function like function auth_function () v = box.session.user(); end will set v to "guest", the user name before the authentication is done. To get the user name after the authentication is done, use the special syntax: function auth_function (user_name) v = user_name; end

If the trigger fails by raising an error, the error is sent to the client and the connection is closed.

Parameters

- trigger-function (function) – function which will become the trigger function
- old-trigger-function (function) – existing trigger function which will be replaced by trigger-function

Return nil or function pointer

If the parameters are (nil, old-trigger-function), then the old trigger is deleted.

If both parameters are omitted, then the response is a list of existing trigger functions.

Details about trigger characteristics are in the triggers section.

Example 1

```
tarantool> function f ()
         >   x = x + 1
         > end
tarantool> box.session.on_auth(f)
```

Example 2

This is a more complex example, with two server instances.

The first server instance listens on port 3301; its default user name is 'admin'. There are three on_auth triggers:

- The first trigger has a function with no arguments, it can only look at box.session.user().
- The second trigger has a function with a user_name argument, it can look at both of: box.session.user() and user_name.
- The third trigger has a function with a user_name argument and a status argument, it can look at all three of: box.session.user() and user_name and status.

The second server instance will connect with console.connect, and then will cause a display of the variables that were set by the trigger functions.

```
-- On the first server instance, which listens on port 3301
box.cfg{listen=3301}
function function1()
  print('function 1, box.session.user()='..box.session.user())
  end
function function2(user_name)
  print('function 2, box.session.user()='..box.session.user())
  print('function 2, user_name='..user_name)
  end
function function3(user_name, status)
  print('function 3, box.session.user()='..box.session.user())
  print('function 3, user_name='..user_name)
  if status == true then
```

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```
    print('function 3, status = true, authorization succeeded')
    end
  end
box.session.on_auth(function1)
box.session.on_auth(function2)
box.session.on_auth(function3)
box.schema.user.passwd('admin')
```

```
-- On the second server instance, that connects to port 3301
console = require('console')
console.connect('admin:admin@localhost:3301')
```

The result looks like this:

```
function 3, box.session.user()=guest
function 3, user_name=admin
function 3, status = true, authorization succeeded
function 2, box.session.user()=guest
function 2, user_name=admin
function 1, box.session.user()=guest
```

box.session.push(message[, sync])

Generate an out-of-band message. By "out-of-band" we mean an extra message which supplements what is passed in a network via the usual channels. Although box.session.push() can be called at any time, in practice it is used with networks that are set up with module net.box, and it is invoked by the server (on the "remote database system" to use our terminology for net.box), and the client has options for getting such messages.

This function returns an error if the session is disconnected.

Parameters

- message (any-Lua-type) – what to send
- sync (int) – an optional argument to indicate what the session is, as taken from an earlier call to box_session:sync(). If it is omitted, the default is the current box.session.sync() value.

Rtype {nil, error} or true:

- If the result is an error, then the first part of the return is nil and the second part is the error object.
- If the result is not an error, then the return is the boolean value true.
- When the return is true, the message has gone to the network buffer as a packet with the code IPROTO_CHUNK (0x80).

The server's sole job is to call box.session.push(), there is no automatic mechanism for showing that the message was received.

The client's job is to check for such messages after it sends something to the server. The major client methods – conn:call, conn:eval, conn:select, conn:insert, conn:replace, conn:update, conn:upsert, delete – may cause the server to send a message.

Situation 1: when the client calls synchronously with the default {async=false} option. There are two optional additional options: on_push=function-name, and on_push_ctx=function-argument. When the client receives an out-of-band message for the session, it invokes "function-name(function-argument)". For example, with options {on_push=table.insert, on_push_ctx=messages}, the client will insert whatever it receives into a table named 'messages'.

Situation 2: when the client calls asynchronously with the non-default {async=true} option. Here on_push and on_push_ctx are not allowed, but the messages can be seen by calling pairs() in a loop.

Situation 2 complication: pairs() is subject to timeout. So there is an optional argument = timeout per iteration. If timeout occurs before there is a new message or a final response, there is an error return. To check for an error one can use the first loop parameter (if the loop starts with "for i, message in future:pairs()" then the first loop parameter is i). If it is box.NULL then the second parameter (in our example, "message") is the error object.

Example

```
-- Make two shells. On Shell#1 set up a "server", and
-- in it have a function that includes box.session.push:
box.cfg{listen=3301}
box.schema.user.grant('guest','read,write,execute','universe')
x = 0
fiber = require('fiber')
function server_function() x=x+1; fiber.sleep(1); box.session.push(x); end

-- On Shell#2 connect to this server as a "client" that
-- can handle Lua (such as another Tarantool server operating
-- as a client), and initialize a table where we'll get messages:
net_box = require('net.box')
conn = net_box.connect(3301)
messages_from_server = {}

-- On Shell#2 remotely call the server function and receive
-- a SYNCHRONOUS out-of-band message:
conn:call('server_function', {},
          {is_async = false,
           on_push = table.insert,
           on_push_ctx = messages_from_server})
messages_from_server
-- After a 1-second pause that is caused by the fiber.sleep()
-- request inside server_function, the result in the
--  messages_from_server table will be: 1. Like this:
-- tarantool> messages_from_server
-- ---
-- - - 1
-- ...
-- Good. That shows that box.session.push(x) worked,
-- because we know that x was 1.

-- On Shell#2 remotely call the same server function and
-- get an ASYNCHRONOUS out-of-band message. For this we cannot
-- use on_push and on_push_ctx options, but we can use pairs():
future = conn:call('server_function', {}, {is_async = true})
messages = {}
keys = {}
for i, message in future:pairs() do
    table.insert(messages, message) table.insert(keys, i) end
messages
future:wait_result(1000)
for i, message in future:pairs() do
    table.insert(messages, message) table.insert(keys, i) end
```

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```
messages
-- There is no pause because conn:call does not wait for
-- server_function to finish. The first time that we go through
-- the pairs() loop, we see the messages table is empty. Like this:
-- tarantool> messages
-- ---
-- - - 2
--   - []
-- ...
-- That is okay because the server hasn't yet called
-- box.session.push(). The second time that we go through
-- the pairs() loop, we see the value of x at the time of
-- the second call to box.session.push(). Like this:
-- tarantool> messages
-- ---
-- - - 2
--   - &0 []
--   - 2
--   - *0
-- ...
-- Good. That shows that the message was asynchronous, and
-- that box.session.push() did its job.
```

Submodule box.slab

Overview

The box.slab submodule provides access to slab allocator statistics. The slab allocator is the main allocator used to store tuples. This can be used to monitor the total memory usage and memory fragmentation.

Index

Below is a list of all box.slab functions.

Name	Use
box.runtime.info()	Show a memory usage report for Lua runtime
box.slab.info()	Show an aggregated memory usage report for slab allocator
box.slab.stats()	Show a detailed memory usage report for slab allocator

box.runtime.info()

Show a memory usage report (in bytes) for the Lua runtime.

Return

- lua is the heap size of the Lua garbage collector;
- maxalloc is the maximal memory quota that can be allocated for Lua;
- used is the current memory size used by Lua.

Rtype table

Example:

```
tarantool> box.runtime.info()
---
- lua: 913710
  maxalloc: 4398046510080
  used: 12582912
...
tarantool> box.runtime.info().used
---
- used: 12582912
...
```

box.slab.info()

Show an aggregated memory usage report (in bytes) for the slab allocator. This report is useful for assessing out-of-memory risks.

box.slab.info gives a few ratios:

- items_used_ratio
- arena_used_ratio
- quota_used_ratio

Here are two possible cases for monitoring memtx memory usage:

Case 1: 0.5 < items_used_ratio < 0.9

	Arena_used_ratio > 0.5	Arena_used_ratio > 0.9
Quota_used_ratio > 0.5	🟩	🟩
Quota_used_ratio > 0.9	🟩	🟨

Apparently your memory is highly fragmented. Check how many slab classes you have by looking at box.slab.stats() and counting the number of different classes. If there are many slab classes (more than a few dozens), you may run out of memory even though memory utilization is not high. While each slab may have few items used, whenever a tuple of a size different from any existing slab class size is allocated, Tarantool may need to get a new slab from the slab arena, and since the arena has few empty slabs left, it will attempt to increase its quota usage, which, in turn, may end up with an out-of-memory error due to the low remaining quota.

Case 2: items_used_ratio > 0.9

	Arena_used_ratio > 0.5	Arena_used_ratio > 0.9
Quota_used_ratio > 0.5	🟩	🟩
Quota_used_ratio > 0.9	🟩	🟥

You are running out of memory. All memory utilization indicators are high. Your memory is not fragmented, but there are few reserves left on each slab allocator level. You should consider increasing Tarantool's memory limit (box.cfg.memtx_memory).

To sum up: your main out-of-memory indicator is quota_used_ratio. However, there are lots of perfectly stable setups with a high quota_used_ratio, so you only need to pay attention to it when both arena and item used ratio are also high.

Return

- items_size is the total amount of memory (including allocated, but currently free slabs) used only for tuples, no indexes;
- items_used_ratio = items_used / items_size, where items_size = slab_count * slab_size (these are slabs used only for tuples, no indexes);
- quota_size is the maximum amount of memory that the slab allocator can use for both tuples and indexes (as configured in the memtx_memory parameter, the default is 2^28 bytes = 268,435,456 bytes);
- quota_used_ratio = quota_used / quota_size;
- arena_used_ratio = arena_used / arena_size;
- items_used is the efficient amount of memory (omitting allocated, but currently free slabs) used only for tuples, no indexes;
- quota_used is the amount of memory that is already distributed to the slab allocator;
- arena_size is the total memory used for tuples and indexes together (including allocated, but currently free slabs);
- arena_used is the efficient memory used for storing tuples and indexes together (omitting allocated, but currently free slabs).

Rtype table

Example:

```
tarantool> box.slab.info()
---
- items_size: 228128
  items_used_ratio: 1.8%
  quota_size: 1073741824
  quota_used_ratio: 0.8%
  arena_used_ratio: 43.2%
  items_used: 4208
  quota_used: 8388608
  arena_size: 2325176
  arena_used: 1003632
...

tarantool> box.slab.info().arena_used
---
- 1003632
...
```

box.slab.stats()

Show a detailed memory usage report (in bytes) for the slab allocator. The report is broken down into groups by data item size as well as by slab size (64-byte, 136-byte, etc). The report includes the memory allocated for storing both tuples and indexes.

return

- mem_free is the allocated, but currently unused memory;
- mem_used is the memory used for storing data items (tuples and indexes);
- item_count is the number of stored items;
- item_size is the size of each data item;
- slab_count is the number of slabs allocated;

- slab_size is the size of each allocated slab.

rtype table

Example:

Here is a sample report for the first group:

```
tarantool> box.slab.stats()[1]
---
- mem_free: 16232
  mem_used: 48
  item_count: 2
  item_size: 24
  slab_count: 1
  slab_size: 16384
...
```

This report is saying that there are 2 data items (item_count = 2) stored in one (slab_count = 1) 24-byte slab (item_size = 24), so mem_used = 2 * 24 = 48 bytes. Also, slab_size is 16384 bytes, of which 16384 - 48 = 16232 bytes are free (mem_free).

A complete report would show memory usage statistics for all groups:

```
tarantool> box.slab.stats()
---
- - mem_free: 16232
    mem_used: 48
    item_count: 2
    item_size: 24
    slab_count: 1
    slab_size: 16384
  - mem_free: 15720
    mem_used: 560
    item_count: 14
    item_size: 40
    slab_count: 1
    slab_size: 16384
  <...>
  - mem_free: 32472
    mem_used: 192
    item_count: 1
    item_size: 192
    slab_count: 1
    slab_size: 32768
  - mem_free: 1097624
    mem_used: 999424
    item_count: 61
    item_size: 16384
    slab_count: 1
    slab_size: 2097152
  ...
```

The total mem_used for all groups in this report equals arena_used in box.slab.info() report.

Submodule box.space

Overview

CRUD operations in Tarantool are implemented by the box.space submodule. It has the data-manipulation functions select, insert, replace, update, upsert, delete, get, put. It also has members, such as id, and whether or not a space is enabled. Submodule source code is available in file src/box/lua/schema.lua.

Index

Below is a list of all box.space functions and members.

Name
space_object:auto_increment()
space_object:bsize()
space_object:count()
space_object:create_index() * Details about index field types * Index field types to use in space_object:create_index() *
space_object:delete()
space_object:drop()
space_object:format()
space_object:frommap()
space_object:get()
space_object:insert()
space_object:len()
space_object:on_replace()
space_object:before_replace()
space_object:pairs()
space_object:put()
space_object:rename()
space_object:replace()
space_object:run_triggers()
space_object:select()
space_object:truncate()
space_object:update()
space_object:upsert()
space_object:user_defined()
space_object:create_check_constraint()
space_object.enabled
space_object.field_count
space_object.id
space_object.index
box.space._cluster
box.space._func
box.space._index
box.space._vindex
box.space._priv
box.space._vpriv
box.space._schema
box.space._sequence
box.space._sequence_data
box.space._space
box.space._vspace

Name
box.space._user
box.space._ck_constraint
box.space._vuser
box.space._collation
box.space._vcollation
box.space._session_settings

object space_object

space_object:auto_increment(tuple)

Insert a new tuple using an auto-increment primary key. The space specified by space_object must have an 'unsigned' or 'integer' or 'number' primary key index of type TREE. The primary-key field will be incremented before the insert.

Since version 1.7.5 this method is deprecated – it is better to use a sequence.

Parameters

- space_object (space_object) – an object reference
- tuple (table/tuple) – tuple's fields, other than the primary-key field

Return the inserted tuple.

Rtype tuple

Complexity factors: Index size, Index type, Number of indexes accessed, WAL settings.

Possible errors:

- index has wrong type;
- primary-key indexed field is not a number.

Example:

```
tarantool> box.space.tester:auto_increment{'Fld#1', 'Fld#2'}
---
- [1, 'Fld#1', 'Fld#2']
...
tarantool> box.space.tester:auto_increment{'Fld#3'}
---
- [2, 'Fld#3']
...
```

space_object:bsize()

Parameters

- space_object (space_object) – an object reference

Return Number of bytes in the space. This number, which is stored in Tarantool's internal memory, represents the total number of bytes in all tuples, not including index keys. For a measure of index size, see index_object:bsize().

Example:

```
tarantool> box.space.tester:bsize()
---
- 22
...
```

space_object:count([key][, iterator])

Return the number of tuples. If compared with len(), this method works slower because count() scans the entire space to count the tuples.

Parameters

- space_object (space_object) – an object reference
- key (scalar/table) – primary-key field values, must be passed as a Lua table if key is multi-part
- iterator – comparison method

Return Number of tuples.

Example:

```
tarantool> box.space.tester:count(2, {iterator='GE'})
---
- 1
...
```

space_object:create_index(index-name[, options])

Create an index. It is mandatory to create an index for a space before trying to insert tuples into it, or select tuples from it. The first created index, which will be used as the primary-key index, must be unique.

Parameters

- space_object (space_object) – an object reference
- index_name (string) – name of index, which should conform to the rules for object names
- options (table) – see "Options for space_object:create_index()", below

Return index object

Rtype index_object

Options for space_object:create_index()

Name	Effect	Type	Default
type	type of index	string ('HASH' or 'TREE' or 'BITSET' or 'RTREE') Note re storage engine: vinyl only supports 'TREE'	'TREE'
id	unique identifier	number	last index's id, +1
unique	index is unique	boolean	true
if_not_exists	no error if duplicate name	boolean	false
parts	field-numbers + types	{field_no, 'unsigned' or 'string' or 'integer' or 'number' or 'double' or 'decimal'`` ` or 'boolean' or 'varbinary' or 'array' or 'scalar', and optional collation or is_nullable value or path}	{1, 'unsigned'}
dimension	affects RTREE only	number	2
distance	affects RTREE only	string ('euclid' or 'manhattan')	'euclid'
bloom_fpr	affects vinyl only	number	vinyl_bloom_fpr
page_size	affects vinyl only	number	vinyl_page_size
range_size	affects vinyl only	number	vinyl_range_size
run_count_per_level	affects vinyl only	number	vinyl_run_count_per_level
run_size_ratio	affects vinyl only	number	vinyl_run_size_ratio
sequence	see section regarding specifying a sequence in create_index()	string or number	not present
func	functional index	string	not present

The options in the above chart are also applicable for index_object:alter().

Note re storage engine: vinyl has extra options which by default are based on configuration parameters vinyl_bloom_fpr, vinyl_page_size, vinyl_range_size, vinyl_run_count_per_level, and vinyl_run_size_ratio – see the description of those parameters. The current values can be seen by selecting from box.space._index.

Building or rebuilding a large index will cause occasional yields so that other requests will not be blocked. If the other requests cause an illegal situation such as a duplicate key in a unique index, the index building or rebuilding will fail.

Possible errors:

- too many parts;

- index '. . . ' already exists;
- primary key must be unique.

```
tarantool> s = box.space.tester
---
...
tarantool> s:create_index('primary', {unique = true, parts = { {field = 1, type = 'unsigned'},
↪{field = 2, type = 'string'}} })
---
...
```

Details about index field types:

The ten index field types (unsigned | string | integer | number | double | boolean | decimal | varbinary | array | scalar) differ depending on what values are allowed, and what index types are allowed.

- unsigned: unsigned integers between 0 and 18446744073709551615, about 18 quintillion. May also be called 'uint' or 'num', but 'num' is deprecated. Legal in memtx TREE or HASH indexes, and in vinyl TREE indexes.
- string: any set of octets, up to the maximum length. May also be called 'str'. Legal in memtx TREE or HASH or BITSET indexes, and in vinyl TREE indexes. A string may have a collation.
- integer: integers between -9223372036854775808 and 18446744073709551615. May also be called 'int'. Legal in memtx TREE or HASH indexes, and in vinyl TREE indexes.
- number: integers between -9223372036854775808 and 18446744073709551615, single-precision floating point numbers, or double-precision floating point numbers, or exact numbers. Legal in memtx TREE or HASH indexes, and in vinyl TREE indexes.
- double: double-precision floating point numbers. Legal in memtx TREE or HASH indexes, and in vinyl TREE indexes.
- boolean: true or false. Legal in memtx TREE or HASH indexes, and in vinyl TREE indexes.
- decimal: exact number returned from a function in the decimal module. Legal in memtx TREE or HASH indexes, and in vinyl TREE indexes.
- varbinary: any set of octets, up to the maximum length. Legal in memtx TREE or HASH indexes, and in vinyl TREE indexes. A varbinary byte sequence does not have a collation because its contents are not UTF-8 characters.
- array: array of numbers. Legal in memtx RTREE indexes.
- scalar: null (input with msgpack.NULL or yaml.NULL or json.NULL), booleans (true or false), or integers between -9223372036854775808 and 18446744073709551615, or single-precision floating point numbers, or double-precison floating-point numbers, or exact numbers, or strings, or (varbinary) byte arrays. When there is a mix of types, the key order is: null, then booleans, then numbers, then strings, then byte arrays. Legal in memtx TREE or HASH indexes, and in vinyl TREE indexes.

Additionally, nil is allowed with any index field type if is_nullable=true is specified.

Index field types to use in space_object:create_index()

Index field type	What can be in it	Where is it legal	Examples
unsigned	integers between 0 and 18446744073709551615	memtx TREE or HASH indexes, vinyl TREE indexes	123456
string	strings – any set of octets	memtx TREE or HASH indexes vinyl TREE indexes	'A B C' '\65 \66 \67'
varbinary	byte sequences – any set of octets	memtx TREE or HASH indexes vinyl TREE indexes	'\65 \66 \67'
integer	integers between -9223372036854775808 and 18446744073709551615	memtx TREE or HASH indexes, vinyl TREE indexes	-2^63
number	integers between -9223372036854775808 and 18446744073709551615, single-precision floating point numbers, double-precision floating point numbers, exact (decimal) numbers	memtx TREE or HASH indexes, vinyl TREE indexes	1.234 -44 1.447e+44
double	double-precision floating point numbers	memtx TREE or HASH indexes, vinyl TREE indexes	1.234
boolean	true or false	memtx TREE or HASH indexes, vinyl TREE indexes	false true
decimal	exact numbers returned by a function in the decimal module	memtx TREE or HASH indexes, vinyl TREE indexes	decimal.new(1.2)
array	array of integers between -9223372036854775808 and 9223372036854775807	memtx RTREE indexes	{10, 11} {3, 5, 9, 10}
scalar	null, booleans (true or false), integers between -9223372036854775808 and 18446744073709551615, single-precision floating point numbers, double-precision floating point numbers, strings	memtx TREE or HASH indexes, vinyl TREE indexes	null true -1 1.234 '' 'py'

Allowing null for an indexed key: If the index type is TREE, and the index is not the primary index, then the parts={...} clause may include is_nullable=true or is_nullable=false (the default). If is_nullable is true, then it is legal to insert nil or an equivalent such as msgpack.NULL (or it is legal to insert nothing at all for trailing nullable fields). Within indexes, such "null values" are always treated as equal to other null values, and are always treated as less than non-null values. Nulls may appear multiple times even in a unique index. Example:

```
box.space.tester:create_index('I',{unique=true,parts={{field = 2, type = 'number', is_nullable = true}}
↪)
```

Warning: It is legal to create multiple indexes for the same field with different is_nullable values, or to call space_object:format() with a different is_nullable value from what is used for an index. When there is a contradiction, the rule is: null is illegal unless is_nullable=true for every index and for the space format.

Using field names instead of field numbers: create_index() can use field names and/or field types described by the optional space_object:format() clause. In the following example, we show format() for a space that has two columns named 'x' and 'y', and then we show five variations of the parts={} clause of create_index(), first for the 'x' column, second for both the 'x' and 'y' columns. The variations include omitting the type, using numbers, and adding extra braces.

```
box.space.tester:format({{name='x', type='scalar'}, {name='y', type='integer'}})
box.space.tester:create_index('I2',{parts={{'x', 'scalar'}}})
box.space.tester:create_index('I3',{parts={{'x','scalar'},{'y','integer'}}})
box.space.tester:create_index('I4',{parts={{1,'scalar'}}})
box.space.tester:create_index('I5',{parts={{1,'scalar'},{2,'integer'}}})
box.space.tester:create_index('I6',{parts={1}})
box.space.tester:create_index('I7',{parts={1,2}})
box.space.tester:create_index('I8',{parts={'x'}})
box.space.tester:create_index('I9',{parts={'x','y'}})
box.space.tester:create_index('I10',{parts={{'x'}}})
box.space.tester:create_index('I11',{parts={{'x'},{'y'}}})
```

Using the path option for map fields (JSON-indexes): To create an index for a field that is a map (a path string and a scalar value), specify the path string during index_create, that is, parts={ field-number,'data-type',path = 'path-name' }. The index type must be 'tree' or 'hash' and the field's contents must always be maps with the same path.

```
-- Example 1 -- The simplest use of path:
-- Result will be - - [{ 'age': 44}]
box.schema.space.create('T')
box.space.T:create_index('I',{parts={{field = 1, type = 'scalar', path = 'age'}}})
box.space.T:insert{{age=44}}
box.space.T:select(44)
-- Example 2 -- path plus format() plus JSON syntax to add clarity
-- Result will be: - [1, { 'FIO': { 'surname': 'Xi', 'firstname': 'Ahmed'}}]
s = box.schema.space.create('T')
format = {{'id', 'unsigned'}, {'data', 'map'}}
s:format(format)
parts = {{'data.FIO["firstname"]', 'str'}, {'data.FIO["surname"]', 'str'}}
i = s:create_index('info', {parts = parts})
s:insert({1, {FIO={firstname='Ahmed', surname='Xi'}}})
```

Note re storage engine: vinyl supports only the TREE index type, and vinyl secondary indexes must be created before tuples are inserted.

Using the path option with [*] The string in a path option can contain '[*]' which is called an array index placeholder. Indexes defined with this are useful for JSON documents that all have the same structure. For example, when creating an index on field#2 for a string document that will start with {'data': [{'name': '...'}, {'name': '...'}], the parts section in the create_index request could look like: parts = {{field = 2, type = 'str', path = 'data[*].name'}}. Then tuples containing names can be retrieved quickly with index_object:select({key-value}). In fact a single field can have multiple keys, as in this example which retrieves the same tuple twice because there are two keys 'A' and 'B' which both match the request:

```
s = box.schema.space.create('json_documents')
s:create_index('primarykey')
i = s:create_index('multikey', {parts = {{field = 2, type = 'str', path = 'data[*].name'}}})
s:insert({1,
         {data = {{name='A'},
                  {name='B'}},
          extra_field = 1}})
i:select({''},{iterator='GE'})
```

The result of the select request looks like this:

```
tarantool> i:select({''},{iterator='GE'})
---
- - [1, {'data': [{'name': 'A'}, {'name': 'B'}], 'extra_field': 1}]
  - [1, {'data': [{'name': 'A'}, {'name': 'B'}], 'extra_field': 1}]
...
```

Some restrictions exist: () '[*]' must be alone or must be at the end of a name in the path; () '[*]' must not appear twice in the path; () if an index has a path with x[*] then no other index can have a path with x.component; () '[*]' must not appear in the path of a primary-key ; () if an index has unique=true and has a path with '[*]' then duplicate keys from different tuples are disallowed but duplicate keys for the same tuple are allowed; () As with Using the path option for map fields, the field's value must have the structure that the path definition implies, or be nil (nil is not indexed).

Making a functional index with space_object:create_index()

Functional indexes are indexes that call a user-defined function for forming the index key, rather than depending entirely on the Tarantool default formation. Functional indexes are useful for condensing or truncating or reversing or any other way that users want to customize the index.

The function definition must expect a tuple (which has the contents of fields at the time a data-change request happens) and must return a tuple (which has the contents that will actually be put in the index).

The space must have a memtx engine. The function must be persistent and deterministic. The key parts must not depend on JSON paths. The create_index definition must include specification of all key parts, and the function must return a table which has the same number of key parts with the same types. The function must access key-part values by index, not by field name. Functional indexes must not be primary-key indexes. Functional indexes cannot be altered and the function cannot be changed if it is used for an index, so the only way to change them is to drop the index and create it again. Only sandboxed functions are suitable for functional indexes.

Example:

A function could make a key using only the first letter of a string field.

```
-- Step 1: Make the space.
-- The space needs a primary-key field, which is not the field that we
-- will use for the functional index.
box.schema.space.create('x', {engine = 'memtx'})
box.space.x:create_index('i',{parts={{field = 1, type = 'string'}}})
-- Step 2: Make the function.
-- The function expects a tuple. In this example it will work on tuple[2]
-- because the key souce is field number 2 in what we will insert.
-- Use string.sub() from the string module to get the first character.
lua_code = [[function(tuple) return {string.sub(tuple[2],1,1)} end]]
```

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```
-- Step 3: Make the function persistent.
-- Use the box.schema.func.create function for this.
box.schema.func.create('F',
    {body = lua_code, is_deterministic = true, is_sandboxed = true})
-- Step 4: Make the functional index.
-- Specify the fields whose values will be passed to the function.
-- Specify the function.
box.space.x:create_index('j',{parts={{field = 1, type = 'string'}},func = 'F'})
-- Step 5: Test.
-- Insert a few tuples.
-- Select using only the first letter, it will work because that is the key
-- Or, select using the same function as was used for insertion
box.space.x:insert{'a', 'wombat'}
box.space.x:insert{'b', 'rabbit'}
box.space.x.index.j:select('w')
box.space.x.index.j:select(box.func.F:call({{'x', 'wombat'}}));
```

The results of the two select requests will look like this:

```
tarantool> box.space.x.index.j:select('w')
---
- - ['a', 'wombat']
...
tarantool> box.space.x.index.j:select(box.func.F:call({{'x','wombat'}}));
---
- - ['a', 'wombat']
...
```

Functions for functional indexes can return multiple keys. Such functions are called "multikey" functions. The box.func.create options must include opts = {is_multikey = true}. The return value must be a table of tuples. If a multikey function returns N tuples, then N keys will be added to the index.

Example:

```
s = box.schema.space.create('withdata')
s:format({{name = 'name', type = 'string'},
          {name = 'address', type = 'string'}})
pk = s:create_index('name', {parts = {{field = 1, type = 'string'}}})
lua_code = [[function(tuple)
               local address = string.split(tuple[2])
               local ret = {}
               for _, v in pairs(address) do
                 table.insert(ret, {utf8.upper(v)})
               end
               return ret
             end]]
box.schema.func.create('address',
                        {body = lua_code,
                         is_deterministic = true,
                         is_sandboxed = true,
                         opts = {is_multikey = true}})
idx = s:create_index('addr', {unique = false,
                              func = 'address',
                              parts = {{field = 1, type = 'string',
                                     collation = 'unicode_ci'}}})
s:insert({"James", "SIS Building Lambeth London UK"})
s:insert({"Sherlock", "221B Baker St Marylebone London NW1 6XE UK"})
```

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```
idx:select('Uk')
-- Both tuples will be returned.
```

space_object:delete(key)

Delete a tuple identified by a primary key.

Parameters

- space_object (space_object) – an object reference
- key (scalar/table) – primary-key field values, must be passed as a Lua table if key is multi-part

Return the deleted tuple

Rtype tuple

Complexity factors: Index size, Index type

Note re storage engine: vinyl will return nil, rather than the deleted tuple.

Example:

```
tarantool> box.space.tester:delete(1)
---
- [1, 'My first tuple']
...
tarantool> box.space.tester:delete(1)
---
...
tarantool> box.space.tester:delete('a')
---
- error: 'Supplied key type of part 0 does not match index part type:
  expected unsigned'
...
```

For more usage scenarios and typical errors see Example: using data operations further in this section.

space_object:drop()

Drop a space. The method is performed in background and doesn't block consequent requests.

Parameters

- space_object (space_object) – an object reference

Return nil

Possible errors: space_object does not exist.

Complexity factors: Index size, Index type, Number of indexes accessed, WAL settings.

Example:

```
box.space.space_that_does_not_exist:drop()
```

space_object:format([format-clause])

Declare field names and types.

Parameters

- space_object (space_object) – an object reference

- format-clause (table) – a list of field names and types

Return nil, unless format-clause is omitted

Possible errors:

- space_object does not exist;
- field names are duplicated;
- type is not legal.

Ordinarily Tarantool allows unnamed untyped fields. But with format users can, for example, document that the Nth field is the surname field and must contain strings. It is also possible to specify a format clause in box.schema.space.create().

The format clause contains, for each field, a definition within braces: {name='...',type='...'[, is_nullable=...]}, where:

- the name value may be any string, provided that two fields do not have the same name;
- the type value may be any of allowed types: any | unsigned | string | integer | number | varbinary | boolean | double | decimal | array | map | scalar, but for creating an index use only indexed fields;
- the optional is_nullable value may be either true or false (the same as the requirement in "Options for space_object:create_index"). See also the warning notice in section Allowing null for an indexed key.

It is not legal for tuples to contain values that have the wrong type; for example after box.space.tester:format({{' ',type='number'}}) the request box.space.tester:insert{'string-which-is-not-a-number'} will cause an error.

It is not legal for tuples to contain null values if is_nullable=false, which is the default; for example after box.space.tester:format({{' ',type='number',is_nullable=false}}) the request box.space.tester:insert{nil,2} will cause an error.

It is legal for tuples to have more fields than are described by a format clause. The way to constrain the number of fields is to specify a space's field_count member.

It is legal for tuples to have fewer fields than are described by a format clause, if the omitted trailing fields are described with is_nullable=true; for example after box.space.tester:format({{'a',type='number'},{'b',type='number',is_nullable=true}}) the request box.space.tester:insert{2} will not cause a format-related error.

It is legal to use format on a space that already has a format, thus replacing any previous definitions, provided that there is no conflict with existing data or index definitions.

It is legal to use format to change the is_nullable flag; for example after box.space.tester:format({{' ',type='scalar',is_nullable=false}}) the request box.space.tester:format({{' ',type='scalar',is_nullable=true}}) will not cause an error – and will not cause rebuilding of the space. But going the other way and changing is_nullable from true to false might cause rebuilding and might cause an error if there are existing tuples with nulls.

Example:

```
box.space.tester:format({{name='surname',type='string'},{name='IDX',type='array'}})
box.space.tester:format({{name='surname',type='string',is_nullable=true}})
```

There are legal variations of the format clause:

- omitting both 'name=' and 'type=',
- omitting 'type=' alone, and

- adding extra braces.

The following examples show all the variations, first for one field named 'x', second for two fields named 'x' and 'y'.

```
box.space.tester:format({{'x'}})
box.space.tester:format({{'x'},{'y'}})
box.space.tester:format({{name='x',type='scalar'}})
box.space.tester:format({{name='x',type='scalar'},{name='y',type='unsigned'}})
box.space.tester:format({{name='x'}})
box.space.tester:format({{name='x'},{name='y'}})
box.space.tester:format({{'x',type='scalar'}})
box.space.tester:format({{'x',type='scalar'},{'y',type='unsigned'}})
box.space.tester:format({{'x','scalar'}})
box.space.tester:format({{'x','scalar'},{'y','unsigned'}})
```

The following example shows how to create a space, format it with all possible types, and insert into it.

```
tarantool> box.schema.space.create('t')
---
- engine: memtx
  before_replace: 'function: 0x4019c488'
  on_replace: 'function: 0x4019c460'
  ck_constraint: []
  field_count: 0
  temporary: false
  index: []
  is_local: false
  enabled: false
  name: t
  id: 534
- created
...
tarantool> ffi = require('ffi')
---
...
tarantool> decimal = require('decimal')
---
...
tarantool> box.space.t:format({{name = '1', type = 'any'},
         >                    {name = '2', type = 'unsigned'},
         >                    {name = '3', type = 'string'},
         >                    {name = '4', type = 'number'},
         >                    {name = '5', type = 'double'},
         >                    {name = '6', type = 'integer'},
         >                    {name = '7', type = 'boolean'},
         >                    {name = '8', type = 'decimal'},
         >                    {name = '9', type = 'scalar'},
         >                    {name = 'a', type = 'array'},
         >                    {name = 'b', type = 'map'}})
---
...
tarantool> box.space.t:create_index('i',{parts={2, type = 'unsigned'}})
---
- unique: true
  parts:
  - type: unsigned
```

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```
    is_nullable: false
    fieldno: 2
  id: 0
  space_id: 534
  type: TREE
  name: i
...
tarantool> box.space.t:insert{{'a'}, -- any
         >                  1, -- unsigned
         >                  'W?', -- string
         >                  5.5, -- number
         >                  ffi.cast('double', 1), -- double
         >                  -0, -- integer
         >                  true, -- boolean
         >                  decimal.new(1.2), -- decimal
         >                  true, -- scalar
         >                  {{'a'}}, -- array
         >                  {val=1}} -- map
---
- [['a'], 1, 'W?', 5.5, 1, 0, true, 1.2, true, [['a']], {'val': 1}]
...
```

Names specified with the format clause can be used in space_object:get() and in space_object:create_index() and in tuple_object[field-name] and in tuple_object[field-path].

If the format clause is omitted, then the returned value is the table that was used in a previous space_object:format(format-clause) invocation. For example, after box.space.tester:format({{'x','scalar'}}), box.space.tester:format() will return [{'name': 'x', 'type': 'scalar'}].

Formatting or reformatting a large space will cause occasional yields so that other requests will not be blocked. If the other requests cause an illegal situation such as a field value of the wrong type, the formatting or reformatting will fail.

space_object:frommap(map[, option])

Convert a map to a tuple instance or to a table. The map must consist of "field name = value" pairs. The field names and the value types must match names and types stated previously for the space, via space_object:format().

Parameters

- space_object (space_object) – an object reference
- map (field-value-pairs) – a series of "field = value" pairs, in any order.
- option (boolean) – the only legal option is {table = true|false}; if the option is omitted or if {table = false}, then return type will be 'cdata' (i.e. tuple); if {table = true}, then return type will be 'table'.

Return a tuple instance or table.

Rtype tuple or table

Possible errors: space_object does not exist or has no format; "unknown field".

Example:

```
-- Create a format with two fields named 'a' and 'b'.
-- Create a space with that format.
```

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```
-- Create a tuple based on a map consistent with that space.
-- Create a table based on a map consistent with that space.
tarantool> format1 = {{name='a',type='unsigned'},{name='b',type='scalar'}}
---
...
tarantool> s = box.schema.create_space('test', {format = format1})
---
...
tarantool> s:frommap({b = 'x', a = 123456})
---
- [123456, 'x']
...
tarantool> s:frommap({b = 'x', a = 123456}, {table = true})
---
- - 123456
  - x
...
```

space_object:get(key)

Search for a tuple in the given space.

Parameters

- space_object (space_object) – an object reference
- key (scalar/table) – value to be matched against the index key, which may be multi-part.

Return the tuple whose index key matches key, or nil.

Rtype tuple

Possible errors: space_object does not exist.

Complexity factors: Index size, Index type, Number of indexes accessed, WAL settings.

The box.space...select function returns a set of tuples as a Lua table; the box.space...get function returns at most a single tuple. And it is possible to get the first tuple in a space by appending [1]. Therefore box.space.tester:get{1} has the same effect as box.space.tester:select{1}[1], if exactly one tuple is found.

Example:

```
box.space.tester:get{1}
```

Using field names instead of field numbers: get() can use field names described by the optional space_object:format() clause. This is true because the object returned by get() can be used with most of the features described in the Submodule box.tuple description, including tuple_object[field-name].

For example, we can format the tester space with a field named x and use the name x in the index definition:

```
box.space.tester:format({{name='x',type='scalar'}})
box.space.tester:create_index('I',{parts={'x'}})
```

Then, if get or select retrieves a single tuple, we can reference the field 'x' in the tuple by its name:

```
box.space.tester:get{1}['x']
box.space.tester:select{1}[1]['x']
```

space_object:insert(tuple)

Insert a tuple into a space.

Parameters

- space_object (space_object) – an object reference
- tuple (tuple/table) – tuple to be inserted.

Return the inserted tuple

Rtype tuple

Possible errors: ER_TUPLE_FOUND if a tuple with the same unique-key value already exists.

Example:

```
tarantool> box.space.tester:insert{5000,'tuple number five thousand'}
---
- [5000, 'tuple number five thousand']
...
```

For more usage scenarios and typical errors see Example: using data operations further in this section.

space_object:len()

Return the number of tuples in the space. If compared with count(), this method works faster because len() does not scan the entire space to count the tuples.

Parameters

- space_object (space_object) – an object reference

Return Number of tuples in the space.

Example:

```
tarantool> box.space.tester:len()
---
- 2
...
```

Note re storage engine: vinyl supports len() but the result may be approximate. If an exact result is necessary then use count() or pairs():length().

space_object:on_replace([trigger-function[, old-trigger-function]])

Create a "replace trigger". The trigger-function will be executed whenever a replace() or insert() or update() or upsert() or delete() happens to a tuple in <space-name>.

Parameters

- trigger-function (function) – function which will become the trigger function; see Example #2 below for details about trigger function parameters
- old-trigger-function (function) – existing trigger function which will be replaced by trigger-function

Return nil or function pointer

If the parameters are (nil, old-trigger-function), then the old trigger is deleted.

If both parameters are omitted, then the response is a list of existing trigger functions.

If it is necessary to know whether the trigger activation happened due to replication or on a specific connection type, the function can refer to box.session.type().

Details about trigger characteristics are in the triggers section.

See also space_object:before_replace().

Example #1:

```
tarantool> function f ()
         >   x = x + 1
         > end
tarantool> box.space.X:on_replace(f)
```

Example #2:

The trigger-function can have up to four parameters:

- (tuple) old value which has the contents before the request started,
- (tuple) new value which has the contents after the request ended,
- (string) space name,
- (string) type of request which is 'INSERT', 'DELETE', 'UPDATE', or 'REPLACE'.

For example, the following code causes nil and 'INSERT' to be printed when the insert request is processed, and causes [1, 'Hi'] and 'DELETE' to be printed when the delete request is processed:

```
box.schema.space.create('space_1')
box.space.space_1:create_index('space_1_index',{})
function on_replace_function (old, new, s, op) print(old) print(op) end
box.space.space_1:on_replace(on_replace_function)
box.space.space_1:insert{1,'Hi'}
box.space.space_1:delete{1}
```

Example #3:

The following series of requests will create a space, create an index, create a function which increments a counter, create a trigger, do two inserts, drop the space, and display the counter value - which is 2, because the function is executed once after each insert.

```
tarantool> s = box.schema.space.create('space53')
tarantool> s:create_index('primary', {parts = {{field = 1, type = 'unsigned'}}})
tarantool> function replace_trigger()
         >   replace_counter = replace_counter + 1
         > end
tarantool> s:on_replace(replace_trigger)
tarantool> replace_counter = 0
tarantool> t = s:insert{1, 'First replace'}
tarantool> t = s:insert{2, 'Second replace'}
tarantool> s:drop()
tarantool> replace_counter
```

Note: You shouldn't use in trigger-functions for on_replace and before_replace

- transactions,

- yield-oprations (explicit or not),
- actions that are not allowed to be used in transactions (see rule #2)

because everything executed inside triggers is already in a transaction.

Example:

```
tarantool> box.space.test:on_replace(fiber.yield)
tarantool> box.space.test:replace{1, 2, 3}
2020-02-02 21:22:03.073 [73185] main/102/init.lua txn.c:532 E> ER_TRANSACTION_YIELD:␣
↪Transaction has been aborted by a fiber yield
---
- error: Transaction has been aborted by a fiber yield
...
```

space_object:before_replace([trigger-function[, old-trigger-function]])

Create a "replace trigger". The trigger-function will be executed whenever a replace() or insert() or update() or upsert() or delete() happens to a tuple in <space-name>.

Parameters

- trigger-function (function) – function which will become the trigger function; for the trigger function's optional parameters see the description of on_replace.
- old-trigger-function (function) – existing trigger function which will be replaced by trigger-function

Return nil or function pointer

If the parameters are (nil, old-trigger-function), then the old trigger is deleted.

If both parameters are omitted, then the response is a list of existing trigger functions.

If it is necessary to know whether the trigger activation happened due to replication or on a specific connection type, the function can refer to box.session.type().

Details about trigger characteristics are in the triggers section.

See also space_object:on_replace().

Administrators can make replace triggers with on_replace(), or make triggers with before_replace(). If they make both types, then all before_replace triggers are executed before all on_replace triggers. The functions for both on_replace and before_replace triggers can make changes to the database, but only the functions for before_replace triggers can change the tuple that is being replaced.

Since a before_replace trigger function has the extra capability of making a change to the old tuple, it also can have extra overhead, to fetch the old tuple before making the change. Therefore an on_replace trigger is better if there is no need to change the old tuple. However, this only applies for the memtx engine – for the vinyl engine, the fetch will happen for either kind of trigger. (With memtx the tuple data is stored along with the index key so no extra search is necessary; with vinyl that is not the case so the extra search is necessary.)

Where the extra capability is not needed, on_replace should be used instead of before_replace. Usually before_replace is used only for certain replication scenarios – it is useful for conflict resolution.

The value that a before_replace trigger function can return affects what will happen after the return. Specifically:

- if there is no return value, then execution proceeds, inserting|replacing the new value;

- if the value is nil, then the tuple will be deleted;
- if the value is the same as the old parameter, then no on_replace function will be called and the data change will be skipped
- if the value is the same as the new parameter, then it's as if the before_replace function wasn't called;
- if the value is some other tuple, then it is used for insert/replace.

However, if a trigger function returns an old tuple, or if a trigger function calls run_triggers(false), that will not affect other triggers that are activated for the same insert|update|replace request.

Example:

The following are before_replace functions that have no return value, or that return nil, or the same as the old parameter, or the same as the new parameter, or something else.

```
function f1 (old, new) return end
function f2 (old, new) return nil end
function f3 (old, new) return old end
function f4 (old, new) return new end
function f5 (old, new) return box.tuple.new({new[1],'b'}) end
```

space_object:pairs([key[, iterator]])

Search for a tuple or a set of tuples in the given space, and allow iterating over one tuple at a time.

Parameters

- space_object (space_object) – an object reference
- key (scalar/table) – value to be matched against the index key, which may be multi-part
- iterator – see index_object:pairs

Return iterator which can be used in a for/end loop or with totable()

Possible errors:

- no such space;
- wrong type.

Complexity factors: Index size, Index type.

For examples of complex pairs requests, where one can specify which index to search and what condition to use (for example "greater than" instead of "equal to"), see the later section index_object:pairs.

For information about iterators' internal structures see the "Lua Functional library" documentation.

Example:

```
tarantool> s = box.schema.space.create('space33')
---
...
tarantool> -- index 'X' has default parts {1, 'unsigned'}
tarantool> s:create_index('X', {})
---
...
```

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```
tarantool> s:insert{0, 'Hello my '}, s:insert{1, 'Lua world'}
---
- [0, 'Hello my ']
- [1, 'Lua world']
...
tarantool> tmp = ''
---
...
tarantool> for k, v in s:pairs() do
         >   tmp = tmp .. v[2]
         > end
---
...
tarantool> tmp
---
- Hello my Lua world
...
```

space_object:rename(space-name)

Rename a space.

Parameters

- space_object (space_object) – an object reference
- space-name (string) – new name for space

Return nil

Possible errors: space_object does not exist.

Example:

```
tarantool> box.space.space55:rename('space56')
---
...
tarantool> box.space.space56:rename('space55')
---
...
```

space_object:replace(tuple)
space_object:put(tuple)

Insert a tuple into a space. If a tuple with the same primary key already exists, box.space...:replace() replaces the existing tuple with a new one. The syntax variants box.space...:replace() and box.space...:put() have the same effect; the latter is sometimes used to show that the effect is the converse of box.space...:get().

Parameters

- space_object (space_object) – an object reference
- tuple (table/tuple) – tuple to be inserted

Return the inserted tuple.

Rtype tuple

Possible errors: ER_TUPLE_FOUND if a different tuple with the same unique-key value already exists. (This will only happen if there is a unique secondary index.)

Complexity factors: Index size, Index type, Number of indexes accessed, WAL settings.

Example:

```
box.space.tester:replace{5000, 'tuple number five thousand'}
```

For more usage scenarios and typical errors see Example: using data operations further in this section.

space_object:run_triggers(true|false)

At the time that a trigger is defined, it is automatically enabled - that is, it will be executed. Replace triggers can be disabled with box.space.space-name:run_triggers(false) and re-enabled with box.space.space-name:run_triggers(true).

Return nil

Example:

The following series of requests will associate an existing function named F with an existing space named T, associate the function a second time with the same space (so it will be called twice), disable all triggers of T, and delete each trigger by replacing with nil.

```
tarantool> box.space.T:on_replace(F)
tarantool> box.space.T:on_replace(F)
tarantool> box.space.T:run_triggers(false)
tarantool> box.space.T:on_replace(nil, F)
tarantool> box.space.T:on_replace(nil, F)
```

space_object:select([key[, options]])

Search for a tuple or a set of tuples in the given space. This method doesn't yield (for details see Cooperative multitasking).

Parameters

- space_object (space_object) – an object reference
- key (scalar/table) – value to be matched against the index key, which may be multi-part.
- options (table/nil) – none, any or all of the same options that index_object:select allows:
  - options.iterator (type of iterator)
  - options.limit (maximum number of tuples)
  - options.offset (number of tuples to skip)

Return the tuples whose primary-key fields are equal to the fields of the passed key. If the number of passed fields is less than the number of fields in the primary key, then only the passed fields are compared, so select{1,2} will match a tuple whose primary key is {1,2,3}.

Rtype array of tuples

A select request can also be done with a specific index and index options, which are the subject of index_object:select.

Possible errors:

- no such space;
- wrong type.

Complexity factors: Index size, Index type.

Example:

```
tarantool> s = box.schema.space.create('tmp', {temporary=true})
---
...
tarantool> s:create_index('primary',{parts = {{field = 1, type = 'unsigned'}, {field = 2, type =
↪'string'}} })
---
...
tarantool> s:insert{1,'A'}
---
- [1, 'A']
...
tarantool> s:insert{1,'B'}
---
- [1, 'B']
...
tarantool> s:insert{1,'C'}
---
- [1, 'C']
...
tarantool> s:insert{2,'D'}
---
- [2, 'D']
...
tarantool> -- must equal both primary-key fields
tarantool> s:select{1,'B'}
---
- - [1, 'B']
...
tarantool> -- must equal only one primary-key field
tarantool> s:select{1}
---
- - [1, 'A']
  - [1, 'B']
  - [1, 'C']
...
tarantool> -- must equal 0 fields, so returns all tuples
tarantool> s:select{}
---
- - [1, 'A']
  - [1, 'B']
  - [1, 'C']
  - [2, 'D']
...
tarantool> -- the first field must be greater than 0, and
tarantool> -- skip the first tuple, and return up to
tarantool> -- 2 tuples. This example's options all
tarantool> -- depend on index characteristics so see
tarantool> -- more explanation in index_object:select().
tarantool> s:select({0},{iterator='GT',offset=1,limit=2})
---
- - [1, 'B']
  - [1, 'C']
...
```

As the last request in the above example shows: to make complex select requests, where you can specify which index to search and what condition to use (for example "greater than" instead of "equal to") and how many tuples to return, it will be necessary to become familiar with index_object:select.

Remember that you can get a field from a tuple both by field number and by field name which is more convenient. See example: using field names instead of field numbers.

For more usage scenarios and typical errors see Example: using data operations further in this section.

space_object:truncate()

Deletes all tuples. The method is performed in background and doesn't block consequent requests.

Parameters

- space_object (space_object) – an object reference

Complexity factors: Index size, Index type, Number of tuples accessed.

Return nil

The truncate method can only be called by the user who created the space, or from within a setuid function created by the user who created the space. Read more about setuid functions in the reference for box.schema.func.create().

The truncate method cannot be called from within a transaction.

Example:

```
tarantool> box.space.tester:truncate()
---
...
tarantool> box.space.tester:len()
---
- 0
...
```

space_object:update(key, {{operator, field_identifier, value}, ...})

Update a tuple.

The update function supports operations on fields — assignment, arithmetic (if the field is numeric), cutting and pasting fragments of a field, deleting or inserting a field. Multiple operations can be combined in a single update request, and in this case they are performed atomically and sequentially. Each operation requires specification of a field identifier, which is usually a number. When multiple operations are present, the field number for each operation is assumed to be relative to the most recent state of the tuple, that is, as if all previous operations in a multi-operation update have already been applied. In other words, it is always safe to merge multiple update invocations into a single invocation, with no change in semantics.

Possible operators are:

- + for addition. values must be numeric, e.g. unsigned or decimal
- - for subtraction. values must be numeric
- & for bitwise AND. values must be unsigned numeric
- | for bitwise OR. values must be unsigned numeric
- ^ for bitwise XOR (exclusive OR). values must be unsigned numeric
- : for string splice.
- ! for insertion of a new field.
- # for deletion.

- = for assignment.

Possible field_identifiers are:

- Positive field number. The first field is 1, the second field is 2, and so on.
- Negative field number. The last field is -1, the second-last field is -2, and so on. In other words: (#tuple + negative field number + 1).
- Name. If the space was formatted with space_object:format(), then this can be a string for the field 'name'.

Parameters

- space_object (space_object) – an object reference
- key (scalar/table) – primary-key field values, must be passed as a Lua table if key is multi-part
- operator (string) – operation type represented in string
- field_identifier (number-or-string) – what field the operation will apply to.
- value (lua_value) – what value will be applied

Return

- the updated tuple
- nil if the key is not found

Rtype tuple or nil

Possible errors: it is illegal to modify a primary-key field.

Complexity factors: Index size, Index type, number of indexes accessed, WAL settings.

Thus, in the instruction:

```
s:update(44, {{'+', 1, 55 }, {'=', 3, 'x'}})
```

the primary-key value is 44, the operators are `'+'` and `'='` meaning add a value to a field and then assign a value to a field, the first affected field is field 1 and the value which will be added to it is 55, the second affected field is field 3 and the value which will be assigned to it is `'x'`.

Example:

Assume that initially there is a space named tester with a primary-key index whose type is unsigned. There is one tuple, with field[1] = 999 and field[2] = `'A'`.

In the update: box.space.tester:update(999, {{`'='`, 2, `'B'`}}) The first argument is tester, that is, the affected space is tester. The second argument is 999, that is, the affected tuple is identified by primary key value = 999. The third argument is =, that is, there is one operation — assignment to a field. The fourth argument is 2, that is, the affected field is field[2]. The fifth argument is `'B'`, that is, field[2] contents change to `'B'`. Therefore, after this update, field[1] = 999 and field[2] = `'B'`.

In the update: box.space.tester:update({999}, {{`'='`, 2, `'B'`}}) the arguments are the same, except that the key is passed as a Lua table (inside braces). This is unnecessary when the primary key has only one field, but would be necessary if the primary key had more than one field. Therefore, after this update, field[1] = 999 and field[2] = `'B'` (no change).

In the update: box.space.tester:update({999}, {{`'='`, 3, 1}}) the arguments are the same, except that the fourth argument is 3, that is, the affected field is field[3]. It is okay that, until now, field[3] has not existed. It gets added. Therefore, after this update, field[1] = 999, field[2] = `'B'`, field[3] = 1.

In the update: box.space.tester:update({999}, {{`'+'`, 3, 1}}) the arguments are the same, except that the third argument is `'+'`, that is, the operation is addition rather than assignment. Since field[3] previously contained 1, this means we're adding 1 to 1. Therefore, after this update, field[1] = 999, field[2] = `'B'`, field[3] = 2.

In the update: box.space.tester:update({999}, {{`'|'`, 3, 1}, {`'='`, 2, `'C'`}}) the idea is to modify two fields at once. The formats are `'|'` and =, that is, there are two operations, OR and assignment. The fourth and fifth arguments mean that field[3] gets OR'ed with 1. The seventh and eighth arguments mean that field[2] gets assigned `'C'`. Therefore, after this update, field[1] = 999, field[2] = `'C'`, field[3] = 3.

In the update: box.space.tester:update({999}, {{`'#'`, 2, 1}, {`'-'`, 2, 3}}) The idea is to delete field[2], then subtract 3 from field[3]. But after the delete, there is a renumbering, so field[3] becomes field[2] before we subtract 3 from it, and that's why the seventh argument is 2, not 3. Therefore, after this update, field[1] = 999, field[2] = 0.

In the update: box.space.tester:update({999}, {{`'='`, 2, `'XYZ'`}}) we're making a long string so that splice will work in the next example. Therefore, after this update, field[1] = 999, field[2] = `'XYZ'`.

In the update: box.space.tester:update({999}, {{`':'`, 2, 2, 1, `'!!'`}}) The third argument is `':'`, that is, this is the example of splice. The fourth argument is 2 because the change will occur in field[2]. The fifth argument is 2 because deletion will begin with the second byte. The sixth argument is 1 because the number of bytes to delete is 1. The seventh argument is `'!!'`, because `'!!'` is to be added at this position. Therefore, after this update, field[1] = 999, field[2] = `'X!!Z'`.

For more usage scenarios and typical errors see Example: using data operations further in this section.

Since Tarantool 2.3 a tuple can also be updated via JSON paths.

space_object:upsert({tuple}, {{operator, field_identifier, value}, ...})

Update or insert a tuple.

If there is an existing tuple which matches the key fields of tuple, then the request has the same effect as space_object:update() and the {{operator, field_identifier, value}, ...} parameter is used. If there is no existing tuple which matches the key fields of tuple, then the request has the same effect as space_object:insert() and the {tuple} parameter is used. However, unlike insert or update, upsert will not read a tuple and perform error checks before returning – this is a design feature which enhances throughput but requires more caution on the part of the user.

Parameters

- space_object (space_object) – an object reference
- tuple (table/tuple) – default tuple to be inserted, if analogue isn't found
- operator (string) – operation type represented in string
- field_identifier (number) – what field the operation will apply to
- value (lua_value) – what value will be applied

Return null

Possible errors:

- It is illegal to modify a primary-key field.
- It is illegal to use upsert with a space that has a unique secondary index.

Complexity factors: Index size, Index type, number of indexes accessed, WAL settings.

Example:

```
box.space.tester:upsert({12,'c'}, {{'=', 3, 'a'}, {'=', 4, 'b'}})
```

For more usage scenarios and typical errors see Example: using data operations further in this section.

space_object:user_defined()

Users can define any functions they want, and associate them with spaces: in effect they can make their own space methods. They do this by:

(1) creating a Lua function,

(2) adding the function name to a predefined global variable which has type = table, and

(3) invoking the function any time thereafter, as long as the server is up, by saying space_object:function-name([parameters]).

The predefined global variable is box.schema.space_mt. Adding to box.schema.space_mt makes the method available for all spaces.

Alternatively, user-defined methods can be made available for only one space, by calling getmetatable(space_object) and then adding the function name to the meta table. See also the example for index_object:user_defined().

Parameters

- index_object (index_object) – an object reference.
- any-name (any-type) – whatever the user defines

Example:

```
-- Visible to any space, no parameters.
-- After these requests, the value of global_variable will be 6.
box.schema.space.create('t')
box.space.t:create_index('i')
global_variable = 5
function f(space_arg) global_variable = global_variable + 1 end
box.schema.space_mt.counter = f
box.space.t:counter()
```

space_object:create_check_constraint(check_constraint_name, expression)

Create a check constraint. A check constraint is a requirement that must be met when a tuple is inserted or updated in a space. Check constraints created with space_object:create_check_constraint have the same effect as check constraints created with an SQL CHECK() clause in a CREATE TABLE statement.

Parameters

- space_object (space_object) – an object reference
- check_constraint_name (string) – name of check constraint, which should conform to the rules for object names
- expression (string) – SQL code of an expression which must return a boolean result

Return check constraint object

Rtype check_constraint_object

The space must be formatted with space_object:format() so that the expression can contain field names. The space must be empty. The space must not be a system space.

The expression must return true or false and should be deterministic. The expresion may be any SQL (not Lua) expression containing field names, built-in function names, literals, and operators. Not subqueries. If a field name contains lower case characters, it must be enclosed in "double quotes".

Check constraints are checked before the request is performed, at the same time as Lua before_replace triggers. If there is more than one check constraint or before_replace trigger, then they are ordered according to time of creation. (This is a change from the earlier behavior of check constraints, which caused checking before the tuple was formed.)

Check constraints can be dropped with space_object.ck_constraint.check_constraint_name:drop().

Check constraints can be disabled with space_object.ck_constraint.check_constraint_name:enable(false) or check_constraint_object:enable(false). Check constraints can be enabled with space_object.ck_constraint.check_constraint_name:enable(true) or check_constraint_object:enable(true). By default a check constraint is 'enabled' which means that the check is performed whenever the request is performed, but can be changed to 'disabled' which means that the check is not performed.

During the recovery process, for example when the Tarantool server is starting, the check is not performed unless force_recovery. is specified.

Example:

```
box.schema.space.create('t')
box.space.t:format({{name = 'f1', type = 'unsigned'},
                    {name = 'f2', type = 'string'},
                    {name = 'f3', type = 'string'}})
box.space.t:create_index('i')
box.space.t:create_check_constraint('c1', [["f2" > 'A']])
box.space.t:create_check_constraint('c2',
                        [["f2"=UPPER("f3") AND NOT "f2" LIKE '__']])
-- This insert will fail, constraint c1 expression returns false
box.space.t:insert{1, 'A', 'A'}
-- This insert will fail, constraint c2 expression returns false
box.space.t:insert{1, 'B', 'c'}
-- This insert will succeed, both constraint expressions return true
box.space.t:insert{1, 'B', 'b'}
-- This update will fail, constraint c2 expression returns false
box.space.t:update(1, {{'=', 2, 'xx'}, {'=', 3, 'xx'}})
```

A list of check constraints is in space_object._ck_constraint.

space_object.enabled

Whether or not this space is enabled. The value is false if the space has no index.

space_object.field_count

The required field count for all tuples in this space. The field_count can be set initially with:

```
box.schema.space.create(..., {
    ... ,
    field_count = *field_count_value* ,
    ...
})
```

The default value is 0, which means there is no required field count.

Example:

```
tarantool> box.space.tester.field_count
---
- 0
...
```

space_object.id

Ordinal space number. Spaces can be referenced by either name or number. Thus, if space tester has id = 800, then box.space.tester:insert{0} and box.space[800]:insert{0} are equivalent requests.

Example:

```
tarantool> box.space.tester.id
---
- 512
...
```

box.space.index

A container for all defined indexes. There is a Lua object of type box.index with methods to search tuples and iterate over them in predefined order.

To reset, use box.stat.reset().

Rtype table

Example:

```
# checking the number of indexes for space 'tester'
tarantool> local counter=0; for i=0,#box.space.tester.index do
  if box.space.tester.index[i]~=nil then counter=counter+1 end
  end; print(counter)
1
---
...
# checking the type of index 'primary'
tarantool> box.space.tester.index.primary.type
---
- TREE
...
```

box.space._cluster

_cluster is a system space for support of the replication feature.

box.space._func

_func is a system space with function tuples made by box.schema.func.create() or box.schema.func.create(func-name [, {options-with-body}]).

Tuples in this space contain the following fields:

- id (integer identifier),
- owner (integer identifier),
- the function name,
- the setuid flag,
- a language name (optional): ‘LUA’ (default) or ‘C’.
- the body
- the is_deterministic flag

- the is_sandboxed flag
- options

If the function tuple was made in the older way without specification of body, then the _func space will contain default values for the body and the is_deterministic flag and the is_sandboxed flag. Such function tuples are called "not persistent". You continue to create Lua functions in the usual way, by saying function function_name () ... end, without adding anything in the _func space. The _func space only exists for storing function tuples so that their names can be used within grant/revoke functions.

If the function tuple was made the newer way with specification of body, then all the fields may contain non-default values. Such functions are called "persistent". They should be invoked with box.func.func-name:call([parameters]).

You can:

- Create a _func tuple with box.schema.func.create(),
- Drop a _func tuple with box.schema.func.drop(),
- Check whether a _func tuple exists with box.schema.func.exists().

Example:

In the following example, we create a function named 'f7', put it into Tarantool's _func space and grant 'execute' privilege for this function to 'guest' user.

```
tarantool> function f7()
         >  box.session.uid()
         > end
---
...
tarantool> box.schema.func.create('f7')
---
...
tarantool> box.schema.user.grant('guest', 'execute', 'function', 'f7')
---
...
tarantool> box.schema.user.revoke('guest', 'execute', 'function', 'f7')
---
...
```

box.space._index

_index is a system space.

Tuples in this space contain the following fields:

- id (= id of space),
- iid (= index number within space),
- name,
- type,
- opts (e.g. unique option), [tuple-field-no, tuple-field-type . . .].

Here is what _index contains in a typical installation:

```
tarantool> box.space._index:select{}
---
- - [272, 0, 'primary', 'tree', {'unique': true}, [[0, 'string']]]
```

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```
  - [280, 0, 'primary', 'tree', {'unique': true}, [[0, 'unsigned']]]
  - [280, 1, 'owner', 'tree', {'unique': false}, [[1, 'unsigned']]]
  - [280, 2, 'name', 'tree', {'unique': true}, [[2, 'string']]]
  - [281, 0, 'primary', 'tree', {'unique': true}, [[0, 'unsigned']]]
  - [281, 1, 'owner', 'tree', {'unique': false}, [[1, 'unsigned']]]
  - [281, 2, 'name', 'tree', {'unique': true}, [[2, 'string']]]
  - [288, 0, 'primary', 'tree', {'unique': true}, [[0, 'unsigned'], [1, 'unsigned']]]
  - [288, 2, 'name', 'tree', {'unique': true}, [[0, 'unsigned'], [2, 'string']]]
  - [289, 0, 'primary', 'tree', {'unique': true}, [[0, 'unsigned'], [1, 'unsigned']]]
  - [289, 2, 'name', 'tree', {'unique': true}, [[0, 'unsigned'], [2, 'string']]]
  - [296, 0, 'primary', 'tree', {'unique': true}, [[0, 'unsigned']]]
  - [296, 1, 'owner', 'tree', {'unique': false}, [[1, 'unsigned']]]
  - [296, 2, 'name', 'tree', {'unique': true}, [[2, 'string']]]
---
...
```

box.space._vindex

_vindex is a system space that represents a virtual view. The structure of its tuples is identical to that of _index, but permissions for certain tuples are limited in accordance with user privileges. _vindex contains only those tuples that are accessible to the current user. See Access control for details about user privileges.

If the user has the full set of privileges (like 'admin'), the contents of _vindex match the contents of _index. If the user has limited access, _vindex contains only tuples accessible to this user.

Note:

- _vindex is a system view, so it allows only read requests.
- While the _index space requires proper access privileges, any user can always read from _vindex.

box.space._priv

_priv is a system space where privileges are stored.

Tuples in this space contain the following fields:

- the numeric id of the user who gave the privilege ("grantor_id"),
- the numeric id of the user who received the privilege ("grantee_id"),
- the type of object: 'space', 'index', 'function', 'sequence', 'user', 'role', or 'universe',
- the numeric id of the object,
- the type of operation: "read" = 1, "write" = 2, "execute" = 4, "create" = 32, "drop" = 64, "alter" = 128, or a combination such as "read,write,execute".

You can:

- Grant a privilege with box.schema.user.grant().
- Revoke a privilege with box.schema.user.revoke().

Note:

- Generally, privileges are granted or revoked by the owner of the object (the user who created it), or by the 'admin' user.

- Before dropping any objects or users, make sure that all their associated privileges have been revoked.
- Only the 'admin' user can grant privileges for the 'universe'.
- Only the 'admin' user or the creator of a space can drop, alter, or truncate the space.
- Only the 'admin' user or the creator of a user can change a different user's password.

box.space._vpriv

_vpriv is a system space that represents a virtual view. The structure of its tuples is identical to that of _priv, but permissions for certain tuples are limited in accordance with user privileges. _vpriv contains only those tuples that are accessible to the current user. See Access control for details about user privileges.

If the user has the full set of privileges (like 'admin'), the contents of _vpriv match the contents of _priv. If the user has limited access, _vpriv contains only tuples accessible to this user.

Note:

- _vpriv is a system view, so it allows only read requests.
- While the _priv space requires proper access privileges, any user can always read from _vpriv.

box.space._schema

_schema is a system space.

This space contains the following tuples:

- version tuple with version information for this Tarantool instance,
- cluster tuple with the instance's replica set ID,
- max_id tuple with the maximal space ID,
- once... tuples that correspond to specific box.once() blocks from the instance's initialization file. The first field in these tuples contains the key value from the corresponding box.once() block prefixed with 'once' (e.g. oncehello), so you can easily find a tuple that corresponds to a specific box.once() block.

Example:

Here is what _schema contains in a typical installation (notice the tuples for two box.once() blocks, `'oncebye'` and `'oncehello'`):

```
tarantool> box.space._schema:select{}
---
- - ['cluster', 'b4e15788-d962-4442-892e-d6c1dd5d13f2']
  - ['max_id', 512]
  - ['oncebye']
  - ['oncehello']
  - ['version', 1, 7, 2]
```

box.space._sequence

_sequence is a system space for support of the sequence feature. It contains persistent information that was established by box.schema.sequence.create() or box.schema.sequence.alter().

box.space._sequence_data

_sequence_data is a system space for support of the sequence feature.

Each tuple in _sequence_data contains two fields:

- the id of the sequence, and
- the last value that the sequence generator returned (non-persistent information).

There is no guarantee that this space will be updated immediately after every data-change request.

box.space._space

_space is a system space. It contains all spaces hosted on the current Tarantool instance, both system ones and created by users.

Tuples in this space contain the following fields:

- id,
- owner (= id of user who owns the space),
- name, engine, field_count,
- flags (e.g. temporary),
- format (as made by a format clause).

These fields are established by space.create().

Example #1:

The following function will display every simple field in all tuples of _space.

```
function example()
  local ta = {}
  local i, line
  for k, v in box.space._space:pairs() do
    i = 1
    line = ''
    while i <= #v do
      if type(v[i]) ~= 'table' then
        line = line .. v[i] .. ' '
      end
    i = i + 1
    end
    table.insert(ta, line)
  end
  return ta
end
```

Here is what example() returns in a typical installation:

```
tarantool> example()
---
- - '272 1 _schema memtx 0  '
  - '280 1 _space memtx 0  '
  - '281 1 _vspace sysview 0  '
  - '288 1 _index memtx 0  '
  - '296 1 _func memtx 0  '
  - '304 1 _user memtx 0  '
  - '305 1 _vuser sysview 0  '
  - '312 1 _priv memtx 0  '
  - '313 1 _vpriv sysview 0  '
  - '320 1 _cluster memtx 0  '
  - '512 1 tester memtx 0  '
  - '513 1 origin vinyl 0  '
  - '514 1 archive memtx 0  '
...
```

Example #2:

The following requests will create a space using box.schema.space.create() with a format clause, then retrieve the _space tuple for the new space. This illustrates the typical use of the format clause, it shows the recommended names and data types for the fields.

```
tarantool> box.schema.space.create('TM', {
         >   id = 12345,
         >   format = {
         >     [1] = {["name"] = "field_1"},
         >     [2] = {["type"] = "unsigned"}
         >   }
         > })
---
- index: []
  on_replace: 'function: 0x41c67338'
  temporary: false
  id: 12345
  engine: memtx
  enabled: false
  name: TM
  field_count: 0
- created
...
tarantool> box.space._space:select(12345)
---
- - [12345, 1, 'TM', 'memtx', 0, {}, [{'name': 'field_1'}, {'type': 'unsigned'}]]
...
```

box.space._vspace

_vspace is a system space that represents a virtual view. The structure of its tuples is identical to that of _space, but permissions for certain tuples are limited in accordance with user privileges. _vspace contains only those tuples that are accessible to the current user. See Access control for details about user privileges.

If the user has the full set of privileges (like 'admin'), the contents of _vspace match the contents of _space. If the user has limited access, _vspace contains only tuples accessible to this user.

Note:

- _vspace is a system view, so it allows only read requests.
- While the _space space requires proper access privileges, any user can always read from _vspace.

box.space._user

_user is a system space where user-names and password hashes are stored.

Tuples in this space contain the following fields:

- the numeric id of the tuple ("id"),
- the numeric id of the tuple's creator,
- the name,
- the type: 'user' or 'role',
- optional password.

There are five special tuples in the _user space: 'guest', 'admin', 'public', 'replication', and 'super'.

Name	ID	Type	Description
guest	0	user	Default user when connecting remotely. Usually an untrusted user with few privileges.
admin	1	user	Default user when using Tarantool as a console. Usually an administrative user with all privileges.
public	2	role	Pre-defined role, automatically granted to new users when they are created with box.schema.user.create(user-name). Therefore a convenient way to grant 'read' on space 't' to every user that will ever exist is with box.schema.role.grant('public','read','space','t').
replication	3	role	Pre-defined role, which the 'admin' user can grant to users who need to use replication features.
super	31	role	Pre-defined role, which the 'admin' user can grant to users who need all privileges on all objects. The 'super' role has these privileges on 'universe': read, write, execute, create, drop, alter.

To select a tuple from the _user space, use box.space._user:select(). For example, here is what happens with a select for user id = 0, which is the 'guest' user, which by default has no password:

```
tarantool> box.space._user:select{0}
---
- - [0, 1, 'guest', 'user']
...
```

Warning: To change tuples in the _user space, do not use ordinary box.space functions for insert or update or delete. The _user space is special, so there are special functions which have appropriate error checking.

To create a new user, use box.schema.user.create():

```
box.schema.user.create(*user-name*)
box.schema.user.create(*user-name*, {if_not_exists = true})
box.schema.user.create(*user-name*, {password = *password*})
```

To change the user's password, use box.schema.user.password():

```
-- To change the current user's password
box.schema.user.passwd(*password*)

-- To change a different user's password
-- (usually only 'admin' can do it)
box.schema.user.passwd(*user-name*, *password*)
```

To drop a user, use box.schema.user.drop():

```
box.schema.user.drop(*user-name*)
```

To check whether a user exists, use box.schema.user.exists(), which returns true or false:

```
box.schema.user.exists(*user-name*)
```

To find what privileges a user has, use box.schema.user.info():

```
box.schema.user.info(*user-name*)
```

Note: The maximum number of users is 32.

Example:

Here is a session which creates a new user with a strong password, selects a tuple in the _user space, and then drops the user.

```
tarantool> box.schema.user.create('JeanMartin', {password = 'Iwtso_6_os$$'})
---
...
tarantool> box.space._user.index.name:select{'JeanMartin'}
---
- - [17, 1, 'JeanMartin', 'user', {'chap-sha1': 't3xjUpQdrt857O+YRvGbMY5py8Q='}]
...
tarantool> box.schema.user.drop('JeanMartin')
---
...
```

box.space._ck_constraint

_ck_constraint is a system space where check constraints are stored.

Tuples in this space contain the following fields:

- the numeric id of the space ("space_id"),
- the name,
- whether the check is deferred ("is_deferred"),
- the language of the expression, such as 'SQL',
- the expression ("code")

Example:

```
tarantool> box.space._ck_constraint:select()
---
- - [527, 'c1', false, 'SQL', '"f2" > ''A''']
  - [527, 'c2', false, 'SQL', '"f2" == UPPER("f3") AND NOT "f2" LIKE ''__''']
...
```

Example: using box.space functions to read _space tuples

This function will illustrate how to look at all the spaces, and for each display: approximately how many tuples it contains, and the first field of its first tuple. The function uses Tarantool box.space functions len() and pairs(). The iteration through the spaces is coded as a scan of the _space system space, which contains metadata. The third field in _space contains the space name, so the key instruction space_name = v[3] means space_name is the space_name field in the tuple of _space that we've just fetched with pairs(). The function returns a table:

```
function example()
  local tuple_count, space_name, line
  local ta = {}
  for k, v in box.space._space:pairs() do
```

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```
    space_name = v[3]
    if box.space[space_name].index[0] ~= nil then
      tuple_count = '1 or more'
    else
      tuple_count = '0'
    end
    line = space_name .. ' tuple_count =' .. tuple_count
    if tuple_count == '1 or more' then
      for k1, v1 in box.space[space_name]:pairs() do
        line = line .. '. first field in first tuple = ' .. v1[1]
        break
      end
    end
    table.insert(ta, line)
  end
  return ta
end
```

And here is what happens when one invokes the function:

```
tarantool> example()
---
- - _schema tuple_count =1 or more. first field in first tuple = cluster
  - _space tuple_count =1 or more. first field in first tuple = 272
  - _vspace tuple_count =1 or more. first field in first tuple = 272
  - _index tuple_count =1 or more. first field in first tuple = 272
  - _vindex tuple_count =1 or more. first field in first tuple = 272
  - _func tuple_count =1 or more. first field in first tuple = 1
  - _vfunc tuple_count =1 or more. first field in first tuple = 1
  - _user tuple_count =1 or more. first field in first tuple = 0
  - _vuser tuple_count =1 or more. first field in first tuple = 0
  - _priv tuple_count =1 or more. first field in first tuple = 1
  - _vpriv tuple_count =1 or more. first field in first tuple = 1
  - _cluster tuple_count =1 or more. first field in first tuple = 1
...
```

Example: using box.space functions to organize a _space tuple

The objective is to display field names and field types of a system space – using metadata to find metadata.

To begin: how can one select the _space tuple that describes _space?

A simple way is to look at the constants in box.schema, which tell us that there is an item named SPACE_ID == 288, so these statements will retrieve the correct tuple:

```
box.space._space:select{ 288 }
-- or --
box.space._space:select{ box.schema.SPACE_ID }
```

Another way is to look at the tuples in box.space._index, which tell us that there is a secondary index named 'name' for space number 288, so this statement also will retrieve the correct tuple:

```
box.space._space.index.name:select{ '_space' }
```

However, the retrieved tuple is not easy to read:

```
tarantool> box.space._space.index.name:select{'_space'}
---
- - [280, 1, '_space', 'memtx', 0, {}, [{'name': 'id', 'type': 'num'}, {'name': 'owner',
        'type': 'num'}, {'name': 'name', 'type': 'str'}, {'name': 'engine', 'type': 'str'},
      {'name': 'field_count', 'type': 'num'}, {'name': 'flags', 'type': 'str'}, {
        'name': 'format', 'type': '*'}]]
...
```

It looks disorganized because field number 7 has been formatted with recommended names and data types. How can one get those specific sub-fields? Since it's visible that field number 7 is an array of maps, this for loop will do the organizing:

```
tarantool> do
         >   local tuple_of_space = box.space._space.index.name:get{'_space'}
         >   for _, field in ipairs(tuple_of_space[7]) do
         >     print(field.name .. ', ' .. field.type)
         >   end
         > end
id, num
owner, num
name, str
engine, str
field_count, num
flags, str
format, *
---
...
```

box.space._vuser

_vuser is a system space that represents a virtual view. The structure of its tuples is identical to that of _user, but permissions for certain tuples are limited in accordance with user privileges. _vuser contains only those tuples that are accessible to the current user. See Access control for details about user privileges.

If the user has the full set of privileges (like 'admin'), the contents of _vuser match the contents of _user. If the user has limited access, _vuser contains only tuples accessible to this user.

To see how _vuser works, connect to a Tarantool database remotely via tarantoolctl and select all tuples from the _user space, both when the 'guest' user is and is not allowed to read from the database.

First, start Tarantool and grant the 'guest' user with read, write and execute privileges:

```
tarantool> box.cfg{listen = 3301}
---
...
tarantool> box.schema.user.grant('guest', 'read,write,execute', 'universe')
---
...
```

Switch to the other terminal, connect to the Tarantool instance and select all tuples from the _user space:

```
$ tarantoolctl connect 3301
localhost:3301> box.space._user:select{}
---
- - [0, 1, 'guest', 'user', {}]
  - [1, 1, 'admin', 'user', {}]
```

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```
  - [2, 1, 'public', 'role', {}]
  - [3, 1, 'replication', 'role', {}]
  - [31, 1, 'super', 'role', {}]
...
```

This result contains the same set of users as if you made the request from your Tarantool instance as 'admin'.

Switch to the first terminal and revoke the read privileges from the 'guest' user:

```
tarantool> box.schema.user.revoke('guest', 'read', 'universe')
---
...
```

Switch to the other terminal, stop the session (to stop tarantoolctl, type Ctrl+C or Ctrl+D) and repeat the box.space._user:select{} request. The access is denied:

```
$ tarantoolctl connect 3301
localhost:3301> box.space._user:select{}
---
- error: Read access to space '_user' is denied for user 'guest'
...
```

However, if you select from _vuser instead, the users' data available for the 'guest' user is displayed:

```
localhost:3301> box.space._vuser:select{}
---
- - [0, 1, 'guest', 'user', {}]
...
```

Note:

- _vuser is a system view, so it allows only read requests.
- While the _user space requires proper access privileges, any user can always read from _vuser.

box.space._collation

_collation is a system space with a list of collations. There are over 270 built-in collations and users may add more. Here is one example:

```
localhost:3301> box.space._collation:select(239)
---
- - [239, 'unicode_uk_s2', 1, 'ICU', 'uk', {'strength': 'secondary'}]
...
```

Explanation of the fields in the example: id = 239 i.e. Tarantool's primary key is 239, name = 'unicode_uk_s2' i.e. according to Tarantool's naming convention this is a Unicode collation + it is for the uk locale + it has secondary strength, owner = 1 i.e. the admin user, type = 'ICU' i.e. the rules are according to International Components for Unicode, locale = 'uk' i.e. Ukrainian, opts = 'strength:secondary' i.e. with this collation comparisons use both primary and secondary weights.

box.space._vcollation

_vcollation is a system space with a list of collations. The structure of its tuples is identical to that of box.space._collation, but permissions for certain tuples are limited in accordance with user privileges.

box.space._session_settings

_session_settings is a temporary system space with a list of settings that may affect behavior, particularly SQL behavior, for the current session. It uses a special engine named 'service'. Every 'service' tuple is created on the fly, that is, new tuples are made every time _session_settings is accessed. Every settings tuple has two fields: name (the primary key) and value. The tuples' names and default values are: sql_default_engine: default storage engine for new SQL tables. Default = 'memtx'. sql_defer_foreign_keys: whether foreign-key checks can wait till commit. Default = false. sql_full_column_names: no effect at this time. Default = false. sql_full_metadata: whether SQL result set metadata will have more than just name and type. Default = false. sql_parser_debug: whether to show parser steps for following statements. Default = false. sql_recursive_triggers: whether a triggered statement can activate a trigger. Default = true. sql_reverse_unordered_selects: whether result rows are usually in reverse order if there is no ORDER BY clause. Default = false. sql_select_debug: whether to show execution steps during SELECT. Default = false. sql_vdbe_debug: for use by Tarantool's developers. Default = false. Three requests are possible: select and get and update. For example, after s = box.space._session_settings, s:select('sql_default_engine') probably returns {'sql_default_engine', 'memtx'}, and s:update('sql_default_engine', {{'=', 'value', 'vinyl'}}) changes the default engine to 'vinyl'. Updating sql_parser_debug or sql_select_debug or sql_vdbe_debug has no effect unless Tarantool was built with -DCMAKE_BUILD_TYPE=Debug. To check if this is so, look at require('tarantool').build.target.

Example: using data operations

This example demonstrates all legal scenarios – as well as typical errors – for each data operation in Tarantool: INSERT, DELETE, UPDATE, UPSERT, REPLACE, and SELECT.

```
-- Bootstrap the database --
box.cfg{}
format = {}
format[1] = {'field1', 'unsigned'}
format[2] = {'field2', 'unsigned'}
format[3] = {'field3', 'unsigned'}
s = box.schema.create_space('test', {format = format})
-- Create a primary index --
pk = s:create_index('pk', {parts = {{field = 'field1'}}})
-- Create a unique secondary index --
sk_uniq = s:create_index('sk_uniq', {parts = {{field = 'field2'}}})
-- Create a non-unique secondary index --
sk_non_uniq = s:create_index('sk_non_uniq', {parts = {{field = 'field3'}}, unique = false})
```

INSERT

insert accepts a well-formatted tuple and checks all keys for duplicates.

```
tarantool> -- Unique indexes: ok --
tarantool> s:insert({1, 1, 1})
---
- [1, 1, 1]
...
tarantool> -- Conflicting primary key: error --
tarantool> s:insert({1, 1, 1})
---
- error: Duplicate key exists in unique index 'pk' in space 'test'
...
```

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```
tarantool> -- Conflicting unique secondary key: error --
tarantool> s:insert({2, 1, 1})
---
- error: Duplicate key exists in unique index 'sk_uniq' in space 'test'
...
tarantool> -- Key {1} exists in sk_non_uniq index, but it is not unique: ok --
tarantool> s:insert({2, 2, 1})
---
- [2, 2, 1]
...
tarantool> s:truncate()
---
...
```

DELETE

delete accepts a full key of any unique index.

space:delete is an alias for "delete by primary key".

```
tarantool> -- Insert some test data --
tarantool> s:insert{3, 4, 5}
---
- [3, 4, 5]
...
tarantool> s:insert{6, 7, 8}
---
- [6, 7, 8]
...
tarantool> s:insert{9, 10, 11}
---
- [9, 10, 11]
...
tarantool> s:insert{12, 13, 14}
---
- [12, 13, 14]
...
tarantool> -- Nothing done here: no {4} key in pk index --
tarantool> s:delete{4}
---
...
tarantool> s:select{}
---
- - [3, 4, 5]
  - [6, 7, 8]
  - [9, 10, 11]
  - [12, 13, 14]
...
tarantool> -- Delete by a primary key: ok --
tarantool> s:delete{3}
---
- [3, 4, 5]
...
tarantool> s:select{}
---
```

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```
- - [6, 7, 8]
  - [9, 10, 11]
  - [12, 13, 14]
...
tarantool> -- Explicitly delete by a primary key: ok --
tarantool> s.index.pk:delete{6}
---
- [6, 7, 8]
...
tarantool> s:select{}
---
- - [9, 10, 11]
  - [12, 13, 14]
...
tarantool> -- Delete by a unique secondary key: ok --
s.index.sk_uniq:delete{10}
---
- [9, 10, 11]
...
s:select{}
---
- - [12, 13, 14]
...
tarantool> -- Delete by a non-unique secondary index: error --
tarantool> s.index.sk_non_uniq:delete{14}
---
- error: Get() doesn't support partial keys and non-unique indexes
...
tarantool> s:select{}
---
- - [12, 13, 14]
...
tarantool> s:truncate()
---
...
```

The key must be full: delete cannot work with partial keys.

```
tarantool> s2 = box.schema.create_space('test2')
---
...
tarantool> pk2 = s2:create_index('pk2', {parts = {{field = 1, type = 'unsigned'}, {field = 2, type = 'unsigned
↪'}}})
---
...
tarantool> s2:insert{1, 1}
---
- [1, 1]
...
tarantool> -- Delete by a partial key: error --
tarantool> s2:delete{1}
---
- error: Invalid key part count in an exact match (expected 2, got 1)
...
tarantool> -- Delete by a full key: ok --
tarantool> s2:delete{1, 1}
```

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```
---
- [1, 1]
...
tarantool> s2:select{}
---
- []
...
tarantool> s2:drop()
---
...
```

UPDATE

Similarly to delete, update accepts a full key of any unique index, and also the operations to execute.

space:update is an alias for "update by primary key".

```
tarantool> -- Insert some test data --
tarantool> s:insert{3, 4, 5}
---
- [3, 4, 5]
...
tarantool> s:insert{6, 7, 8}
---
- [6, 7, 8]
...
tarantool> s:insert{9, 10, 11}
---
- [9, 10, 11]
...
tarantool> s:insert{12, 13, 14}
---
- [12, 13, 14]
...
tarantool> -- Nothing done here: no {4} key in pk index --
s:update({4}, {{'=', 2, 400}})
---
...
tarantool> s:select{}
---
- - [3, 4, 5]
  - [6, 7, 8]
  - [9, 10, 11]
  - [12, 13, 14]
...
tarantool> -- Update by a primary key: ok --
tarantool> s:update({3}, {{'=', 2, 400}})
---
- [3, 400, 5]
...
tarantool> s:select{}
---
- - [3, 400, 5]
  - [6, 7, 8]
  - [9, 10, 11]
```

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```
  - [12, 13, 14]
...
tarantool> -- Explicitly update by a primary key: ok --
tarantool> s.index.pk:update({6}, {{'=', 2, 700}})
---
- [6, 700, 8]
...
tarantool> s:select{}
---
- - [3, 400, 5]
  - [6, 700, 8]
  - [9, 10, 11]
  - [12, 13, 14]
...
tarantool> -- Update by a unique secondary key: ok --
tarantool> s.index.sk_uniq:update({10}, {{'=', 2, 1000}})
---
- [9, 1000, 11]
...
tarantool> s:select{}
---
- - [3, 400, 5]
  - [6, 700, 8]
  - [9, 1000, 11]
  - [12, 13, 14]
...
tarantool> -- Update by a non-unique secondary key: error --
tarantool> s.index.sk_non_uniq:update({14}, {{'=', 2, 1300}})
---
- error: Get() doesn't support partial keys and non-unique indexes
...
tarantool> s:select{}
---
- - [3, 400, 5]
  - [6, 700, 8]
  - [9, 1000, 11]
  - [12, 13, 14]
...
tarantool> s:truncate()
---
...
```

UPSERT

upsert accepts a well-formatted tuple and update operations.

If an old tuple is found by the primary key of the specified tuple, then the update operations are applied to the old tuple, and the new tuple is ignored.

If no old tuple is found, then the new tuple is inserted, and the update operations are ignored.

Indexes have no upsert method - this is a method of a space.

```
tarantool> s.index.pk.upsert == nil
---
- true
```

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```
...
tarantool> s.index.sk_uniq.upsert == nil
---
- true
...
tarantool> s.upsert ~= nil
---
- true
...
tarantool> -- As the first argument, upsert accepts --
tarantool> -- a well-formatted tuple, NOT a key! --
tarantool> s:insert{1, 2, 3}
---
- [1, 2, 3]
...
tarantool> s:upsert({1}, {{'=', 2, 200}})
---
- error: Tuple field count 1 is less than required by space format or defined indexes
    (expected at least 3)
...
tarantool> s:select{}
---
- - [1, 2, 3]
...
tarantool> s:delete{1}
---
- [1, 2, 3]
...
```

upsert turns into insert when no old tuple is found by the primary key.

```
tarantool> s:upsert({1, 2, 3}, {{'=', 2, 200}})
---
...
tarantool> -- As you can see, {1, 2, 3} were inserted, --
tarantool> -- and the update operations were not applied. --
s:select{}
---
- - [1, 2, 3]
...
tarantool> -- Performing another upsert with the same primary key, --
tarantool> -- but different values in the other fields. --
s:upsert({1, 20, 30}, {{'=', 2, 200}})
---
...
tarantool> -- The old tuple was found by the primary key {1} --
tarantool> -- and update operations were applied. --
tarantool> -- The new tuple was ignored. --
tarantool> s:select{}
---
- - [1, 200, 3]
...
```

upsert searches for an old tuple by the primary index, NOT by a secondary index. This can lead to a duplication error if the new tuple ruins the uniqueness of a secondary index.

```
tarantool> s:upsert({2, 200, 3}, {{'=', 3, 300}})
---
- error: Duplicate key exists in unique index 'sk_uniq' in space 'test'
...
s:select{}
---
- - [1, 200, 3]
...
tarantool> -- But this works, when uniqueness is preserved. --
tarantool> s:upsert({2, 0, 0}, {{'=', 3, 300}})
---
...
tarantool> s:select{}
---
- - [1, 200, 3]
  - [2, 0, 0]
...
tarantool> s:truncate()
---
...
```

REPLACE

replace accepts a well-formatted tuple and searches for an old tuple by the primary key of the new tuple.

If the old tuple is found, then it is deleted, and the new tuple is inserted.

If the old tuple was not found, then just the new tuple is inserted.

```
tarantool> s:replace{1, 2, 3}
---
- [1, 2, 3]
...
tarantool> s:select{}
---
- - [1, 2, 3]
...
tarantool> s:replace{1, 3, 4}
---
- [1, 3, 4]
...
tarantool> s:select{}
---
- - [1, 3, 4]
...
tarantool> s:truncate()
---
...
```

replace can ruin unique constraints, like upsert does.

```
tarantool> s:insert{1, 1, 1}
---
- [1, 1, 1]
...
tarantool> s:insert{2, 2, 2}
```

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```
---
- [2, 2, 2]
...
tarantool> -- This replace fails, because if the new tuple {1, 2, 0} replaces --
tarantool> -- the old tuple by the primary key from 'pk' index {1, 1, 1}, --
tarantool> -- this results in a duplicate unique secondary key in 'sk_uniq' index: --
tarantool> -- key {2} is used both in the new tuple and in {2, 2, 2}. --
tarantool> s:replace{1, 2, 0}
---
- error: Duplicate key exists in unique index 'sk_uniq' in space 'test'
...
tarantool> s:truncate()
---
...
```

SELECT

select works with any indexes (primary/secondary) and with any keys (unique/non-unique, full/partial).

If a key is partial, then select searches by all keys, where the prefix matches the specified key part.

```
tarantool> s:insert{1, 2, 3}
---
- [1, 2, 3]
...
tarantool> s:insert{4, 5, 6}
---
- [4, 5, 6]
...
tarantool> s:insert{7, 8, 9}
---
- [7, 8, 9]
...
tarantool> s:insert{10, 11, 9}
---
- [10, 11, 9]
...
tarantool> s:select{1}
---
- - [1, 2, 3]
...
tarantool> s:select{}
---
- - [1, 2, 3]
  - [4, 5, 6]
  - [7, 8, 9]
  - [10, 11, 9]
...
tarantool> s.index.pk:select{4}
---
- - [4, 5, 6]
...
tarantool> s.index.sk_uniq:select{8}
---
- - [7, 8, 9]
```

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```
...
tarantool> s.index.sk_non_uniq:select{9}
---
- - [7, 8, 9]
  - [10, 11, 9]
...
```

Submodule box.stat

The box.stat submodule provides access to request and network statistics.

Use box.stat() to show the average number of requests per second, and the total number of requests since startup, broken down by request type.

Use box.stat.net() to see network activity: the number of bytes sent and received, the number of connections, and the number of active requests (current, average, and total).

Use box.stat.vinyl() to see vinyl-storage-engine activity, for example box.stat.vinyl().tx has the number of commits and rollbacks. See details at the end of this section.

Use box.stat.reset() to reset the statistics of box.stat(), box.stat.net(), box.stat.vinyl() and box.space.index.

In the tables that box.stat() returns:

- total stands for "total number of requests processed per second since the server started",
- rps stands for "average number of requests per second in the last 5 seconds".

"ERROR" is the count of requests that resulted in an error.

In the tables that box.stat.net() returns:

- SENT.rps and RECEIVED.rps – average number of bytes sent/received per second in the last 5 seconds
- SENT.total and RECEIVED.total – total number of bytes sent/received since the server started
- CONNECTIONS.rps – number of connections opened per second in the last 5 seconds
- CONNECTIONS.total – total number of connections opened since the server started
- REQUESTS.current – number of requests in progress, which can be limited by box.cfg.net_msg_max
- REQUESTS.rps – number of requests processed per second in the last 5 seconds
- REQUESTS.total – total number of requests processed since startup

```
tarantool> box.stat() -- return 11 tables
---
- DELETE:
    total: 1873949
    rps: 123
  SELECT:
    total: 1237723
    rps: 4099
  INSERT:
    total: 0
    rps: 0
  EVAL:
    total: 0
    rps: 0
```

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```
  CALL:
    total: 0
    rps: 0
  REPLACE:
    total: 1239123
    rps: 7849
  UPSERT:
    total: 0
    rps: 0
  AUTH:
    total: 0
    rps: 0
  ERROR:
    total: 0
    rps: 0
  EXECUTE:
    total: 0
    rps: 0
  UPDATE:
    total: 0
    rps: 0
...
tarantool> box.stat().DELETE -- total + requests per second from one table
---
- total: 0
  rps: 0
...
tarantool> box.stat.net() -- 4 tables
---
- SENT:
    total: 0
    rps: 0
  CONNECTIONS:
    current: 0
    rps: 0
    total: 0
  REQUESTS:
    current: 0
    rps: 0
    total: 0
  RECEIVED:
    total: 0
    rps: 0
...
tarantool> box.stat.vinyl().tx.commit -- one item of the vinyl table
---
- 1047632
...
```

Here are details about the box.stat.vinyl() items.

Details about box.stat.vinyl().regulator: The vinyl regulator decides when to take or delay actions for disk IO, grouping activity in batches so that it is consistent and efficient. The regulator is invoked by the vinyl scheduler, once per second, and updates related variables whenever it is invoked.

- box.stat.vinyl().regulator.dump_bandwidth is the estimated average rate at which dumps are done. Initially this will appear as 10485760 (10 megabytes per second). Only significant dumps (larger than one megabyte) are used for estimating.

- box.stat.vinyl().regulator.dump_watermark is the point when dumping must occur. The value is slightly smaller than the amount of memory that is allocated for vinyl trees, which is the vinyl_memory parameter.
- box.stat.vinyl().regulator.write_rate is the actual average rate at which recent writes to disk are done. Averaging is done over a 5-second time window, so if there has been no activity for 5 seconds then regulator.write_rate = 0. The write_rate may be slowed when a dump is in progress or when the user has set snap_io_rate_limit.
- box.stat.vinyl().regulator.rate_limit is the write rate limit, in bytes per second, imposed on transactions by the regulator based on the observed dump/compaction performance.

Details about box.stat.vinyl().disk: Since vinyl is an on-disk storage engine (unlike memtx which is an in-memory storage engine), it can handle large databases – but if a database is larger than the amount of memory that is allocated for vinyl, then there will be more disk activity.

- box.stat.vinyl().disk.data and box.stat.vinyl().disk.index are the amount of data that has gone into files in a subdirectory of vinyl_dir, with names like {lsn}.run and {lsn}.index. The size of the run will be related to the output of scheduler.dump_*.
- box.stat.vinyl().disk.data_compacted Sum size of data stored at the last LSM tree level, in bytes, without taking disk compression into account. It can be thought of as the size of disk space that the user data would occupy if there were no compression, indexing, or space increase caused by the LSM tree design.

Details about box.stat.vinyl().memory: Although the vinyl storage engine is not "in-memory", Tarantool does need to have memory for write buffers and for caches:

- box.stat.vinyl().memory.tuple_cache is the number of bytes that are being used for tuples (data).
- box.stat.vinyl().memory.tx is transactional memory. This will usually be 0.
- box.stat.vinyl().memory.level0 is the "level0" memory area, sometimes abbreviated "L0", which is the area that vinyl can use for in-memory storage of an LSM tree.

Therefore we can say that "L0 is becoming full" when the amount in memory.level0 is close to the maximum, which is regulator.dump_watermark. We can expect that "L0 = 0" immediately after a dump. box.stat.vinyl().memory.page_index and box.stat.vinyl().memory.bloom_filter have the current amount being used for index-related structures. The size is a function of the number and size of keys, plus vinyl_page_size, plus vinyl_bloom_fpr. This is not a count of bloom filter "hits" (the number of reads that could be avoided because the bloom filter predicts their presence in a run file) – that statistic can be found with index_object:stat().

Details about box.stat.vinyl().tx: This is about requests that affect transactional activity ("tx" is used here as an abbreviation for "transaction"):

- box.stat.vinyl().tx.conflict counts conflicts that caused a transaction to roll back.
- box.stat.vinyl().tx.commit is the count of commits (successful transaction ends). It includes implicit commits, for example any insert causes a commit unless it is within a begin-end block.
- box.stat.vinyl().tx.rollback is the count of rollbacks (unsuccessful transaction ends). This is not merely a count of explicit box.rollback requests – it includes requests that ended in errors. For example, after an attempted insert request that causes a "Duplicate key exists in unique index" error, tx.rollback is incremented.
- box.stat.vinyl().tx.statements will usually be 0.
- box.stat.vinyl().tx.transactions is the number of transactions that are currently running.

- box.stat.vinyl().tx.gap_locks is the number of gap locks that are outstanding during execution of a request. For a low-level description of Tarantool's implementation of gap locking, see Gap locks in Vinyl transaction manager.
- box.stat.vinyl().tx.read_views shows whether a transaction has entered a read-only state to avoid conflict temporarily. This will usually be 0.

Details about box.stat.vinyl().scheduler: This primarily has counters related to tasks that the scheduler has arranged for dumping or compaction: (most of these items are reset to 0 when the server restarts or when box.stat.reset() occurs):

- box.stat.vinyl().scheduler.compaction_* is the amount of data from recent changes that has been compacted. This is divided into scheduler.compaction_input (the amount that is being compacted), scheduler.compaction_queue (the amount that is waiting to be compacted), scheduler.compaction_time (total time spent by all worker threads performing compaction, in seconds), and scheduler.compaction_output (the amount that has been compacted, which is presumably smaller than scheduler.compaction_input).
- box.stat.vinyl().scheduler.tasks_* is about dump/compaction tasks, in three categories, scheduler.tasks_inprogress (currently running), scheduler.tasks_completed (successfully completed) scheduler.tasks_failed (aborted due to errors).
- box.stat.vinyl().scheduler_dump_* has the amount of data from recent changes that has been dumped, including dump_time (total time spent by all worker threads performing dumps, in seconds), and dump_count (the count of completed dumps), dump_input and dump_output.

  A "dump" is explained in section Storing data with vinyl:

  > Sooner or later the number of elements in an LSM tree exceeds the L0 size and that is when L0 gets written to a file on disk (called a 'run') and then cleared for storing new elements. This operation is called a 'dump'.

  Thus it can be predicted that a dump will occur if the size of L0 (which is memory.level0) is approaching the maximum (which is regulator.dump_watermark) and a dump is not already in progress. In fact Tarantool will try to arrange a dump before this hard limit is reached.

  A dump will also occur during a snapshot operation.

Function box.snapshot

box.snapshot()

Memtx

Take a snapshot of all data and store it in memtx_dir/<latest-lsn>.snap. To take a snapshot, Tarantool first enters the delayed garbage collection mode for all data. In this mode, the Tarantool garbage collector will not remove files which were created before the snapshot started, it will not remove them until the snapshot has finished. To preserve consistency of the primary key, used to iterate over tuples, a copy-on-write technique is employed. If the master process changes part of a primary key, the corresponding process page is split, and the snapshot process obtains an old copy of the page. In effect, the snapshot process uses multi-version concurrency control in order to avoid copying changes which are superseded while it is running.

Since a snapshot is written sequentially, you can expect a very high write performance (averaging to 80MB/second on modern disks), which means an average database instance gets saved in a matter of minutes. You may restrict the speed by changing snap_io_rate_limit.

Note: As long as there are any changes to the parent index memory through concurrent updates, there are going to be page splits, and therefore you need to have some extra free memory to run this command. 10% of memtx_memory is, on average, sufficient. This statement waits until a snapshot is taken and returns operation result.

Note: Change notice: Prior to Tarantool version 1.6.6, the snapshot process caused a fork, which could cause occasional latency spikes. Starting with Tarantool version 1.6.6, the snapshot process creates a consistent read view and this view is written to the snapshot file by a separate thread (the "Write Ahead Log" thread).

Although box.snapshot() does not cause a fork, there is a separate fiber which may produce snapshots at regular intervals – see the discussion of the checkpoint daemon.

Example:

```
tarantool> box.info.version
---
- 1.7.0-1216-g73f7154
...
tarantool> box.snapshot()
---
- ok
...
tarantool> box.snapshot()
---
- error: can't save snapshot, errno 17 (File exists)
...
```

Taking a snapshot does not cause the server to start a new write-ahead log. Once a snapshot is taken, old WALs can be deleted as long as all replicated data is up to date. But the WAL which was current at the time box.snapshot() started must be kept for recovery, since it still contains log records written after the start of box.snapshot().

An alternative way to save a snapshot is to send a SIGUSR1 signal to the instance. While this approach could be handy, it is not recommended for use in automation: a signal provides no way to find out whether the snapshot was taken successfully or not.

Vinyl

In vinyl, inserted data is stacked in memory until the limit, set in the vinyl_memory parameter, is reached. Then vinyl automatically dumps it to the disc. box.snapshot() forces this dump in order to have the ability to recover from this checkpoint. The snapshot files are stored in space_id/index_id/ *.run. Thus, strictly all the data that was written at the time of LSN of the checkpoint is in the *.run files on the disk, and all operations that happened after the checkpoint will be written in the *.xlog. All dump files created by box.snapshot() are consistent and have the same LSN as checkpoint.

At the checkpoint vinyl also rotates the metadata log *.vylog, containing data manipulation operations like "create file" and "delete file". It goes through the log, removes duplicating operations from the memory and creates a new *.vylog file, giving it the name according to the vclock of the new checkpoint, with "create" operations only. This procedure cleans *.vylog and is useful for recovery because the name of the log is the same as the checkpoint signature.

Submodule box.tuple

Overview

The box.tuple submodule provides read-only access for the tuple userdata type. It allows, for a single tuple: selective retrieval of the field contents, retrieval of information about size, iteration over all the fields, and conversion to a Lua table.

Index

Below is a list of all box.tuple functions.

Name	Use
box.tuple.new()	Create a tuple
#tuple_object	Count tuple fields
tuple_object:bsize()	Get count of bytes in a tuple
tuple_object[field-number]	Get a tuple's field by specifying a number
tuple_object[field-name]	Get a tuple's field by specifying a name
tuple_object[field-path]	Get a tuple's fields or parts by specifying a path
tuple_object:find()	Get the number of the first field matching the search value
tuple_object:findall()	Get the number of all fields matching the search value
tuple_object:next()	Get the next field value from tuple
tuple_object:ipairs()	Prepare for iterating
tuple_object:pairs()	Prepare for iterating
tuple_object:totable()	Get a tuple's fields as a table
tuple_object:tomap()	Get a tuple's fields as a table along with key:value pairs
tuple_object:transform()	Remove (and replace) a tuple's fields
tuple_object:unpack()	Get a tuple's fields
tuple_object:update()	Update a tuple
tuple_object:upsert()	Update a tuple ignoring errors

box.tuple.new(value)

Construct a new tuple from either a scalar or a Lua table. Alternatively, one can get new tuples from tarantool's select or insert or replace or update requests, which can be regarded as statements that do new() implicitly.

Parameters

- value (lua-value) – the value that will become the tuple contents.

Return a new tuple

Rtype tuple

In the following example, x will be a new table object containing one tuple and t will be a new tuple object. Saying t returns the entire tuple t.

Example:

```
tarantool> x = box.space.tester:insert{
         >   33,
         >   tonumber('1'),
         >   tonumber64('2')
         > }:totable()
---
...
```

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```
tarantool> t = box.tuple.new{'abc', 'def', 'ghi', 'abc'}
---
...
tarantool> t
---
- ['abc', 'def', 'ghi', 'abc']
...
```

object tuple_object

#<tuple_object>
The # operator in Lua means "return count of components". So, if t is a tuple instance, #t will return the number of fields.

Rtype number

In the following example, a tuple named t is created and then the number of fields in t is returned.

```
tarantool> t = box.tuple.new{'Fld#1', 'Fld#2', 'Fld#3', 'Fld#4'}
---
...
tarantool> #t
---
- 4
...
```

tuple_object:bsize()
If t is a tuple instance, t:bsize() will return the number of bytes in the tuple. With both the memtx storage engine and the vinyl storage engine the default maximum is one megabyte (memtx_max_tuple_size or vinyl_max_tuple_size). Every field has one or more "length" bytes preceding the actual contents, so bsize() returns a value which is slightly greater than the sum of the lengths of the contents.

The value does not include the size of "struct tuple" (for the current size of this structure look in the tuple.h file in Tarantool's source code).

Return number of bytes

Rtype number

In the following example, a tuple named t is created which has three fields, and for each field it takes one byte to store the length and three bytes to store the contents, and then there is one more byte to store a count of the number of fields, so bsize() returns 3*(1+3)+1. This is the same as the size of the string that msgpack.encode({'aaa','bbb','ccc'}) would return.

```
tarantool> t = box.tuple.new{'aaa', 'bbb', 'ccc'}
---
...
tarantool> t:bsize()
---
- 13
...
```

<tuple_object>(field-number)
If t is a tuple instance, t[field-number] will return the field numbered field-number in the tuple. The first field is t[1].

Return field value.

Rtype lua-value

In the following example, a tuple named t is created and then the second field in t is returned.

```
tarantool> t = box.tuple.new{'Fld#1', 'Fld#2', 'Fld#3', 'Fld#4'}
---
...
tarantool> t[2]
---
- Fld#2
...
```

<tuple_object>(field-name)

If t is a tuple instance, t['field-name'] will return the field named 'field-name' in the tuple. Fields have names if the tuple has been retrieved from a space that has an associated format. t[lua-variable-name] will do the same thing if lua-variable-name contains 'field-name'.

There is a variation which the Lua manual calls "syntactic sugar": use t.field-name as an equivalent of t['field-name'].

Return field value.

Rtype lua-value

In the following example, a tuple named t is returned from replace and then the second field in t named 'field2' is returned.

```
tarantool> format = {}
---
...
tarantool> format[1] = {name = 'field1', type = 'unsigned'}
---
...
tarantool> format[2] = {name = 'field2', type = 'string'}
---
...
tarantool> s = box.schema.space.create('test', {format = format})
---
...
tarantool> pk = s:create_index('pk')
---
...
tarantool> t = s:replace{1, 'Я'}
---
...
tarantool> t['field2']
---
- Я
...
```

<tuple_object>(field-path)

If t is a tuple instance, t['path'] will return the field or subset of fields that are in path. path must be a well formed JSON specification. path may contain field names if the tuple has been retrieved from a space that has an associated format.

To prevent ambiguity, Tarantool first tries to interpret the request as tuple_object[field-number] or tuple_object[field-name]. If and only if that fails, Tarantool tries to interpret the request as tuple_object[field-path].

The path must be a well formed JSON specification, but it may be preceded by '.'. The '.' is a signal that the path acts as a suffix for the tuple.

The advantage of specifying a path is that Tarantool will use it to search through a tuple body and get only the tuple part, or parts, that are actually necessary.

In the following example, a tuple named t is returned from replace and then only the relevant part (in this case, matching a name) of a relevant field is returned. Namely: the second field, the sixth part, the value following 'value='.

```
tarantool> format = {}
---
...
tarantool> format[1] = {name = 'field1', type = 'unsigned'}
---
...
tarantool> format[2] = {name = 'field2', type = 'array'}
---
...
tarantool> format[3] = {name = 'field4', type = 'string' }
---
...
tarantool> format[4] = {name = "[2][6]['пw']['Я']", type = 'string'}
---
...
tarantool> s = box.schema.space.create('test', {format = format})
---
...
tarantool> pk = s:create_index('pk')
---
...
tarantool> field2 = {1, 2, 3, "4", {5,6,7}, {пw={Я="п"}, key="V!", value="K!"}}
---
...
tarantool> t = s:replace{1, field2, "123456", "Not K!"}
---
...
tarantool> t["[2][6]['value']"]
---
- K!
...
```

tuple_object:find([field-number], search-value)

tuple_object:findall([field-number], search-value)

If t is a tuple instance, t:find(search-value) will return the number of the first field in t that matches the search value, and t:findall(search-value [, search-value ...]) will return numbers of all fields in t that match the search value. Optionally one can put a numeric argument field-number before the search-value to indicate "start searching at field number field-number."

Return the number of the field in the tuple.

Rtype number

In the following example, a tuple named t is created and then: the number of the first field in t which matches 'a' is returned, then the numbers of all the fields in t which match 'a' are returned, then the numbers of all the fields in t which match 'a' and are at or after the second field are returned.

```
tarantool> t = box.tuple.new{'a', 'b', 'c', 'a'}
---
...
tarantool> t:find('a')
---
- 1
...
tarantool> t:findall('a')
---
- 1
- 4
...
tarantool> t:findall(2, 'a')
---
- 4
...
```

tuple_object:next(tuple[, pos])

An analogue of the Lua next() function, but for a tuple object. When called without arguments, tuple:next() returns the first field from a tuple. Otherwise, it returns the field next to the indicated position.

However tuple:next() is not really efficient, and it is better to use tuple:pairs()/ipairs().

Return field number and field value

Rtype number and field type

```
tarantool> tuple = box.tuple.new({5, 4, 3, 2, 0})
---
...

tarantool> tuple:next()
---
- 1
- 5
...

tarantool> tuple:next(1)
---
- 2
- 4
...

tarantool> ctx, field = tuple:next()
---
...

tarantool> while field do
         > print(field)
         > ctx, field = tuple:next(ctx)
         > end
5
4
3
2
0
---
```

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```
...
```

tuple_object:pairs()
tuple_object:ipairs()

In Lua, lua-table-value:pairs() is a method which returns: function, lua-table-value, nil. Tarantool has extended this so that tuple-value:pairs() returns: function, tuple-value, nil. It is useful for Lua iterators, because Lua iterators traverse a value's components until an end marker is reached.

tuple_object:ipairs() is the same as pairs(), because tuple fields are always integers.

Return function, tuple-value, nil

Rtype function, lua-value, nil

In the following example, a tuple named t is created and then all its fields are selected using a Lua for-end loop.

```
tarantool> t = box.tuple.new{'Fld#1', 'Fld#2', 'Fld#3', 'Fld#4', 'Fld#5'}
---
...
tarantool> tmp = ''
---
...
tarantool> for k, v in t:pairs() do
         >   tmp = tmp .. v
         > end
---
...
tarantool> tmp
---
- Fld#1Fld#2Fld#3Fld#4Fld#5
...
```

tuple_object:totable([start-field-number[, end-field-number]])

If t is a tuple instance, t:totable() will return all fields, t:totable(1) will return all fields starting with field number 1, t:totable(1,5) will return all fields between field number 1 and field number 5.

It is preferable to use t:totable() rather than t:unpack().

Return field(s) from the tuple

Rtype lua-table

In the following example, a tuple named t is created, then all its fields are selected, then the result is returned.

```
tarantool> t = box.tuple.new{'Fld#1', 'Fld#2', 'Fld#3', 'Fld#4', 'Fld#5'}
---
...
tarantool> t:totable()
---
- ['Fld#1', 'Fld#2', 'Fld#3', 'Fld#4', 'Fld#5']
...
```

tuple_object:tomap([options])

A Lua table can have indexed values, also called key:value pairs. For example, here:

```
a = {}; a['field1'] = 10; a['field2'] = 20
```

a is a table with "field1: 10" and "field2: 20".

The tuple_object:totable() function only returns a table containing the values. But the tuple_object:tomap() function returns a table containing not only the values, but also the key:value pairs.

This only works if the tuple comes from a space that has been formatted with a format clause.

Parameters

- options (table) – the only possible option is names_only.

  If names_only is false or omitted (default), then all the fields will appear twice, first with numeric headings and second with name headings.

  If names_only is true, then all the fields will appear only once, with name headings.

Return field-number:value pair(s) and key:value pair(s) from the tuple

Rtype lua-table

In the following example, a tuple named t1 is returned from a space that has been formatted, then tables named t1map1 and t1map2 are produced from t1.

```
format = {{'field1', 'unsigned'}, {'field2', 'unsigned'}}
s = box.schema.space.create('test', {format = format})
s:create_index('pk',{parts={1,'unsigned',2,'unsigned'}})
t1 = s:insert{10, 20}
t1map = t1:tomap()
t1map_names_only = t1:tomap({names_only=true})
```

t1map will contain "1: 10", "2: 20", "field1: 10", "field2: 20".

t1map_names_only will contain "field1: 10", "field2: 20".

tuple_object:transform(start-field-number, fields-to-remove[, field-value, ...])

If t is a tuple instance, t:transform(start-field-number,fields-to-remove) will return a tuple where, starting from field start-field-number, a number of fields (fields-to-remove) are removed. Optionally one can add more arguments after fields-to-remove to indicate new values that will replace what was removed.

If the original tuple comes from a space that has been formatted with a format clause, the formatting will not be preserved for the result tuple.

Parameters

- start-field-number (integer) – base 1, may be negative
- fields-to-remove (integer) –
- field-value(s) (lua-value) –

Return tuple

Rtype tuple

In the following example, a tuple named t is created and then, starting from the second field, two fields are removed but one new one is added, then the result is returned.

```
tarantool> t = box.tuple.new{'Fld#1', 'Fld#2', 'Fld#3', 'Fld#4', 'Fld#5'}
---
...
tarantool> t:transform(2, 2, 'x')
---
- ['Fld#1', 'x', 'Fld#4', 'Fld#5']
...
```

tuple_object:unpack([start-field-number[, end-field-number]])

If t is a tuple instance, t:unpack() will return all fields, t:unpack(1) will return all fields starting with field number 1, t:unpack(1,5) will return all fields between field number 1 and field number 5.

Return field(s) from the tuple.

Rtype lua-value(s)

In the following example, a tuple named t is created and then all its fields are selected, then the result is returned.

```
tarantool> t = box.tuple.new{'Fld#1', 'Fld#2', 'Fld#3', 'Fld#4', 'Fld#5'}
---
...
tarantool> t:unpack()
---
- Fld#1
- Fld#2
- Fld#3
- Fld#4
- Fld#5
...
```

tuple_object:update({{operator, field_no, value}, ...})

Update a tuple.

This function updates a tuple which is not in a space. Compare the function box.space.space-name:update(key, {{format, field_identifier, value}, ...}) which updates a tuple in a space.

For details: see the description for operator, field_identifier, and value in the section box.space.space-name:update{key, format, {field_identifier, value}. . . }.

If the original tuple comes from a space that has been formatted with a format clause, the formatting will be preserved for the result tuple.

Parameters

- operator (string) – operation type represented in string (e.g. '=' for 'assign new value')
- field_no (number) – what field the operation will apply to. The field number can be negative, meaning the position from the end of tuple. (#tuple + negative field number + 1)
- value (lua_value) – what value will be applied

Return new tuple

Rtype tuple

In the following example, a tuple named t is created and then its second field is updated to equal 'B'.

```
tarantool> t = box.tuple.new{'Fld#1', 'Fld#2', 'Fld#3', 'Fld#4', 'Fld#5'}
---
...
tarantool> t:update({{'=', 2, 'B'}})
---
- ['Fld#1', 'B', 'Fld#3', 'Fld#4', 'Fld#5']
...
```

Since Tarantool 2.3 a tuple can also be updated via JSON paths.

tuple_object:upsert({{operator, field_no, value}, ...})

The same as tuple_object:update(), but ignores errors. In case of an error the tuple is left intact, but an error message is printed. Only client errors are ignored, such as a bad field type, or wrong field index/name. System errors, such as OOM, are not ignored and raised just like with a normal update(). Note that only bad operations are ignored. All correct operations are applied.

Parameters

- operator (string) – operation type represented as a string (e.g. '=' for 'assign new value')
- field_no (number) – the field to which the operation will be applied. The field number can be negative, meaning the position from the end of tuple. (#tuple + negative field number + 1)
- value (lua_value) – the value which will be applied

Return new tuple

Rtype tuple

See the following example where one operation is applied, and one is not.

```
tarantool> t = box.tuple.new({1, 2, 3})
tarantool> t2 = t:upsert({{'=', 5, 100}})
UPSERT operation failed:
ER_NO_SUCH_FIELD_NO: Field 5 was not found in the tuple
---
...

tarantool> t
---
- [1, 2, 3]
...

tarantool> t2
---
- [1, 2, 3]
...

tarantool> t2 = t:upsert({{'=', 5, 100}, {'+', 1, 3}})
UPSERT operation failed:
ER_NO_SUCH_FIELD_NO: Field 5 was not found in the tuple
---
...

tarantool> t
---
- [1, 2, 3]
```

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```
...

tarantool> t2
---
- [4, 2, 3]
...
```

Example

This function will illustrate how to convert tuples to/from Lua tables and lists of scalars:

```
tuple = box.tuple.new({scalar1, scalar2, ... scalar_n}) -- scalars to tuple
lua_table = {tuple:unpack()}                            -- tuple to Lua table
lua_table = tuple:totable()                             -- tuple to Lua table
scalar1, scalar2, ... scalar_n = tuple:unpack()         -- tuple to scalars
tuple = box.tuple.new(lua_table)                        -- Lua table to tuple
```

Then it will find the field that contains 'b', remove that field from the tuple, and display how many bytes remain in the tuple. The function uses Tarantool box.tuple functions new(), unpack(), find(), transform(), bsize().

```
function example()
  local tuple1, tuple2, lua_table_1, scalar1, scalar2, scalar3, field_number
  local luatable1 = {}
  tuple1 = box.tuple.new({'a', 'b', 'c'})
  luatable1 = tuple1:totable()
  scalar1, scalar2, scalar3 = tuple1:unpack()
  tuple2 = box.tuple.new(luatable1[1],luatable1[2],luatable1[3])
  field_number = tuple2:find('b')
  tuple2 = tuple2:transform(field_number, 1)
  return 'tuple2 = ' , tuple2 , ' # of bytes = ' , tuple2:bsize()
end
```

. . . And here is what happens when one invokes the function:

```
tarantool> example()
---
- tuple2 =
- ['a', 'c']
- ' # of bytes = '
- 5
...
```

Functions for transaction management

Overview

For general information and examples, see section Transaction control.

Observe the following rules when working with transactions:

Rule #1

The requests in a transaction must be sent to a server as a single block. It is not enough to enclose them between begin and commit or rollback. To ensure they are sent as a single block: put them in a function, or put them all on one line, or use a delimiter so that multi-line requests are handled together.

Rule #2

All database operations in a transaction should use the same storage engine. It is not safe to access tuple sets that are defined with {engine=`'vinyl'`} and also access tuple sets that are defined with {engine=`'memtx'`}, in the same transaction.

Rule #3

Requests which cause changes to the data definition – create, alter, drop, truncate – are only allowed with Tarantool version 2.1 or later. Data-definition requests which change an index or change a format, such as space_object:create_index() and space_object:format(), are not allowed inside transactions except as the first request after box.begin().

Index

Below is a list of all functions for transaction management.

Name	Use
box.begin()	Begin the transaction
box.commit()	End the transaction and save all changes
box.rollback()	End the transaction and discard all changes
box.savepoint()	Get a savepoint descriptor
box.rollback_to_savepoint()	Do not end the transaction and discard all changes made after a savepoint
box.atomic()	Execute a function, treating it as a transaction
box.on_commit()	Define a trigger that will be activated by box.commit
box.on_rollback()	Define a trigger that will be activated by box.rollback
box.is_in_txn()	State whether a transaction is in progress

box.begin()

Begin the transaction. Disable implicit yields until the transaction ends. Signal that writes to the write-ahead log will be deferred until the transaction ends. In effect the fiber which executes box.begin() is starting an “active multi-request transaction”, blocking all other fibers.

Possible errors: error if this operation is not permitted because there is already an active transaction. error if for some reason memory cannot be allocated.

box.commit()

End the transaction, and make all its data-change operations permanent.

Possible errors: error and abort the transaction in case of a conflict. error if the operation fails to write to disk. error if for some reason memory cannot be allocated.

box.rollback()

End the transaction, but cancel all its data-change operations. An explicit call to functions outside box.space that always yield, such as fiber.sleep() or fiber.yield(), will have the same effect.

box.savepoint()

Return a descriptor of a savepoint (type = table), which can be used later by box.rollback_to_savepoint(savepoint). Savepoints can only be created while a transaction is active, and they are destroyed when a transaction ends.

Return savepoint table

Rtype Lua object

Return error if the savepoint cannot be set in absence of active transaction.

Possible errors: error if for some reason memory cannot be allocated.

box.rollback_to_savepoint(savepoint)

Do not end the transaction, but cancel all its data-change and box.savepoint() operations that were done after the specified savepoint.

Return error if the savepoint cannot be set in absence of active transaction.

Possible errors: error if the savepoint does not exist.

Example:

```
function f()
  box.begin()           -- start transaction
  box.space.t:insert{1} -- this will not be rolled back
  local s = box.savepoint()
  box.space.t:insert{2} -- this will be rolled back
  box.rollback_to_savepoint(s)
  box.commit()          -- end transaction
end
```

box.atomic(tx-function[, function-arguments])

Execute a function, acting as if the function starts with an implicit box.begin() and ends with an implicit box.commit() if successful, or ends with an implicit box.rollback() if there is an error.

Return the result of the function passed to atomic() as an argument.

Possible errors: any error that box.begin() and box.commit() can return.

box.on_commit(trigger-function[, old-trigger-function])

Define a trigger for execution when a transaction ends due to an event such as box.commit.

The trigger function may take an iterator parameter, as described in an example for this section.

The trigger function should not access any database spaces.

If the trigger execution fails and raises an error, the effect is severe and should be avoided – use Lua's pcall() mechanism around code that might fail.

box.on_commit() must be invoked within a transaction, and the trigger ceases to exist when the transaction ends.

Parameters

- trigger-function (function) – function which will become the trigger function
- old-trigger-function (function) – existing trigger function which will be replaced by trigger-function

Return nil or function pointer

If the parameters are (nil, old-trigger-function), then the old trigger is deleted.

Details about trigger characteristics are in the triggers section.

Simple and useless example: this will display 'commit happened':

```
function f()
function f() print('commit happened') end
box.begin() box.on_commit(f) box.commit()
```

But of course there is more to it: the function parameter can be an ITERATOR.

The iterator goes through the effects of every request that changed a space during the transaction.

The iterator will have:

- an ordinal request number,
- the old value of the tuple before the request (this will be nil for an insert request),
- the new value of the tuple after the request (this will be nil for a delete request),
- and the id of the space.

Less simple more useful example: this will display the effects of two replace requests:

```
box.space.test:drop()
s = box.schema.space.create('test')
i = box.space.test:create_index('i')
function f(iterator)
  for request_number, old_tuple, new_tuple, space_id in iterator() do
    print('request_number ' .. tostring(request_number))
    print('  old_tuple ' .. tostring(old_tuple[1]) .. ' ' .. old_tuple[2])
    print('  new_tuple ' .. tostring(new_tuple[1]) .. ' ' .. new_tuple[2])
    print('  space_id ' .. tostring(space_id))
  end
end
s:insert{1,'-'}
box.begin() s:replace{1,'x'} s:replace{1,'y'} box.on_commit(f) box.commit()
```

The result will look like this:

```
tarantool> box.begin() s:replace{1,'x'} s:replace{1,'y'} box.on_commit(f) box.commit()
request_number 1
  old_tuple 1 -
  new_tuple 1 x
  space_id 517
request_number 2
  old_tuple 1 x
  new_tuple 1 y
  space_id 517
```

box.on_rollback(trigger-function[, old-trigger-function])

Define a trigger for execution when a transaction ends due to an event such as box.rollback.

The parameters and warnings are exactly the same as for box.on-commit.

box.is_in_txn()

If a transaction is in progress (for example the user has called box.begin and has not yet called either box.commit or box.rollback, return true. Otherwise return false.

Functions for SQL

The box module contains some functions related to SQL:

- box.schema.func.create – for making Lua functions callable from SQL statements. See Calling Lua routines from SQL in the SQL Plus Lua section.
- box.execute – for making SQL statements callable from Lua functions. See the SQL user guide.
- box.prepare and box.unprepare.

Some SQL statements are illustrated in the SQL tutorial.

box.execute(sql-statement[, extra-parameters])

Execute the SQL statement contained in the sql-statement parameter.

Parameters

- sql-statement (string) – statement, which should conform to the rules for SQL grammar
- extra-parameters (table) – optional table for placeholders in the statement

Return depends on statement

There are two ways to pass extra parameters for box.execute():

- The first way, which is the preferred way, is to put placeholders in the string, and pass a second argument, an extra-parameters table. A placeholder is either a question mark "?", or a colon ":" followed by a name. An extra parameter is any Lua expression. If placeholders are question marks, then they will be replaced by extra-parameter values in corresponding positions, that is, the first ? will be replaced by the first extra parameter, the second ? will be replaced by the second extra parameter, and so on. If placeholders are :names, then they will be replaced by extra-parameter values with corrresponding names. For example this request which contains literal values 1 and 'x': box.execute([[INSERT INTO tt VALUES (1, 'x');]]); is the same as this request which contains two question-mark placeholders (? and ?) and a two-element extra-parameters table: x = {1,'x'} box.execute([[INSERT INTO tt VALUES (?, ?);]], x); and is the same as this request which contains two :name placeholders (:a and :b) and a two-element extra-parameters table with elements named "a" and "b": box.execute([[INSERT INTO tt VALUES (:a, :b);]], {{[':a']=1},{[':b']='x'}})
- The second way is to concatenate strings. For example, this Lua script will insert 10 rows with different primary-key values into table t: for i=1,10,1 do   box.execute("insert into t values (" .. i .. ")") end When creating SQL statements based on user input, application developers should beware of SQL injection.

Since box.execute() is an invocation of a Lua function, it either causes an error message or returns a value.

For some statements the returned value will contain a field named "rowcount". For example;

```
tarantool> box.execute([[CREATE TABLE table1 (column1 INT PRIMARY key, column2 VARCHAR(10));
↪]])
---
- rowcount: 1
...
tarantool> box.execute([[INSERT INTO table1 VALUES (55,'Hello SQL world!');]])
---
- rowcount: 1
...
```

For statements that cause generation of values for PRIMARY KEY AUTOINCREMENT columns, there will also be a field named "autoincrement_ids".

For SELECT or PRAGMA statements, the returned value will be a result set, containing a field named "metadata" (a table with column names and Tarantool/NoSQL type names) and a field named "rows" (a table with the contents of each row).

For example, for a statement SELECT "x" FROM t WHERE "x"=5; where "x" is an INTEGER column and there is one row, a display on the Tarantool client will look like this:

```
tarantool> box.execute([[SELECT "x" FROM t WHERE "x"=5;]])
---
- metadata:
  - name: x
    type: integer
  rows:
  - [5]
...
```

The data for the result set, in MsgPack format, will look like this

```
dd 00 00 00 01                1-element array
82                         2-element map (for metadata + rows)
a8 6d 65 74 61 64 61 74 61       string = "metadata"
91                         1-element array (for column count)
82                         2-element map (for name + type)
a4 6e 61 6d 65                  string = "name"
a1 78                       string = "x"
a4 74 79 70 6                  string = "type"
a7 69 6e 74 65 67 65 72            string = "integer"
a4 72 6f 77 73                  string = "rows"
91                         1-element array (for row count)
91                         1-element array (for field count)
05                         contents
```

For a look at the raw format see Binary protocol – illustration.

The order of components within a map is not guaranteed.

If sql_full_metadata in the _session_settings system table is TRUE, then result set metadata may include these things in addition to name and type:

- collation (present only if COLLATE clause is specified for a STRING) = "Collation".
- is_nullable (present only if the select list specified a base table column and nothing else) = false if column was defined as NOT NULL, otherwise true. If this is not present, that implies that nullability is unknown.
- is_autoincrement (present only if the select list specified a base table column and nothing else) = true if column was defined as PRIMARY KEY AUTOINCREMENT, otherwise false.
- span (always present) = the original expression in a select list, which will often be the same as name if the select list specifies a column name and nothing else, but otherwise will differ, for example after SELECT x+55 AS x FROM t; the name is X and the span is x+55. If span and name are the same then the content is MP_NIL.

Alternative: if you are using the Tarantool server as a client, you can switch languages thus:

```
\set language sql
\set delimiter ;
```

Afterwards, you can enter any SQL statement directly without needing box.execute().

There is also an execute() function available via module net.box, for example after conn = net_box.connect(url-string) one can say conn:execute(sql-statement]).

box.prepare(sql-statement)

Prepare the SQL statement contained in the sql-statement parameter. The syntax and requirements for box.prepare are the same as for box.execute.

Parameters

- sql-statement (string) – statement, which should conform to the rules for SQL grammar

Return prepared_table, with id and methods and metadata

Rtype table

box.prepare compiles an SQL statement into byte code and saves the byte code in a cache. Since compiling takes a significant amount of time, preparing a statement will enhance performance if the statement is executed many times.

If box.prepare succeeds, prepared_table contains:

- stmt_id: integer – an identifier generated by a hash of the statement string
- execute: function
- params: map [name : string, type : string] – parameter descriptions
- unprepare: function
- metadata: map [name : string, type : string] (This is present only for SELECT or PRAGMA statements and has the same contents as the result set metadata for box.execute)
- param_count: integer – number of parameters

This can be used by prepared_table:execute() and by prepared_table:unprepare().

The prepared statement cache (which is also called the prepared statement holder) is "shared", that is, there is one cache for all sessions. However, session X cannot execute a statement prepared by session Y. For monitoring the cache, see box.info().sql. For changing the cache, see (Configuration reference) sql_cache_size.

Prepared statements will "expire" (become invalid) if any database object is dropped or created or altered – even if the object is not mentioned in the SQL statement, even if the create or drop or alter is rolled back, even if the create or drop or alter is done in a different session.

object prepared_table

prepared_table:execute([extra-parameters])

Execute a statement that has been prepared with box.prepare().

Parameter prepared_table should be the result from box.prepare(). Parameter extra-parameters should be an optional table to match placeholders or named parameters in the statement.

There are two ways to execute: with the method or with the statement id. That is, prepared_table:execute() and box.execute(prepared_table.stmt_id) do the same thing.

Example: here is a test. This function inserts a million rows in a table using a prepared INSERT statement.

```
function f()
  local p, start_time
  box.execute([[DROP TABLE IF EXISTS t;]])
  box.execute([[CREATE TABLE t (s1 INTEGER PRIMARY KEY);]])
  start_time = os.time()
  p = box.prepare([[INSERT INTO t VALUES (?);]])
  for i=1,1000000 do p:execute({i}) end
  p:unprepare()
  end_time = os.time()
  box.execute([[COMMIT;]])
  print(end_time - start_time) -- elapsed time
end
f()
```

Take note of the elapsed time. Now change the line with the loop to: for i=1,1000000 do box.execute([[INSERT INTO t VALUES (?);]], {i}) end Run the function again, and take note of the elapsed time again. The function which executes the prepared statement will be about 15% faster, though of course this will vary depending on Tarantool version and environment.

prepared_table:unprepare()

Undo the result of an earlier box.prepare() request. This is equivalent to standard-SQL DEALLOCATE PREPARE.

Parameter prepared_table should be the result from box.prepare().

There are two ways to unprepare: with the method or with the statement id. That is, prepared_table:unprepare() and box.unprepare(prepared_table.stmt_id) do the same thing.

Tarantool strongly recommends using unprepare as soon as the immediate objective (executing a prepared statement multiple times) is done, or whenever a prepared statement expires. There is no automatic eviction policy, although automatic unprepare will happen when the session disconnects (the session's prepared statements will be removed from the prepared-statment cache).

5.2.2 Module buffer

The buffer module returns a dynamically resizable buffer which is solely for optional use by methods of the net.box module or the msgpack module.

Ordinarily the net.box methods return a Lua table. If a buffer option is used, then the net.box methods return a raw MsgPack string. This saves time on the server, if the client application has its own routine for decoding raw MsgPack strings.

The buffer uses four pointers to manage its capacity:

- buf – a pointer to the beginning of the buffer
- rpos – a pointer to the beginning of the range; available for reading data ("read position")
- wpos – a pointer to the end of the range; available for reading data, and to the beginning of the range for writing new data ("write position")
- epos – a pointer to the end of the range; available for writing new data ("end position")

buffer.ibuf()

Create a new buffer.

Example:

In this example we will show that using buffer allows you to keep the data in the format that you get from the server. So if you get the data only for sending it somewhere else, buffer fastens this a lot.

```
box.cfg{listen = 3301}
buffer = require('buffer')
net_box = require('net.box')
msgpack = require('msgpack')

box.schema.space.create('tester')
box.space.tester:create_index('primary')
box.space.tester:insert({1, 'ABCDE', 12345})

box.schema.user.create('usr1', {password = 'pwd1'})
box.schema.user.grant('usr1', 'read,write,execute', 'space', 'tester')

ibuf = buffer.ibuf()

conn = net_box.connect('usr1:pwd1@localhost:3301')
conn.space.tester:select({}, {buffer=ibuf})

msgpack.decode_unchecked(ibuf.rpos)
```

The result of the final request looks like this:

```
tarantool> msgpack.decode_unchecked(ibuf.rpos)
---
- {48: [['ABCDE', 12345]]}
- 'cdata<char *>: 0x7f97ba10c041'
...
```

Note: Before Tarantool version 1.7.7, the function to use for this case is msgpack.ibuf_decode(ibuf.rpos). Starting with Tarantool version 1.7.7, ibuf_decode is deprecated.

object buffer_object

buffer_object:alloc(size)
Allocate size bytes for buffer_object.

Parameters

- size (number) – memory in bytes to allocate

Return wpos

buffer_object:capacity()
Return the capacity of the buffer_object.

Return epos - buf

buffer_object:checksize(size)
Check if size bytes are available for reading in buffer_object.

Parameters

- size (number) – memory in bytes to check

Return rpos

buffer_object:pos()
Return the size of the range occupied by data.

Return rpos - buf

buffer_object:read(size)
: Read size bytes from buffer.

buffer_object:recycle()
: Clear the memory slots allocated by buffer_object.

```
tarantool> ibuf:recycle()
---
...
tarantool> ibuf.buf, ibuf.rpos, ibuf.wpos, ibuf.epos
---
- 'cdata<char *>: NULL'
- 'cdata<char *>: NULL'
- 'cdata<char *>: NULL'
- 'cdata<char *>: NULL'
...
```

buffer_object:reset()
: Clear the memory slots used by buffer_object. This method allows to keep the buffer but remove data from it. It is useful when you want to use the buffer further.

```
tarantool> ibuf:reset()
---
...
tarantool> ibuf.buf, ibuf.rpos, ibuf.wpos, ibuf.epos
---
- 'cdata<char *>: 0x010cc28030'
- 'cdata<char *>: 0x010cc28030'
- 'cdata<char *>: 0x010cc28030'
- 'cdata<char *>: 0x010cc2c000'
...
```

buffer_object:reserve(size)
: Reserve memory for buffer_object. Check if there is enough memory to write size bytes after wpos. If not, epos shifts until size bytes will be available.

buffer_object:size()
: Return a range, available for reading data.

  Return wpos - rpos

buffer_object:unused()
: Return a range for writing data.

  Return epos - wpos

Module buffer and skip_header

The example in the previous section

```
tarantool> msgpack.decode_unchecked(ibuf.rpos)
---
- {48: [['ABCDE', 12345]]}
- 'cdata<char *>: 0x7f97ba10c041'
...
```

showed that, ordinarily, the response from net.box includes a header – 48 (hexadecimal 30) that is the key for IPROTO_DATA. But in some situations, for example when passing the buffer to a C function that expects a MsgPack byte array without a header, the header can be skipped. This is done by specifying skip_header=true as an option to conn.space.space-name:select{...} or conn.space.space-name:insert{...}

or conn.space.space-name:replace{. . . } or conn.space.space-name:update{. . . } or conn.space.space-name:upsert{. . . } or conn.space.space-name:delete{. . . }. The default is skip_header=false.

Now here is the end of the same example, except that skip_header=true is used.

```
ibuf = buffer.ibuf()

conn = net_box.connect('usr1:pwd1@localhost:3301')
conn.space.tester:select({}, {buffer=ibuf, skip_header=true})

msgpack.decode_unchecked(ibuf.rpos)
```

The result of the final request looks like this:

```
tarantool> msgpack.decode_unchecked(ibuf.rpos)
---
- [['ABCDE', 12345]]
- 'cdata<char *>: 0x7f8fd102803f'
...
```

Notice that the IPROTO_DATA header (48) is gone.

The result is still inside an array, as is clear from the fact that it is shown inside square brackets. It is possible to skip the array header too, with msgpack.decode_array_header().

5.2.3 Module clock

Overview

The clock module returns time values derived from the Posix / C CLOCK_GETTIME function or equivalent. Most functions in the module return a number of seconds; functions whose names end in “64” return a 64-bit number of nanoseconds.

Index

Below is a list of all clock functions.

Name	Use
clock.time() clock.realtime()	Get the wall clock time in seconds
clock.time64() clock.realtime64()	Get the wall clock time in nanoseconds
clock.monotonic()	Get the monotonic time in seconds
clock.monotonic64()	Get the monotonic time in nanoseconds
clock.proc()	Get the processor time in seconds
clock.proc64()	Get the processor time in nanoseconds
clock.thread()	Get the thread time in seconds
clock.thread64()	Get the thread time in nanoseconds
clock.bench()	Measure the time a function takes within a processor

clock.time()
clock.time64()
clock.realtime()
clock.realtime64()

The wall clock time. Derived from C function clock_gettime(CLOCK_REALTIME). This is the best function for knowing what the official time is, as determined by the system administrator.

Return seconds or nanoseconds since epoch (1970-01-01 00:00:00), adjusted.

Rtype number or number64

Example:

```
-- This will print an approximate number of years since 1970.
clock = require('clock')
print(clock.time() / (365*24*60*60))
```

See also fiber.time64 and the standard Lua function os.clock.

clock.monotonic()
clock.monotonic64()

The monotonic time. Derived from C function clock_gettime(CLOCK_MONOTONIC). Monotonic time is similar to wall clock time but is not affected by changes to or from daylight saving time, or by changes done by a user. This is the best function to use with benchmarks that need to calculate elapsed time.

Return seconds or nanoseconds since the last time that the computer was booted.

Rtype number or number64

Example:

```
-- This will print nanoseconds since the start.
clock = require('clock')
print(clock.monotonic64())
```

clock.proc()
clock.proc64()

The processor time. Derived from C function clock_gettime(CLOCK_PROCESS_CPUTIME_ID). This is the best function to use with benchmarks that need to calculate how much time has been spent within a CPU.

Return seconds or nanoseconds since processor start.

Rtype number or number64

Example:

```
-- This will print nanoseconds in the CPU since the start.
clock = require('clock')
print(clock.proc64())
```

clock.thread()
clock.thread64()

The thread time. Derived from C function clock_gettime(CLOCK_THREAD_CPUTIME_ID). This is the best function to use with benchmarks that need to calculate how much time has been spent within a thread within a CPU.

Return seconds or nanoseconds since the transaction processor thread started.

Rtype number or number64

Example:

```
-- This will print seconds in the thread since the start.
clock = require('clock')
print(clock.thread64())
```

clock.bench(function[, ...])

The time that a function takes within a processor. This function uses clock.proc(), therefore it calculates elapsed CPU time. Therefore it is not useful for showing actual elapsed time.

Parameters

- function (function) – function or function reference
- ... – whatever values are required by the function.

Return table. first element - seconds of CPU time, second element - whatever the function returns.

Example:

```
-- Benchmark a function which sleeps 10 seconds.
-- NB: bench() will not calculate sleep time.
-- So the returned value will be {a number less than 10, 88}.
clock = require('clock')
fiber = require('fiber')
function f(param)
  fiber.sleep(param)
  return 88
end
clock.bench(f, 10)
```

5.2.4 Module console

Overview

The console module allows one Tarantool instance to access another Tarantool instance, and allows one Tarantool instance to start listening on an admin port.

Index

Below is a list of all console functions.

Name	Use
console.connect()	Connect to an instance
console.listen()	Listen for incoming requests
console.start()	Start the console
console.ac()	Set the auto-completion flag
console.delimiter()	Set a delimiter
console.get_default_output()	Get default output format
console.set_default_output()	Set default output format
console.eos()	Set or get end-of-output string

console.connect(uri)

Connect to the instance at URI, change the prompt from 'tarantool>' to 'uri>', and act henceforth as a client until the user ends the session or types control-D.

The console.connect function allows one Tarantool instance, in interactive mode, to access another Tarantool instance. Subsequent requests will appear to be handled locally, but in reality the requests are being sent to the remote instance and the local instance is acting as a client. Once connection is successful, the prompt will change and subsequent requests are sent to, and executed on, the remote instance. Results are displayed on the local instance. To return to local mode, enter control-D.

If the Tarantool instance at uri requires authentication, the connection might look something like: console.connect('admin:secretpassword@distanthost.com:3301').

There are no restrictions on the types of requests that can be entered, except those which are due to privilege restrictions – by default the login to the remote instance is done with user name = 'guest'. The remote instance could allow for this by granting at least one privilege: box.schema.user.grant('guest', 'execute','universe').

Parameters

- uri (string) – the URI of the remote instance

Return nil

Possible errors: the connection will fail if the target Tarantool instance was not initiated with box.cfg{listen=...}.

Example:

```
tarantool> console = require('console')
---
...
tarantool> console.connect('198.18.44.44:3301')
---
...
198.18.44.44:3301> -- prompt is telling us that instance is remote
```

console.listen(uri)

Listen on URI. The primary way of listening for incoming requests is via the connection-information string, or URI, specified in box.cfg{listen=...}. The alternative way of listening is via the URI specified in console.listen(...). This alternative way is called "administrative" or simply "admin port". The listening is usually over a local host with a Unix domain socket.

Parameters

- uri (string) – the URI of the local instance

The "admin" address is the URI to listen on. It has no default value, so it must be specified if connections will occur via an admin port. The parameter is expressed with URI = Universal Resource Identifier format, for example "/tmpdir/unix_domain_socket.sock", or a numeric TCP port. Connections are often made with telnet. A typical port value is 3313.

Example:

```
tarantool> console = require('console')
---
...
tarantool> console.listen('unix/:/tmp/X.sock')
... main/103/console/unix/:/tmp/X I> started
---
- fd: 6
  name:
    host: unix/
    family: AF_UNIX
    type: SOCK_STREAM
    protocol: 0
    port: /tmp/X.sock
...
```

console.start()

Start the console on the current interactive terminal.

Example:

A special use of console.start() is with initialization files. Normally, if one starts the Tarantool instance with tarantool initialization file there is no console. This can be remedied by adding these lines at the end of the initialization file:

```
local console = require('console')
console.start()
```

console.ac([true|false])

Set the auto-completion flag. If auto-completion is true, and the user is using Tarantool as a client or the user is using Tarantool via console.connect(), then hitting the TAB key may cause tarantool to complete a word automatically. The default auto-completion value is true.

console.delimiter(marker)

Set a custom end-of-request marker for Tarantool console.

The default end-of-request marker is a newline (line feed). Custom markers are not necessary because Tarantool can tell when a multi-line request has not ended (for example, if it sees that a function declaration does not have an end keyword). Nonetheless for special needs, or for entering multi-line requests in older Tarantool versions, you can change the end-of-request marker. As a result, newline alone is not treated as end of request.

To go back to normal mode, say: console.delimiter('')<marker>

Parameters

- marker (string) – a custom end-of-request marker for Tarantool console

Example:

```
tarantool> console = require('console'); console.delimiter('!')
---
...
tarantool> function f ()
         > statement_1 = 'a'
         > statement_2 = 'b'
         > end!
---
...
tarantool> console.delimiter('')!
---
...
```

console.get_default_output()

Return the current default output format. The result will be fmt="yaml", or it will be fmt="lua" if the last set_default_output call was console.set_default_output('lua').

console.set_default_output('yaml'|'lua')

Set the default output format. The possible values are 'yaml' (the default default) or 'lua'. The output format can be changed within a session by executing console.eval('\\set output yaml|lua'); see the description of output format in the Interactive console section.

console.eos([string])

Set or access the end-of-output string if default output is 'lua'. This is the string that appears at the end of output in a response to any Lua request. The default value is ; semicolon. Saying eos() will return the current value. For example, after require('console').eos('!!') responses will end with '!!'.

5.2.5 Module crypto

Overview

"Crypto" is short for "Cryptography", which generally refers to the production of a digest value from a function (usually a Cryptographic hash function), applied against a string. Tarantool's crypto module supports ten types of cryptographic hash functions (AES, DES, DSS, MD4, MD5, MDC2, RIPEMD, SHA-1, SHA-2). Some of the crypto functionality is also present in the Module digest module.

Index

Below is a list of all crypto functions.

Name	Use
crypto.cipher.{algorithm}.{cipher_mode}.encrypt()	Encrypt a string
crypto.cipher.{algorithm}.{cipher_mode}.decrypt()	Decrypt a string
crypto.digest.{algorithm}()	Get a digest
crypto.hmac.{algorithm}()	Get a hash key

crypto.cipher.{aes128|aes192|aes256|des}.{cbc|cfb|ecb|ofb}.encrypt(string, key, initialization_vector)
crypto.cipher.{aes128|aes192|aes256|des}.{cbc|cfb|ecb|ofb}.decrypt(string, key, initialization_vector)

Pass or return a cipher derived from the string, key, and (optionally, sometimes) initialization vector. The four choices of algorithms:

- aes128 - aes-128 (with 192-bit binary strings using AES)
- aes192 - aes-192 (with 192-bit binary strings using AES)
- aes256 - aes-256 (with 256-bit binary strings using AES)
- des - des (with 56-bit binary strings using DES, though DES is not recommended)

Four choices of block cipher modes are also available:

- cbc - Cipher Block Chaining
- cfb - Cipher Feedback
- ecb - Electronic Codebook
- ofb - Output Feedback

For more information, read the article about Encryption Modes

Example:

```
_16byte_iv='1234567890123456'
_16byte_pass='1234567890123456'
e=crypto.cipher.aes128.cbc.encrypt('string', _16byte_pass, _16byte_iv)
crypto.cipher.aes128.cbc.decrypt(e,  _16byte_pass, _16byte_iv)
```

crypto.digest.{dss|dss1|md4|md5|mdc2|ripemd160}(string)
crypto.digest.{sha1|sha224|sha256|sha384|sha512}(string)

Pass or return a digest derived from the string. The eleven algorithm choices:

- dss - dss (using DSS)
- dss1 - dss (using DSS-1)
- md4 - md4 (with 128-bit binary strings using MD4)

- md5 - md5 (with 128-bit binary strings using MD5)
- mdc2 - mdc2 (using MDC2)
- ripemd160 - ripemd (with 160-bit binary strings using RIPEMD-160)
- sha1 - sha-1 (with 160-bit binary strings using SHA-1)
- sha224 - sha-224 (with 224-bit binary strings using SHA-2)
- sha256 - sha-256 (with 256-bit binary strings using SHA-2)
- sha384 - sha-384 (with 384-bit binary strings using SHA-2)
- sha512 - sha-512(with 512-bit binary strings using SHA-2).

Example:

```
crypto.digest.md4('string')
crypto.digest.sha512('string')
```

crypto.hmac.{md4|md5|ripemd160}(key, string)
crypto.hmac.{sha1|sha224|sha256|sha384|sha512}(key, string)

Pass a key and a string. The result is an HMAC message authentication code. The eight algorithm choices:

- md4 or md4_hex - md4 (with 128-bit binary strings using MD4)
- md5 or md5_hex - md5 (with 128-bit binary strings using MD5)
- ripemd160 or ripemd160_hex - ripemd (with 160-bit binary strings using RIPEMD-160)
- sha1 or sha1_hex - sha-1 (with 160-bit binary strings using SHA-1)
- sha224 or sha224_hex - sha-224 (with 224-bit binary strings using SHA-2)
- sha256 or sha256_hex - sha-256 (with 256-bit binary strings using SHA-2)
- sha384 or sha384_hex - sha-384 (with 384-bit binary strings using SHA-2)
- sha512 or sha512_hex - sha-512(with 512-bit binary strings using SHA-2).

Example:

```
crypto.hmac.md4('key', 'string')
crypto.hmac.md4_hex('key', 'string')
```

Incremental methods in the crypto module

Suppose that a digest is done for a string ‘A’, then a new part ‘B’ is appended to the string, then a new digest is required. The new digest could be recomputed for the whole string ‘AB’, but it is faster to take what was computed before for ‘A’ and apply changes based on the new part ‘B’. This is called multi-step or “incremental” digesting, which Tarantool supports for all crypto functions.

```
crypto = require('crypto')

-- print aes-192 digest of 'AB', with one step, then incrementally
key = 'key/key/key/key/key/key/'
iv =  'iviviviviviviviv'
print(crypto.cipher.aes192.cbc.encrypt('AB', key, iv))
c = crypto.cipher.aes192.cbc.encrypt.new(key)
c:init(nil, iv)
```

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```
c:update('A')
c:update('B')
print(c:result())
c:free()

-- print sha-256 digest of 'AB', with one step, then incrementally
print(crypto.digest.sha256('AB'))
c = crypto.digest.sha256.new()
c:init()
c:update('A')
c:update('B')
print(c:result())
c:free()
```

Getting the same results from digest and crypto modules

The following functions are equivalent. For example, the digest function and the crypto function will both produce the same result.

```
crypto.cipher.aes256.cbc.encrypt('x',b32,b16)==digest.aes256cbc.encrypt('x',b32,b16)
crypto.digest.md4('string') == digest.md4('string')
crypto.digest.md5('string') == digest.md5('string')
crypto.digest.sha1('string') == digest.sha1('string')
crypto.digest.sha224('string') == digest.sha224('string')
crypto.digest.sha256('string') == digest.sha256('string')
crypto.digest.sha384('string') == digest.sha384('string')
crypto.digest.sha512('string') == digest.sha512('string')
```

5.2.6 Module csv

Overview

The csv module handles records formatted according to Comma-Separated-Values (CSV) rules.

The default formatting rules are:

- Lua escape sequences such as \n or \10 are legal within strings but not within files,
- Commas designate end-of-field,
- Line feeds, or line feeds plus carriage returns, designate end-of-record,
- Leading or trailing spaces are ignored,
- Quote marks may enclose fields or parts of fields,
- When enclosed by quote marks, commas and line feeds and spaces are treated as ordinary characters, and a pair of quote marks "" is treated as a single quote mark.

The possible options which can be passed to csv functions are:

- delimiter = string (default: comma) – single-byte character to designate end-of-field
- quote_char = string (default: quote mark) – single-byte character to designate encloser of string
- chunk_size = number (default: 4096) – number of characters to read at once (usually for file-IO efficiency)

- skip_head_lines = number (default: 0) – number of lines to skip at the start (usually for a header)

Index

Below is a list of all csv functions.

Name	Use
csv.load()	Load a CSV file
csv.dump()	Transform input into a CSV-formatted string
csv.iterate()	Iterate over CSV records

csv.load(readable[, {options}])

Get CSV-formatted input from readable and return a table as output. Usually readable is either a string or a file opened for reading. Usually options is not specified.

Parameters

- readable (object) – a string, or any object which has a read() method, formatted according to the CSV rules
- options (table) – see above

Return loaded_value

Rtype table

Example:

Readable string has 3 fields, field#2 has comma and space so use quote marks:

```
tarantool> csv = require('csv')
---
...
tarantool> csv.load('a,"b,c ",d')
---
- - a
  - 'b,c '
  - d
...
```

Readable string contains 2-byte character = Cyrillic Letter Palochka: (This displays a palochka if and only if character set = UTF-8.)

```
tarantool> csv.load('a\\211\\128b')
---
- - a\211\128b
...
```

Semicolon instead of comma for the delimiter:

```
tarantool> csv.load('a,b;c,d', {delimiter = ';'})
---
- - a,b
  - c,d
...
```

Readable file ./file.csv contains two CSV records. Explanation of fio is in section fio. Source CSV file and example respectively:

```
tarantool> -- input in file.csv is:
tarantool> -- a,"b,c ",d
tarantool> -- a\\211\\128b
tarantool> fio = require('fio')
---
...
tarantool> f = fio.open('./file.csv', {'O_RDONLY'})
---
...
tarantool> csv.load(f, {chunk_size = 4096})
---
- - - a
    - 'b,c '
    - d
  - - a\\211\\128b
...
tarantool> f:close()
---
- true
...
```

csv.dump(csv-table[, options, writable])

Get table input from csv-table and return a CSV-formatted string as output. Or, get table input from csv-table and put the output in writable. Usually options is not specified. Usually writable, if specified, is a file opened for writing. csv.dump() is the reverse of csv.load().

Parameters

- csv-table (table) – a table which can be formatted according to the CSV rules.
- options (table) – optional. see above
- writable (object) – any object which has a write() method

Return dumped_value

Rtype string, which is written to writable if specified

Example:

CSV-table has 3 fields, field#2 has "," so result has quote marks

```
tarantool> csv = require('csv')
---
...
tarantool> csv.dump({'a','b,c ','d'})
---
- 'a,"b,c ",d

  '
...
```

Round Trip: from string to table and back to string

```
tarantool> csv_table = csv.load('a,b,c')
---
...
tarantool> csv.dump(csv_table)
---
- 'a,b,c
```

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```
'
...
```

csv.iterate(input, {options})

Form a Lua iterator function for going through CSV records one field at a time. Use of an iterator is strongly recommended if the amount of data is large (ten or more megabytes).

Parameters

- csv-table (table) – a table which can be formatted according to the CSV rules.
- options (table) – see above

Return Lua iterator function

Rtype iterator function

Example:

csv.iterate() is the low level of csv.load() and csv.dump(). To illustrate that, here is a function which is the same as the csv.load() function, as seen in the Tarantool source code.

```
tarantool> load = function(readable, opts)
         >   opts = opts or {}
         >   local result = {}
         >   for i, tup in csv.iterate(readable, opts) do
         >     result[i] = tup
         >   end
         >   return result
         > end
---
...
tarantool> load('a,b,c')
---
- - a
  - b
  - c
...
```

5.2.7 Module decimal

The decimal module has functions for working with exact numbers. This is important when numbers are large or even the slighest inaccuracy is unacceptable. For example Lua calculates 0.16666666666667 * 6 with floating-point so the result is 1. But with the decimal module (using decimal.new to convert the number to decimal type) decimal.new('0.16666666666667') * 6 is 1.00000000000002.

To construct a decimal number, bring in the module with require('decimal') and then use decimal.new(n) or any function in the decimal module: abs(n) exp(n) ln(n) log10(n) new(n) precision(n) rescale(decimal-number, new-scale) scale(n) sqrt(n) trim(decimal-number), where n can be a string or a non-decimal number or a decimal number. If it is a string or a non-decimal number, Tarantool converts it to a decimal number before working with it. It is best to construct from strings, and to convert back to strings after calculations, because Lua numbers have only 15 digits of precision. Decimal numbers have 38 digits of precision, that is, the total number of digits before and after the decimal point can be 38. Tarantool supports the usual arithmetic and comparison operators + - * / % ^ < > <= >= ~= ==. If an operation has both decimal and non-decimal operands, then the non-decimal operand is converted to decimal before the operation happens.

Use tostring(decimal-number) to convert back to a string.

A decimal operation will fail if overflow happens (when a number is greater than 10^38 - 1 or less than -10^38 - 1). A decimal operation will fail if arithmetic is impossible (such as division by zero or square root of minus 1). A decimal operation will not fail if rounding of post-decimal digits is necessary to get 38-digit precision.

decimal.abs(string-or-number-or-decimal-number)
: Returns absolute value of a decimal number. For example if a is -1 then decimal.abs(a) returns 1.

decimal.exp(string-or-number-or-decimal-number)
: Returns e raised to the power of a decimal number. For example if a is 1 then decimal.exp(a) returns 2.7182818284590452353602874713526624978. Compare math.exp(1) from the Lua math library, which returns 2.718281828459.

decimal.ln(string-or-number-or-decimal-number)
: Returns natural logarithm of a decimal number. For example if a is 1 then decimal.ln(a) returns 0.

decimal.log10(string-or-number-or-decimal-number)
: Returns base-10 logarithm of a decimal number. For example if a is 100 then decimal.log10(a) returns 2.

decimal.new(string-or-number-or-decimal-number)
: Returns the value of the input as a decimal number. For example if a is 1E-1 then decimal.new(a) returns 0.1.

decimal.precision(string-or-number-or-decimal-number)
: Returns the number of digits in a decimal number. For example if a is 123.4560 then decimal.precision(a) returns 7.

decimal.rescale(decimal-number, new-scale)
: Returns the number after possible rounding or padding. If the number of post-decimal digits is greater than new-scale, then rounding occurs. The rounding rule is: round half away from zero. If the number of post-decimal digits is less than new-scale, then padding of zeros occurs. For example if a is -123.4550 then decimal.rescale(a, 2) returns -123.46, and decimal.rescale(a, 5) returns -123.45500.

decimal.scale(string-or-number-or-decimal-number)
: Returns the number of post-decimal digits in a decimal number. For example if a is 123.4560 then decimal.scale(a) returns 4.

decimal.sqrt(string-or-number-or-decimal-number)
: Returns the square root of a decimal number. For example if a is 2 then decimal.sqrt(a) returns 1.4142135623730950488016887242096980786.

decimal.trim(decimal-number)
: Returns a decimal number after possible removing of trailing post-decimal zeros. For example if a is 2.20200 then decimal.trim(a) returns 2.202.

5.2.8 Module digest

Overview

A "digest" is a value which is returned by a function (usually a Cryptographic hash function), applied against a string. Tarantool's digest module supports several types of cryptographic hash functions (AES, MD4, MD5, SHA-1, SHA-2, PBKDF2) as well as a checksum function (CRC32), two functions for base64, and two non-cryptographic hash functions (guava, murmur). Some of the digest functionality is also present in the crypto.

Index

Below is a list of all digest functions.

Name	Use
digest.aes256cbc.encrypt()	Encrypt a string using AES
digest.aes256cbc.decrypt()	Decrypt a string using AES
digest.md4()	Get a digest made with MD4
digest.md4_hex()	Get a hexadecimal digest made with MD4
digest.md5()	Get a digest made with MD5
digest.md5_hex()	Get a hexadecimal digest made with MD5
digest.pbkdf2()	Get a digest made with PBKDF2
digest.sha1()	Get a digest made with SHA-1
digest.sha1_hex()	Get a hexadecimal digest made with SHA-1
digest.sha224()	Get a 224-bit digest made with SHA-2
digest.sha224_hex()	Get a 56-byte hexadecimal digest made with SHA-2
digest.sha256()	Get a 256-bit digest made with SHA-2
digest.sha256_hex()	Get a 64-byte hexadecimal digest made with SHA-2
digest.sha384()	Get a 384-bit digest made with SHA-2
digest.sha384_hex()	Get a 96-byte hexadecimal digest made with SHA-2
digest.sha512()	Get a 512-bit digest made with SHA-2
digest.sha512_hex()	Get a 128-byte hexadecimal digest made with SHA-2
digest.base64_encode()	Encode a string to Base64
digest.base64_decode()	Decode a Base64-encoded string
digest.urandom()	Get an array of random bytes
digest.crc32()	Get a 32-bit checksum made with CRC32
digest.crc32.new()	Initiate incremental CRC32
digest.guava()	Get a number made with a consistent hash
digest.murmur()	Get a digest made with MurmurHash
digest.murmur.new()	Initiate incremental MurmurHash

digest.aes256cbc.encrypt(string, key, iv)
digest.aes256cbc.decrypt(string, key, iv)
Returns 256-bit binary string = digest made with AES.

digest.md4(string)
Returns 128-bit binary string = digest made with MD4.

digest.md4_hex(string)
Returns 32-byte string = hexadecimal of a digest calculated with md4.

digest.md5(string)
Returns 128-bit binary string = digest made with MD5.

digest.md5_hex(string)
Returns 32-byte string = hexadecimal of a digest calculated with md5.

digest.pbkdf2(string, salt[, iterations[, digest-length]])
Returns binary string = digest made with PBKDF2. For effective encryption the iterations value should be at least several thousand. The digest-length value determines the length of the resulting binary string.

Note: digest.pbkdf2() yields and should not be used in a transaction (between box.begin() and box.commit()/box.rollback()). PBKDF2 is a time-consuming hash algorithm. It runs in a separate coio thread. While calculations are performed, the fiber that calls digest.pbkdf2() yields and another fiber continues working in the tx thread.

digest.sha1(string)
Returns 160-bit binary string = digest made with SHA-1.

digest.sha1_hex(string)
Returns 40-byte string = hexadecimal of a digest calculated with sha1.

digest.sha224(string)
Returns 224-bit binary string = digest made with SHA-2.

digest.sha224_hex(string)
Returns 56-byte string = hexadecimal of a digest calculated with sha224.

digest.sha256(string)
Returns 256-bit binary string = digest made with SHA-2.

digest.sha256_hex(string)
Returns 64-byte string = hexadecimal of a digest calculated with sha256.

digest.sha384(string)
Returns 384-bit binary string = digest made with SHA-2.

digest.sha384_hex(string)
Returns 96-byte string = hexadecimal of a digest calculated with sha384.

digest.sha512(string)
Returns 512-bit binary tring = digest made with SHA-2.

digest.sha512_hex(string)
Returns 128-byte string = hexadecimal of a digest calculated with sha512.

digest.base64_encode()
Returns base64 encoding from a regular string.

The possible options are:

- nopad – result must not include '=' for padding at the end,
- nowrap – result must not include line feed for splitting lines after 72 characters,
- urlsafe – result must not include '=' or line feed, and may contain '-' or '_' instead of '+' or '/' for positions 62 and 63 in the index table.

Options may be true or false, the default value is false.

For example:

```
digest.base64_encode(string_variable,{nopad=true})
```

digest.base64_decode(string)
Returns a regular string from a base64 encoding.

digest.urandom(integer)
Returns array of random bytes with length = integer.

digest.crc32(string)
Returns 32-bit checksum made with CRC32.

The crc32 and crc32_update functions use the Cyclic Redundancy Check polynomial value: 0x1EDC6F41 / 4812730177. (Other settings are: input = reflected, output = reflected, initial value =

0xFFFFFFFF, final xor value = 0x0.) If it is necessary to be compatible with other checksum functions in other programming languages, ensure that the other functions use the same polynomial value.

For example, in Python, install the crcmod package and say:

```
>>> import crcmod
>>> fun = crcmod.mkCrcFun('4812730177')
>>> fun('string')
3304160206L
```

In Perl, install the Digest::CRC module and run the following code:

```
use Digest::CRC;
$d = Digest::CRC->new(width => 32, poly => 0x1EDC6F41, init => 0xFFFFFFFF, refin => 1, refout␣
↪=> 1);
$d->add('string');
print $d->digest;
```

(the expected output is 3304160206).

digest.crc32.new()
: Initiates incremental crc32. See incremental methods notes.

digest.guava(state, bucket)
: Returns a number made with consistent hash.

  The guava function uses the Consistent Hashing algorithm of the Google guava library. The first parameter should be a hash code; the second parameter should be the number of buckets; the returned value will be an integer between 0 and the number of buckets. For example,

```
tarantool> digest.guava(10863919174838991, 11)
---
- 8
...
```

digest.murmur(string)
: Returns 32-bit binary string = digest made with MurmurHash.

digest.murmur.new(opts)
: Initiates incremental MurmurHash. See incremental methods notes. For example:

```
murmur.new({seed=0})
```

Incremental methods in the digest module

Suppose that a digest is done for a string 'A', then a new part 'B' is appended to the string, then a new digest is required. The new digest could be recomputed for the whole string 'AB', but it is faster to take what was computed before for 'A' and apply changes based on the new part 'B'. This is called multi-step or "incremental" digesting, which Tarantool supports with crc32 and with murmur. . .

```
digest = require('digest')

-- print crc32 of 'AB', with one step, then incrementally
print(digest.crc32('AB'))
c = digest.crc32.new()
c:update('A')
c:update('B')
```

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```
print(c:result())

-- print murmur hash of 'AB', with one step, then incrementally
print(digest.murmur('AB'))
m = digest.murmur.new()
m:update('A')
m:update('B')
print(m:result())
```

Example

In the following example, the user creates two functions, password_insert() which inserts a SHA-1 digest of the word "^S^e^c^ret Wordpass" into a tuple set, and password_check() which requires input of a password.

```
tarantool> digest = require('digest')
---
...
tarantool> function password_insert()
         >   box.space.tester:insert{1234, digest.sha1('^S^e^c^ret Wordpass')}
         >   return 'OK'
         > end
---
...
tarantool> function password_check(password)
         >   local t = box.space.tester:select{12345}
         >   if digest.sha1(password) == t[2] then
         >     return 'Password is valid'
         >   else
         >     return 'Password is not valid'
         >   end
         > end
---
...
tarantool> password_insert()
---
- 'OK'
...
```

If a later user calls the password_check() function and enters the wrong password, the result is an error.

```
tarantool> password_check('Secret Password')
---
- 'Password is not valid'
...
```

5.2.9 Module errno

Overview

The errno module is typically used within a function or within a Lua program, in association with a module whose functions can return operating-system errors, such as fio.

Index

Below is a list of all errno functions.

Name	Use
errno()	Get an error number for the last OS-related function
errno.strerror()	Get an error message for the corresponding error number

errno()

Return an error number for the last operating-system-related function, or 0. To invoke it, simply say errno(), without the module name.

Rtype integer

errno.strerror([code])

Return a string, given an error number. The string will contain the text of the conventional error message for the current operating system. If code is not supplied, the error message will be for the last operating-system-related function, or 0.

Parameters

- code (integer) – number of an operating-system error

Rtype string

Example:

This function displays the result of a call to fio.open() which causes error 2 (errno.ENOENT). The display includes the error number, the associated error string, and the error name.

```
tarantool> function f()
         >   local fio = require('fio')
         >   local errno = require('errno')
         >   fio.open('no_such_file')
         >   print('errno() = ' .. errno())
         >   print('errno.strerror() = ' .. errno.strerror())
         >   local t = getmetatable(errno).__index
         >   for k, v in pairs(t) do
         >     if v == errno() then
         >       print('errno() constant = ' .. k)
         >     end
         >   end
         > end
---
...

tarantool> f()
errno() = 2
errno.strerror() = No such file or directory
errno() constant = ENOENT
---
...
```

To see all possible error names stored in the errno metatable, say getmetatable(errno) (output abridged):

```
tarantool> getmetatable(errno)
---
- __newindex: 'function: 0x41666a38'
```

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```
  __call: 'function: 0x41666890'
  __index:
  ENOLINK: 67
  EMSGSIZE: 90
  EOVERFLOW: 75
  ENOTCONN: 107
  EFAULT: 14
  EOPNOTSUPP: 95
  EEXIST: 17
  ENOSR: 63
  ENOTSOCK: 88
  EDESTADDRREQ: 89
  <...>
...
```

5.2.10 Module fiber

Overview

With the fiber module, you can:

- create, run and manage fibers,
- send and receive messages between different processes (i.e. different connections, sessions, or fibers) via channels, and
- use a synchronization mechanism for fibers, similar to "condition variables" and similar to operating-system functions such as pthread_cond_wait() plus pthread_cond_signal().

Index

Below is a list of all fiber functions and members.

Name	Use
fiber.create()	Create and start a fiber
fiber.new()	Create but do not start a fiber
fiber.self()	Get a fiber object
fiber.channel()	Create a communication channel
channel_object:close()	Close a channel
channel_object:count()	Count messages in a channel
channel_object:get()	Fetch a message from a channel
channel_object:has_readers()	Check if an empty channel has any readers waiting
channel_object:has_writers()	Check if a full channel has any writers waiting
channel_object:is_closed()	Check if a channel is closed
channel_object:is_empty()	Check if a channel is empty
channel_object:is_full()	Check if a channel is full
channel_object:put()	Send a message via a channel
fiber.cond()	Create a condition variable
cond_object:broadcast()	Wake up all fibers
cond_object:signal()	Wake up a single fiber
cond_object:wait()	Make a fiber go to sleep until woken by another fiber

Continued on next page

Table 4 – continued from previous page

Name	Use
fiber.find()	Get a fiber object by ID
fiber.info()	Get information about all fibers
fiber.kill()	Cancel a fiber
fiber_object:cancel()	Cancel a fiber
fiber_object:id()	Get a fiber's ID
fiber_object:join()	Wait for a fiber's state to become 'dead'
fiber_object:name()	Get a fiber's name
fiber_object:name(name)	Set a fiber's name
fiber_object:set_joinable()	Make it possible for a new fiber to join
fiber_object:status()	Get a fiber's status
fiber_object.storage	Local storage within the fiber
fiber.sleep()	Make a fiber go to sleep
fiber.status()	Get the current fiber's status
fiber.time()	Get the system time in seconds
fiber.time64()	Get the system time in microseconds
fiber.clock()	Get the monotonic time in seconds
fiber.clock64()	Get the monotonic time in microseconds
fiber.testcancel()	Check if the current fiber has been cancelled
fiber.top()	Return a table of alive fibers and show their CPU consumption
fiber.yield()	Yield control

Fibers

A fiber is a set of instructions which are executed with cooperative multitasking. Fibers managed by the fiber module are associated with a user-supplied function called the fiber function.

A fiber has three possible states: running, suspended or dead. When a fiber is created with fiber.create(), it is running. When a fiber is created with fiber.new() or yields control with fiber.sleep(), it is suspended. When a fiber ends (because the fiber function ends), it is dead.

All fibers are part of the fiber registry. This registry can be searched with fiber.find() - via fiber id (fid), which is a numeric identifier.

A runaway fiber can be stopped with fiber_object.cancel. However, fiber_object.cancel is advisory — it works only if the runaway fiber calls fiber.testcancel() occasionally. Most box.* functions, such as box.space...delete() or box.space...update(), do call fiber.testcancel() but box.space...select{} does not. In practice, a runaway fiber can only become unresponsive if it does many computations and does not check whether it has been cancelled.

The other potential problem comes from fibers which never get scheduled, because they are not subscribed to any events, or because no relevant events occur. Such morphing fibers can be killed with fiber.kill() at any time, since fiber.kill() sends an asynchronous wakeup event to the fiber, and fiber.testcancel() is checked whenever such a wakeup event occurs.

Like all Lua objects, dead fibers are garbage collected. The Lua garbage collector frees pool allocator memory owned by the fiber, resets all fiber data, and returns the fiber (now called a fiber carcass) to the fiber pool. The carcass can be reused when another fiber is created.

A fiber has all the features of a Lua coroutine and all the programming concepts that apply for Lua coroutines will apply for fibers as well. However, Tarantool has made some enhancements for fibers and has used fibers internally. So, although use of coroutines is possible and supported, use of fibers is recommended.

fiber.create(function[, function-arguments])

Create and start a fiber. The fiber is created and begins to run immediately.

Parameters

- function – the function to be associated with the fiber
- function-arguments – what will be passed to function

Return created fiber object

Rtype userdata

Example:

```
tarantool> fiber = require('fiber')
---
...
tarantool> function function_name()
         >   print("I'm a fiber")
         > end
---
...
tarantool> fiber_object = fiber.create(function_name); print("Fiber started")
I'm a fiber
Fiber started
---
...
```

fiber.new(function[, function-arguments])

Create but do not start a fiber: the fiber is created but does not begin to run immediately – it starts after the fiber creator (that is, the job that is calling fiber.new()) yields, under transaction control. The initial fiber state is 'suspended'. Thus fiber.new() differs slightly from fiber.create().

Ordinarily fiber.new() is used in conjunction with fiber_object:set_joinable() and fiber_object:join().

Parameters

- function – the function to be associated with the fiber
- function-arguments – what will be passed to function

Return created fiber object

Rtype userdata

Example:

```
tarantool> fiber = require('fiber')
---
...
tarantool> function function_name()
         >   print("I'm a fiber")
         > end
---
...
tarantool> fiber_object = fiber.new(function_name); print("Fiber not started yet")
Fiber not started yet
---
...
tarantool> I'm a fiber
---
...
```

fiber.self()

Return fiber object for the currently scheduled fiber.

Rtype userdata

Example:

```
tarantool> fiber.self()
---
- status: running
  name: interactive
  id: 101
...
```

fiber.find(id)

Parameters

- id – numeric identifier of the fiber.

Return fiber object for the specified fiber.

Rtype userdata

Example:

```
tarantool> fiber.find(101)
---
- status: running
  name: interactive
  id: 101
...
```

fiber.sleep(time)

Yield control to the scheduler and sleep for the specified number of seconds. Only the current fiber can be made to sleep.

Parameters

- time – number of seconds to sleep.

Exception see the Example of yield failure.

Example:

```
tarantool> fiber.sleep(1.5)
---
...
```

fiber.yield()

Yield control to the scheduler. Equivalent to fiber.sleep(0).

Exception see the Example of yield failure.

Example:

```
tarantool> fiber.yield()
---
...
```

fiber.status([fiber_object])

Return the status of the current fiber. Or, if optional fiber_object is passed, return the status of the specified fiber.

Return the status of fiber. One of: “dead”, “suspended”, or “running”.

Rtype string

Example:

```
tarantool> fiber.status()
---
- running
...
```

fiber.info()

Return information about all fibers.

Return number of context switches, backtrace, id, total memory, used memory, name for each fiber.

Rtype table

Example:

```
tarantool> fiber.info()
---
- 101:
    csw: 7
    backtrace: []
    fid: 101
    memory:
      total: 65776
      used: 0
    name: interactive
...
```

fiber.top()

Show all alive fibers and their CPU consumption.

Return a table with two entries: cpu and cpu_misses

cpu itself is a table whose keys are strings containing fiber ids and names. The three metrics available for each fiber are:

1. instant (in per cent), which indicates the share of time the fiber was executing during the previous event loop iteration.
2. average (in per cent), which is calculated as an exponential moving average of instant values over all the previous event loop iterations.
3. time (in seconds), which estimates how much CPU time each fiber spent processing during its lifetime.

   The time entry is also added to each fiber’s output in fiber.info() (it duplicates the time entry from fiber.top().cpu per fiber).

   Note that time is only counted while fiber.top() is enabled.

cpu_misses indicates the number of times the TX thread detected it was rescheduled on a different CPU core during the last event loop iteration. fiber.top() uses the CPU timestamp counter to measure each fiber’s execution time. However, each CPU core may have its own counter value (you can only rely on counter deltas if both measurements were taken on the same core, otherwise the delta may even get negative). When the TX thread is rescheduled to a different CPU core, Tarantool just assumes the CPU delta was zero for the latest measurement. This lowers the precision of our computations, so the bigger cpu misses value the lower the precision of fiber.top() results.

Let's take a look at the example:

Example

```
tarantool> fiber.top()
---
- cpu:
    107/lua:
      instant: 30.967324490456
      time: 0.351821993
      average: 25.582738345233
    104/lua:
      instant: 9.6473633128437
      time: 0.110869897
      average: 7.9693406131877
    101/on_shutdown:
      instant: 0
      time: 0
      average: 0
    103/lua:
      instant: 9.8026528631511
      time: 0.112641118
      average: 18.138387232255
    106/lua:
      instant: 20.071174377224
      time: 0.226901357
      average: 17.077908441831
    102/interactive:
      instant: 0
      time: 9.6858e-05
      average: 0
    105/lua:
      instant: 9.2461986412164
      time: 0.10657528
      average: 7.7068458630827
    1/sched:
      instant: 20.265286315108
      time: 0.237095335
      average: 23.141537169257
  cpu_misses: 0
...
```

Note: Enabling fiber.top() slows down fiber switching by about 15%, so it is disabled by default. To enable it, say fiber.top_enable(). To disable it after you finished debugging, with fiber.top_disable().

fiber.kill(id)

Locate a fiber by its numeric id and cancel it. In other words, fiber.kill() combines fiber.find() and fiber_object:cancel().

Parameters

- id – the id of the fiber to be cancelled.

Exception the specified fiber does not exist or cancel is not permitted.

Example:

```
tarantool> fiber.kill(fiber.id()) -- kill self, may make program end
---
- error: fiber is cancelled
...
```

fiber.testcancel()

Check if the current fiber has been cancelled and throw an exception if this is the case.

Note: Even if you catch the exception, the fiber will remain cancelled. Most types of calls will check fiber.testcancel(). However, some functions (id, status, join etc.) will return no error. We recommend application developers to implement occasional checks with fiber.testcancel() and to end fiber's execution as soon as possible in case it has been cancelled.

Example:

```
tarantool> fiber.testcancel()
---
- error: fiber is cancelled
...
```

object fiber_object

fiber_object:id()

Parameters

- fiber_object – generally this is an object referenced in the return from fiber.create or fiber.self or fiber.find

Return id of the fiber.

Rtype number

fiber.self():id() can also be expressed as fiber.id().

Example:

```
tarantool> fiber_object = fiber.self()
---
...
tarantool> fiber_object:id()
---
- 101
...
```

fiber_object:name()

Parameters

- fiber_object – generally this is an object referenced in the return from fiber.create or fiber.self or fiber.find

Return name of the fiber.

Rtype string

fiber.self():name() can also be expressed as fiber.name().

Example:

```
tarantool> fiber.self():name()
---
- interactive
...
```

fiber_object:name(name[, options])

Change the fiber name. By default a Tarantool server's interactive-mode fiber is named 'interactive' and new fibers created due to fiber.create are named 'lua'. Giving fibers distinct names makes it easier to distinguish them when using fiber.info. Max length is 32.

Parameters

- fiber_object – generally this is an object referenced in the return from fiber.create or fiber.self or fiber.find
- name (string) – the new name of the fiber.
- options –
  - truncate=true – truncates the name to the max length if it is too long. If this option is false (the default), fiber.name(new_name) fails with an exception if a new name is too long.

Return nil

Example:

```
tarantool> fiber.self():name('non-interactive')
---
...
```

fiber_object:status()

Return the status of the specified fiber.

Parameters

- fiber_object – generally this is an object referenced in the return from fiber.create or fiber.self or fiber.find

Return the status of fiber. One of: "dead", "suspended", or "running".

Rtype string

fiber.self():status(can also be expressed as fiber.status().

Example:

```
tarantool> fiber.self():status()
---
- running
...
```

fiber_object:cancel()

Cancel a fiber. Running and suspended fibers can be cancelled. After a fiber has been cancelled, attempts to operate on it will cause errors, for example fiber_object:name() will cause error: the fiber is dead. But a dead fiber can still report its id and status.

Parameters

- fiber_object – generally this is an object referenced in the return from fiber.create or fiber.self or fiber.find

Return nil

Possible errors: cancel is not permitted for the specified fiber object.

Example:

```
tarantool> fiber.self():cancel() -- kill self, may make program end
---
...
tarantool> fiber.self():cancel()
---
- error: fiber is cancelled
...
tarantool> fiber.self:id()
---
- 163
...
tarantool> fiber.self:status()
---
- dead
...
```

fiber_object.storage

Local storage within the fiber. It is a Lua table created when it is first accessed. The storage can contain any number of named values, subject to memory limitations. Naming may be done with fiber_object.storage.name or fiber_object.storage['name']. or with a number fiber_object.storage[number]. Values may be either numbers or strings.

fiber.storage is destroyed when the fiber is finished, regardless of how is it finished – via fiber_object:cancel(), or the fiber's function did 'return'. Moreover, the storage is cleaned up even for pooled fibers used to serve IProto requests. Pooled fibers never really die, but nonetheless their storage is cleaned up after each request. That makes possible to use fiber.storage as a full featured request-local storage.

This storage may be created for a fiber, no matter how the fiber itself was created – from C or from Lua. For example, a fiber can be created in C using fiber_new(), then it can insert into a space, which has Lua on_replace triggers, and one of the triggers can create fiber.storage. That storage will be deleted when the fiber is stopped.

Example:

```
tarantool> fiber = require('fiber')
---
...
tarantool> function f () fiber.sleep(1000); end
---
...
tarantool> fiber_function = fiber.create(f)
---
...
tarantool> fiber_function.storage.str1 = 'string'
---
...
tarantool> fiber_function.storage['str1']
---
- string
...
tarantool> fiber_function:cancel()
---
...
```

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```
tarantool> fiber_function.storage['str1']
---
- error: '[string "return fiber_function.storage[''str1'']"]:1: the fiber is dead'
...
```

See also box.session.storage.

fiber_object:set_joinable(true_or_false)

fiber_object:set_joinable(true) makes a fiber joinable; fiber_object:set_joinable(false) makes a fiber not joinable; the default is false.

A joinable fiber can be waited for, with fiber_object:join().

Best practice is to call fiber_object:set_joinable() before the fiber function begins to execute, because otherwise the fiber could become 'dead' before fiber_object:set_joinable() takes effect. The usual sequence could be:

1. Call fiber.new() instead of fiber.create() to create a new fiber_object.

   Do not yield at this point, because that will cause the fiber function to begin.

2. Call fiber_object:set_joinable(true) to make the new fiber_object joinable.

   Now it is safe to yield.

3. Call fiber_object:join().

   Usually fiber_object:join() should be called, otherwise the fiber's status may become 'suspended' when the fiber function ends, instead of 'dead'.

Parameters

- true_or_false – the boolean value that changes the set_joinable flag

Return nil

Example:

The result of the following sequence of requests is:

- the global variable d will be 6 (which proves that the function was not executed until after d was set to 1, when fiber.sleep(1) caused a yield);
- fiber.status(fi2) will be 'suspended' (which proves that after the function was executed the fiber status did not change to 'dead').

```
fiber=require('fiber')
d=0
function fu2() d=d+5 end
fi2=fiber.new(fu2) fi2:set_joinable(true) d=1 fiber.sleep(1)
print(d)
fiber.status(fi2)
```

fiber_object:join()

"Join" a joinable fiber. That is, let the fiber's function run and wait until the fiber's status is 'dead' (normally a status becomes 'dead' when the function execution finishes). Joining will cause a yield, therefore, if the fiber is currently in a suspended state, execution of its fiber function will resume.

This kind of waiting is more convenient than going into a loop and periodically checking the status; however, it works only if the fiber was created with fiber.new() and was made joinable with fiber_object:set_joinable().

Return two values. The first value is boolean. If the first value is true, then the join succeeded because the fiber's function ended normally and the second result has the return value from the fiber's function. If the first value is false, then the join succeeded because the fiber's function ended abnormally and the second result has the details about the error, which one can unpack in the same way that one unpacks a pcall result.

Rtype boolean +result type, or boolean + struct error

Example:

The result of the following sequence of requests is:

- the first fiber.status() call returns 'suspended',
- the join() call returns true,
- the elapsed time is usually 5 seconds, and
- the second fiber.status() call returns 'dead'.

This proves that the join() does not return until the function – which sleeps 5 seconds – is 'dead'.

```
fiber=require('fiber')
function fu2() fiber.sleep(5) end
fi2=fiber.new(fu2) fi2:set_joinable(true)
start_time = os.time()
fiber.status(fi2)
fi2:join()
print('elapsed = ' .. os.time() - start_time)
fiber.status(fi2)
```

fiber.time()

Return current system time (in seconds since the epoch) as a Lua number. The time is taken from the event loop clock, which makes this call very cheap, but still useful for constructing artificial tuple keys.

Rtype number

Example:

```
tarantool> fiber.time(), fiber.time()
---
- 1448466279.2415
- 1448466279.2415
...
```

fiber.time64()

Return current system time (in microseconds since the epoch) as a 64-bit integer. The time is taken from the event loop clock.

Rtype cdata

Example:

```
tarantool> fiber.time(), fiber.time64()
---
- 1448466351.2708
- 1448466351270762
...
```

fiber.clock()

Get the monotonic time in seconds. It is better to use fiber.clock() for calculating timeouts instead of fiber.time() because fiber.time() reports real time so it is affected by system time changes.

Return a floating-point number of seconds, representing elapsed wall-clock time since some time in the past that is guaranteed not to change during the life of the process

Rtype number

Example:

```
tarantool> start = fiber.clock()
---
...
tarantool> print(start)
248700.58805
---
...
tarantool> print(fiber.time(), fiber.time()-start)
1600785979.8291 1600537279.241
---
...
```

fiber.clock64()

Same as fiber.clock() but in microseconds.

Return a number of seconds as 64-bit integer, representing elapsed wall-clock time since some time in the past that is guaranteed not to change during the life of the process

Rtype cdata

Example

Make the function which will be associated with the fiber. This function contains an infinite loop. Each iteration of the loop adds 1 to a global variable named gvar, then goes to sleep for 2 seconds. The sleep causes an implicit fiber.yield().

```
tarantool> fiber = require('fiber')
tarantool> function function_x()
         >   gvar = 0
         >   while true do
         >     gvar = gvar + 1
         >     fiber.sleep(2)
         >   end
         > end
---
...
```

Make a fiber, associate function_x with the fiber, and start function_x. It will immediately "detach" so it will be running independently of the caller.

```
tarantool> gvar = 0

tarantool> fiber_of_x = fiber.create(function_x)
---
...
```

Get the id of the fiber (fid), to be used in later displays.

```
tarantool> fid = fiber_of_x:id()
---
...
```

Pause for a while, while the detached function runs. Then . . . Display the fiber id, the fiber status, and gvar (gvar will have gone up a bit depending how long the pause lasted). The status is suspended because the fiber spends almost all its time sleeping or yielding.

```
tarantool> print('#', fid, '. ', fiber_of_x:status(), '. gvar=', gvar)
# 102 .  suspended . gvar= 399
---
...
```

Pause for a while, while the detached function runs. Then . . . Cancel the fiber. Then, once again . . . Display the fiber id, the fiber status, and gvar (gvar will have gone up a bit more depending how long the pause lasted). This time the status is dead because the cancel worked.

```
tarantool> fiber_of_x:cancel()
---
...
tarantool> print('#', fid, '. ', fiber_of_x:status(), '. gvar=', gvar)
# 102 .  dead . gvar= 421
---
...
```

Example of yield failure

Warning: yield() and any function which implicitly yields (such as sleep()) can fail (raise an exception).

For example, this function has a loop which repeats until cancel() happens. The last thing that it will print is 'before yield', which demonstrates that yield() failed, the loop did not continue until testcancel() failed.

```
fiber = require('fiber')
function function_name()
  while true do
    print('before testcancel')
    fiber.testcancel()
    print('before yield')
    fiber.yield()
  end
end
fiber_object = fiber.create(function_name)
fiber.sleep(.1)
fiber_object:cancel()
```

Channels

Call fiber.channel() to allocate space and get a channel object, which will be called channel for examples in this section.

Call the other routines, via channel, to send messages, receive messages, or check channel status.

Message exchange is synchronous. The Lua garbage collector will mark or free the channel when no one is using it, as with any other Lua object. Use object-oriented syntax, for example channel:put(message) rather than fiber.channel.put(message).

fiber.channel([capacity])

Create a new communication channel.

Parameters

- capacity (int) – the maximum number of slots (spaces for channel:put messages) that can be in use at once. The default is 0.

Return new channel.

Rtype userdata, possibly including the string "channel ...".

object channel_object

channel_object:put(message[, timeout])

Send a message using a channel. If the channel is full, channel:put() waits until there is a free slot in the channel.

Parameters

- message (lua-value) – what will be sent, usually a string or number or table
- timeout (number) – maximum number of seconds to wait for a slot to become free

Return If timeout is specified, and there is no free slot in the channel for the duration of the timeout, then the return value is false. If the channel is closed, then the return value is false. Otherwise, the return value is true, indicating success.

Rtype boolean

channel_object:close()

Close the channel. All waiters in the channel will stop waiting. All following channel:get() operations will return nil, and all following channel:put() operations will return false.

channel_object:get([timeout])

Fetch and remove a message from a channel. If the channel is empty, channel:get() waits for a message.

Parameters

- timeout (number) – maximum number of seconds to wait for a message

Return If timeout is specified, and there is no message in the channel for the duration of the timeout, then the return value is nil. If the channel is closed, then the return value is nil. Otherwise, the return value is the message placed on the channel by channel:put().

Rtype usually string or number or table, as determined by channel:put

channel_object:is_empty()

Check whether the channel is empty (has no messages).

Return true if the channel is empty. Otherwise false.

Rtype boolean

channel_object:count()

Find out how many messages are in the channel.

Return the number of messages.

Rtype number

channel_object:is_full()

Check whether the channel is full.

Return true if the channel is full (the number of messages in the channel equals the number of slots so there is no room for a new message). Otherwise false.

Rtype boolean

channel_object:has_readers()

Check whether readers are waiting for a message because they have issued channel:get() and the channel is empty.

Return true if readers are waiting. Otherwise false.

Rtype boolean

channel_object:has_writers()

Check whether writers are waiting because they have issued channel:put() and the channel is full.

Return true if writers are waiting. Otherwise false.

Rtype boolean

channel_object:is_closed()

Return true if the channel is already closed. Otherwise false.

Rtype boolean

Example

This example should give a rough idea of what some functions for fibers should look like. It's assumed that the functions would be referenced in fiber.create().

```
fiber = require('fiber')
channel = fiber.channel(10)
function consumer_fiber()
    while true do
        local task = channel:get()
        ...
    end
end

function consumer2_fiber()
    while true do
        -- 10 seconds
        local task = channel:get(10)
        if task ~= nil then
            ...
        else
            -- timeout
```

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```
        end
    end
end

function producer_fiber()
    while true do
        task = box.space...:select{...}
        ...
        if channel:is_empty() then
            -- channel is empty
        end

        if channel:is_full() then
            -- channel is full
        end

        ...
        if channel:has_readers() then
            -- there are some fibers
            -- that are waiting for data
        end
        ...

        if channel:has_writers() then
            -- there are some fibers
            -- that are waiting for readers
        end
        channel:put(task)
    end
end

function producer2_fiber()
    while true do
        task = box.space...select{...}
        -- 10 seconds
        if channel:put(task, 10) then
            ...
        else
            -- timeout
        end
    end
end
```

Condition variables

Call fiber.cond() to create a named condition variable, which will be called 'cond' for examples in this section.

Call cond:wait() to make a fiber wait for a signal via a condition variable.

Call cond:signal() to send a signal to wake up a single fiber that has executed cond:wait().

Call cond:broadcast() to send a signal to all fibers that have executed cond:wait().

fiber.cond()
    Create a new condition variable.

        Return new condition variable.

Rtype Lua object

object cond_object

cond_object:wait([timeout])

Make the current fiber go to sleep, waiting until another fiber invokes the signal() or broadcast() method on the cond object. The sleep causes an implicit fiber.yield().

Parameters

- timeout – number of seconds to wait, default = forever.

Return If timeout is provided, and a signal doesn't happen for the duration of the timeout, wait() returns false. If a signal or broadcast happens, wait() returns true.

Rtype boolean

cond_object:signal()

Wake up a single fiber that has executed wait() for the same variable. Does not yield.

Rtype nil

cond_object:broadcast()

Wake up all fibers that have executed wait() for the same variable. Does not yield.

Rtype nil

Example

Assume that a tarantool instance is running and listening for connections on localhost port 3301. Assume that guest users have privileges to connect. We will use the tarantoolctl utility to start two clients.

On terminal #1, say

```
$ tarantoolctl connect '3301'
tarantool> fiber = require('fiber')
tarantool> cond = fiber.cond()
tarantool> cond:wait()
```

The job will hang because cond:wait() – without an optional timeout argument – will go to sleep until the condition variable changes.

On terminal #2, say

```
$ tarantoolctl connect '3301'
tarantool> cond:signal()
```

Now look again at terminal #1. It will show that the waiting stopped, and the cond:wait() function returned true.

This example depended on the use of a global conditional variable with the arbitrary name cond. In real life, programmers would make sure to use different conditional variable names for different applications.

5.2.11 Module fio

Overview

Tarantool supports file input/output with an API that is similar to POSIX syscalls. All operations are performed asynchronously. Multiple fibers can access the same file simultaneously.

The fio module contains:

- functions for common pathname manipulations,
- functions for directory or file existence and type checks,
- functions for common file manipulations, and
- constants which are the same as POSIX flag values (for example fio.c.flag.O_RDONLY = POSIX O_RDONLY).

Index

Below is a list of all fio functions and members.

Name	Use
fio.pathjoin()	Form a path name from one or more partial strings
fio.basename()	Get a file name
fio.dirname()	Get a directory name
fio.abspath()	Get a directory and file name
fio.path.exists()	Check if file or directory exists
fio.path.is_dir()	Check if file or directory is a directory
fio.path.is_file()	Check if file or directory is a file
fio.path.is_link()	Check if file or directory is a link
fio.path.lexists()	Check if file or directory exists
fio.umask()	Set mask bits
fio.lstat() fio.stat()	Get information about a file object
fio.mkdir() fio.rmdir()	Create or delete a directory
fio.chdir()	Change working directory
fio.listdir()	List files in a directory
fio.glob()	Get files whose names match a given string
fio.tempdir()	Get the name of a directory for storing temporary files
fio.cwd()	Get the name of the current working directory
fio.copytree() fio.mktree() fio.rmtree()	Create and delete directories
fio.link() fio.symlink() fio.readlink() fio.unlink()	Create and delete links
fio.rename()	Rename a file or directory
fio.utime()	Change file update time
fio.copyfile()	Copy a file
fio.chown() fio.chmod()	Manage rights to and ownership of file objects
fio.truncate()	Reduce the file size
fio.sync()	Ensure that changes are written to disk
fio.open()	Open a file
file-handle:close()	Close a file
file-handle:pread() file-handle:pwrite()	Perform random-access read or write on a file
file-handle:read() file-handle:write()	Perform non-random-access read or write on a file
file-handle:truncate()	Change the size of an open file
file-handle:seek()	Change position in a file
file-handle:stat()	Get statistics about an open file
file-handle:fsync() file-handle:fdatasync()	Ensure that changes made to an open file are written to disk
fio.c	Table of constants similar to POSIX flag values

Common pathname manipulations

fio.pathjoin(partial-string[, partial-string ...])

Concatenate partial string, separated by '/' to form a path name.

Parameters

- partial-string (string) – one or more strings to be concatenated.

Return path name

Rtype string

Example:

```
tarantool> fio.pathjoin('/etc', 'default', 'myfile')
---
- /etc/default/myfile
...
```

fio.basename(path-name[, suffix])

Given a full path name, remove all but the final part (the file name). Also remove the suffix, if it is passed.

Parameters

- path-name (string) – path name
- suffix (string) – suffix

Return file name

Rtype string

Example:

```
tarantool> fio.basename('/path/to/my.lua', '.lua')
---
- my
...
```

fio.dirname(path-name)

Given a full path name, remove the final part (the file name).

Parameters

- path-name (string) – path name

Return directory name, that is, path name except for file name.

Rtype string

Example:

```
tarantool> fio.dirname('/path/to/my.lua')
---
- '/path/to/'
```

fio.abspath(file-name)

Given a final part (the file name), return the full path name.

Parameters

- file-name (string) – file name

Return directory name, that is, path name including file name.

Rtype string

Example:

```
tarantool> fio.abspath('my.lua')
---
- '/path/to/my.lua'
...
```

Directory or file existence and type checks

Functions in this section are similar to some Python os.path functions.

fio.path.exists(path-name)

Parameters

- path-name (string) – path to directory or file.

Return true if path-name refers to a directory or file that exists and is not a broken symbolic link; otherwise false

Rtype boolean

fio.path.is_dir(path-name)

Parameters

- path-name (string) – path to directory or file.

Return true if path-name refers to a directory; otherwise false

Rtype boolean

fio.path.is_file(path-name)

Parameters

- path-name (string) – path to directory or file.

Return true if path-name refers to a file; otherwise false

Rtype boolean

fio.path.is_link(path-name)

Parameters

- path-name (string) – path to directory or file.

Return true if path-name refers to a symbolic link; otherwise false

Rtype boolean

fio.path.lexists(path-name)

Parameters

- path-name (string) – path to directory or file.

Return true if path-name refers to a directory or file that exists or is a broken symbolic link; otherwise false

Rtype boolean

Common file manipulations

fio.umask(mask-bits)

Set the mask bits used when creating files or directories. For a detailed description type man 2 umask.

Parameters

- mask-bits (number) – mask bits.

Return previous mask bits.

Rtype number

Example:

```
tarantool> fio.umask(tonumber('755', 8))
---
- 493
...
```

fio.lstat(path-name)
fio.stat(path-name)

Returns information about a file object. For details type man 2 lstat or man 2 stat.

Parameters

- path-name (string) – path name of file.

Return (If no error) table of fields which describe the file's block size, creation time, size, and other attributes. (If error) two return values: null, error message.

Rtype table.

Additionally, the result of fio.stat('file-name') will include methods equivalent to POSIX macros:

- is_blk() = POSIX macro S_ISBLK,
- is_chr() = POSIX macro S_ISCHR,
- is_dir() = POSIX macro S_ISDIR,
- is_fifo() = POSIX macro S_ISFIFO,
- is_link() = POSIX macro S_ISLINK,
- is_reg() = POSIX macro S_ISREG,
- is_sock() = POSIX macro S_ISSOCK.

For example, fio.stat('/'):is_dir() will return true.

Example:

```
tarantool> fio.lstat('/etc')
---
- inode: 1048577
  rdev: 0
  size: 12288
  atime: 1421340698
  mode: 16877
  mtime: 1424615337
  nlink: 160
  uid: 0
  blksize: 4096
```

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```
  gid: 0
  ctime: 1424615337
  dev: 2049
  blocks: 24
...
```

fio.mkdir(path-name[, mode])
fio.rmdir(path-name)

Create or delete a directory. For details type man 2 mkdir or man 2 rmdir.

Parameters

- path-name (string) – path of directory.
- mode (number) – Mode bits can be passed as a number or as string constants, for example S_IWUSR. Mode bits can be combined by enclosing them in braces.

Return (If no error) true. (If error) two return values: false, error message.

Rtype boolean

Example:

```
tarantool> fio.mkdir('/etc')
---
- false
...
```

fio.chdir(path-name)

Change working directory. For details type man 2 chdir.

Parameters

- path-name (string) – path of directory.

Return (If success) true. (If failure) false.

Rtype boolean

Example:

```
tarantool> fio.chdir('/etc')
---
- true
...
```

fio.listdir(path-name)

List files in directory. The result is similar to the ls shell command.

Parameters

- path-name (string) – path of directory.

Return (If no error) a list of files. (If error) two return values: null, error message.

Rtype table

Example:

```
tarantool> fio.listdir('/usr/lib/tarantool')
---
```

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```
- - mysql
...
```

fio.glob(path-name)

Return a list of files that match an input string. The list is constructed with a single flag that controls the behavior of the function: GLOB_NOESCAPE. For details type man 3 glob.

Parameters

- path-name (string) – path-name, which may contain wildcard characters.

Return list of files whose names match the input string

Rtype table

Possible errors: nil.

Example:

```
tarantool> fio.glob('/etc/x*')
---
- - /etc/xdg
  - /etc/xml
  - /etc/xul-ext
...
```

fio.tempdir()

Return the name of a directory that can be used to store temporary files.

Example:

```
tarantool> fio.tempdir()
---
- /tmp/lG31e7
...
```

fio.cwd()

Return the name of the current working directory.

Example:

```
tarantool> fio.cwd()
---
- /home/username/tarantool_sandbox
...
```

fio.copytree(from-path, to-path)

Copy everything in the from-path, including subdirectory contents, to the to-path. The result is similar to the cp -r shell command. The to-path should not be empty.

Parameters

- from-path (string) – path-name.
- to-path (string) – path-name.

Return (If no error) true. (If error) two return values: false, error message.

Rtype boolean

Example:

```
tarantool> fio.copytree('/home/original','/home/archives')
---
- true
...
```

fio.mktree(path-name)

Create the path, including parent directories, but without file contents. The result is similar to the mkdir -p shell command.

Parameters

- path-name (string) – path-name.

Return (If no error) true. (If error) two return values: false, error message.

Rtype boolean

Example:

```
tarantool> fio.mktree('/home/archives')
---
- true
...
```

fio.rmtree(path-name)

Remove the directory indicated by path-name, including subdirectories. The result is similar to the rmdir -r shell command. The directory should not be empty.

Parameters

- path-name (string) – path-name.

Return (If no error) true. (If error) two return values: null, error message.

Rtype boolean

Example:

```
tarantool> fio.rmtree('/home/archives')
---
- true
...
```

fio.link(src, dst)
fio.symlink(src, dst)
fio.readlink(src)
fio.unlink(src)

Functions to create and delete links. For details type man readlink, man 2 link, man 2 symlink, man 2 unlink.

Parameters

- src (string) – existing file name.
- dst (string) – linked name.

Return (If no error) fio.link and fio.symlink and fio.unlink return true, fio.readlink returns the link value. (If error) two return values: false|null, error message.

Example:

```
tarantool> fio.link('/home/username/tmp.txt', '/home/username/tmp.txt2')
---
- true
...
tarantool> fio.unlink('/home/username/tmp.txt2')
---
- true
...
```

fio.rename(path-name, new-path-name)

Rename a file or directory. For details type man 2 rename.

Parameters

- path-name (string) – original name.
- new-path-name (string) – new name.

Return (If no error) true. (If error) two return values: false, error message.

Rtype boolean

Example:

```
tarantool> fio.rename('/home/username/tmp.txt', '/home/username/tmp.txt2')
---
- true
...
```

fio.utime(file-name[, accesstime[, updatetime]])

Change the access time and possibly also change the update time of a file. For details type man 2 utime. Times should be expressed as number of seconds since the epoch.

Parameters

- file-name (string) – name.
- accesstime (number) – time of last access. default current time.
- updatetime (number) – time of last update. default = access time.

Return (If no error) true. (If error) two return values: false, error message.

Rtype boolean

Example:

```
tarantool> fio.utime('/home/username/tmp.txt')
---
- true
...
```

fio.copyfile(path-name, new-path-name)

Copy a file. The result is similar to the cp shell command.

Parameters

- path-name (string) – path to original file.
- new-path-name (string) – path to new file.

Return (If no error) true. (If error) two return values: false, error message.

Rtype boolean

Example:

```
tarantool> fio.copyfile('/home/user/tmp.txt', '/home/usern/tmp.txt2')
---
- true
...
```

fio.chown(path-name, owner-user, owner-group)
fio.chmod(path-name, new-rights)

Manage the rights to file objects, or ownership of file objects. For details type man 2 chown or man 2 chmod.

Parameters

- owner-user (string) – new user uid.
- owner-group (string) – new group uid.
- new-rights (number) – new permissions

Return null

Example:

```
tarantool> fio.chmod('/home/username/tmp.txt', tonumber('0755', 8))
---
- true
...
tarantool> fio.chown('/home/username/tmp.txt', 'username', 'username')
---
- true
...
```

fio.truncate(path-name, new-size)

Reduce file size to a specified value. For details type man 2 truncate.

Parameters

- path-name (string) –
- new-size (number) –

Return (If no error) true. (If error) two return values: false, error message.

Rtype boolean

Example:

```
tarantool> fio.truncate('/home/username/tmp.txt', 99999)
---
- true
...
```

fio.sync()

Ensure that changes are written to disk. For details type man 2 sync.

Return true if success, false if failure.

Rtype boolean

Example:

```
tarantool> fio.sync()
---
- true
...
```

fio.open(path-name[, flags[, mode]])

Open a file in preparation for reading or writing or seeking.

Parameters

- path-name (string) – Full path to the file to open.
- flags (number) – Flags can be passed as a number or as string constants, for example 'O_RDONLY', 'O_WRONLY', 'O_RDWR'. Flags can be combined by enclosing them in braces. On Linux the full set of flags as described on the Linux man page is:
  - O_APPEND (start at end of file),
  - O_ASYNC (signal when IO is possible),
  - O_CLOEXEC (enable a flag related to closing),
  - O_CREAT (create file if it doesn't exist),
  - O_DIRECT (do less caching or no caching),
  - O_DIRECTORY (fail if it's not a directory),
  - O_EXCL (fail if file cannot be created),
  - O_LARGEFILE (allow 64-bit file offsets),
  - O_NOATIME (no access-time updating),
  - O_NOCTTY (no console tty),
  - O_NOFOLLOW (no following symbolic links),
  - O_NONBLOCK (no blocking),
  - O_PATH (get a path for low-level use),
  - O_SYNC (force writing if it's possible),
  - O_TMPFILE (the file will be temporary and nameless),
  - O_TRUNC (truncate)

  . . . and, always, one of:

  - O_RDONLY (read only),
  - O_WRONLY (write only), or
  - O_RDWR (either read or write).
- mode (number) – Mode bits can be passed as a number or as string constants, for example S_IWUSR. Mode bits are significant if flags include O_CREAT or O_TMPFILE. Mode bits can be combined by enclosing them in braces.

Return (If no error) file handle (abbreviated as 'fh' in later description). (If error) two return values: null, error message.

Rtype userdata

Possible errors: nil.

Example 1:

```
tarantool> fh = fio.open('/home/username/tmp.txt', {'O_RDWR', 'O_APPEND'})
---
...
tarantool> fh -- display file handle returned by fio.open
---
- fh: 11
...
```

Example 2:

Using fio.open() with tonumber('N', 8) to set permissions as an octal number:

```
tarantool> fio.open('x.txt', {'O_WRONLY', 'O_CREAT'}, tonumber('644',8))
---
- fh: 12
...
```

object file-handle

file-handle:close()

Close a file that was opened with fio.open. For details type man 2 close.

Parameters

- fh (userdata) – file-handle as returned by fio.open().

Return true if success, false if failure.

Rtype boolean

Example:

```
tarantool> fh:close() -- where fh = file-handle
---
- true
...
```

file-handle:pread(count, offset)
file-handle:pread(buffer, count, offset)

Perform random-access read operation on a file, without affecting the current seek position of the file. For details type man 2 pread.

Parameters

- fh (userdata) – file-handle as returned by fio.open()
- buffer – where to read into (if the format is pread(buffer, count, offset))
- count (number) – number of bytes to read
- offset (number) – offset within file where reading begins

If the format is pread(count, offset) then return a string containing the data that was read from the file, or empty string if failure.

If the format is pread(buffer, count, offset) then return the data to the buffer. Buffers can be acquired with buffer.ibuf.

Example:

```
tarantool> fh:pread(25, 25)
---
- |
  elete from t8//
  insert in
...
```

file-handle:pwrite(new-string, offset)
file-handle:pwrite(buffer, count, offset)

Perform random-access write operation on a file, without affecting the current seek position of the file. For details type man 2 pwrite.

Parameters

- fh (userdata) – file-handle as returned by fio.open()
- new-string (string) – value to write (if the format is pwrite(new-string, offset))
- buffer (cdata) – value to write (if the format is pwrite(buffer, count, offset))
- count (number) – number of bytes to write
- offset (number) – offset within file where writing begins

Return true if success, false if failure.

Rtype boolean

If the format is pwrite(new-string, offset) then the returned string is written to the file, as far as the end of the string.

If the format is pwrite(buffer, count, offset) then the buffer contents are written to the file, for count bytes. Buffers can be acquired with buffer.ibuf.

```
tarantool> ibuf = require('buffer').ibuf()
---
...

tarantool> fh:pwrite(ibuf, 1, 0)
---
- true
...
```

file-handle:read([count])
file-handle:read(buffer, count)

Perform non-random-access read on a file. For details type man 2 read or man 2 write.

Note: fh:read and fh:write affect the seek position within the file, and this must be taken into account when working on the same file from multiple fibers. It is possible to limit or prevent file access from other fibers with fiber.cond() or fiber.channel().

Parameters

- fh (userdata) – file-handle as returned by fio.open().
- buffer – where to read into (if the format is read(buffer, count))
- count (number) – number of bytes to read

Return

- If the format is read() – omitting count – then read all bytes in the file.
- If the format is read() or read([count]) then return a string containing the data that was read from the file, or empty string if failure.
- If the format is read(buffer, count) then return the data to the buffer. Buffers can be acquired with buffer.ibuf.
- In case of an error the method returns nil, err and sets the error to errno.

```
tarantool> ibuf = require('buffer').ibuf()
---
...

tarantool> fh:read(ibuf:reserve(5), 5)
---
- 5
...

tarantool> require('ffi').string(ibuf:alloc(5),5)
---
- abcde
```

file-handle:write(new-string)
file-handle:write(buffer, count)

Perform non-random-access write on a file. For details type man 2 write.

Note: fh:read and fh:write affect the seek position within the file, and this must be taken into account when working on the same file from multiple fibers. It is possible to limit or prevent file access from other fibers with fiber.cond() or fiber.channel().

Parameters

- fh (userdata) – file-handle as returned by fio.open()
- new-string (string) – value to write (if the format is write(new-string))
- buffer (cdata) – value to write (if the format is write(buffer, count))
- count (number) – number of bytes to write

Return true if success, false if failure.

Rtype boolean

If the format is write(new-string) then the returned string is written to the file, as far as the end of the string.

If the format is write(buffer, count) then the buffer contents are written to the file, for count bytes. Buffers can be acquired with buffer.ibuf.

Example:

```
tarantool> fh:write("new data")
---
- true
...
tarantool> ibuf = require('buffer').ibuf()
```

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```
---
...
tarantool> fh:write(ibuf, 1)
---
- true
...
```

file-handle:truncate(new-size)

Change the size of an open file. Differs from fio.truncate, which changes the size of a closed file.

Parameters

- fh (userdata) – file-handle as returned by fio.open().

Return true if success, false if failure.

Rtype boolean

Example:

```
tarantool> fh:truncate(0)
---
- true
...
```

file-handle:seek(position[, offset-from])

Shift position in the file to the specified position. For details type man 2 seek.

Parameters

- fh (userdata) – file-handle as returned by fio.open().
- position (number) – position to seek to
- offset-from (string) – 'SEEK_END' = end of file, 'SEEK_CUR' = current position, 'SEEK_SET' = start of file.

Return the new position if success

Rtype number

Possible errors: nil.

Example:

```
tarantool> fh:seek(20, 'SEEK_SET')
---
- 20
...
```

file-handle:stat()

Return statistics about an open file. This differs from fio.stat which return statistics about a closed file. For details type man 2 stat.

Parameters

- fh (userdata) – file-handle as returned by fio.open().

Return details about the file.

Rtype table

Example:

```
tarantool> fh:stat()
---
- inode: 729866
  rdev: 0
  size: 100
  atime: 140942855
  mode: 33261
  mtime: 1409430660
  nlink: 1
  uid: 1000
  blksize: 4096
  gid: 1000
  ctime: 1409430660
  dev: 2049
  blocks: 8
...
```

file-handle:fsync()
file-handle:fdatasync()

Ensure that file changes are written to disk, for an open file. Compare fio.sync, which is for all files. For details type man 2 fsync or man 2 fdatasync.

Parameters

- fh (userdata) – file-handle as returned by fio.open().

Return true if success, false if failure.

Example:

```
tarantool> fh:fsync()
---
- true
...
```

FIO constants

fio.c

Table with constants which are the same as POSIX flag values on the target platform (see man 2 stat).

Example:

```
tarantool> fio.c
---
- seek:
    SEEK_SET: 0
    SEEK_END: 2
    SEEK_CUR: 1
  mode:
    S_IWGRP: 16
    S_IXGRP: 8
    S_IROTH: 4
    S_IXOTH: 1
    S_IRUSR: 256
    S_IXUSR: 64
    S_IRWXU: 448
    S_IRWXG: 56
```

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```
    S_IWOTH: 2
    S_IRWXO: 7
    S_IWUSR: 128
    S_IRGRP: 32
  flag:
    O_EXCL: 2048
    O_NONBLOCK: 4
    O_RDONLY: 0
    <...>
...
```

5.2.12 Module fun

Luafun, also known as the Lua Functional Library, takes advantage of the features of LuaJIT to help users create complex functions. Inside the module are "sequence processors" such as map, filter, reduce, zip – they take a user-written function as an argument and run it against every element in a sequence, which can be faster or more convenient than a user-written loop. Inside the module are "generators" such as range, tabulate, and rands – they return a bounded or boundless series of values. Within the module are "reducers", "filters", "composers" . . . or, in short, all the important features found in languages like Standard ML, Haskell, or Erlang.

The full documentation is On the luafun section of github. However, the first chapter can be skipped because installation is already done, it's inside Tarantool. All that is needed is the usual require request. After that, all the operations described in the Lua fun manual will work, provided they are preceded by the name returned by the require request. For example:

```
tarantool> fun = require('fun')
---
...
tarantool> for _k, a in fun.range(3) do
         >   print(a)
         > end
1
2
3
---
...
```

5.2.13 Module http

Overview

The http module, specifically the http.client submodule, provides the functionality of an HTTP client with support for HTTPS and keepalive. It uses routines in the libcurl library.

Index

Below is a list of all http functions.

Name	Use
http.client.new()	Create an HTTP client instance
client_object:request()	Perform an HTTP request
client_object:stat()	Get a table with statistics

http.client.new([options])

Construct a new HTTP client instance.

Parameters

- options (table) – integer settings which are passed to libcurl.

The two possible options are max_connections and max_total_connections.

max_connections is the maximum number of entries in the cache. It affects libcurl CURLMOPT_MAXCONNECTS. The default is -1.

max_total_connections is the maximum number of active connections. It affects libcurl CURLMOPT_MAX_TOTAL_CONNECTIONS. It is ignored if the curl version is less than 7.30. The default is 0, which allows libcurl to scale accordingly to easily handles count.

The default option values are usually good enough but in rare cases it might be good to set them. In that case here are two tips.

1. You may want to control the maximum number of sockets that a particular HTTP client uses simultaneously. If a system passes many requests to distinct hosts, then libcurl cannot reuse sockets. In this case setting max_total_connections may be useful, since it causes curl to avoid creating too many sockets which would not be used anyway.
2. Do not set max_connections less than max_total_connections unless you are confident about your actions. When max_connections is less then max_total_connections, in some cases libcurl will not reuse sockets for requests that are going to the same host. If the limit is reached and a new request occurs, then libcurl will first create a new socket, send the request, wait for the first connection to be free, and close it, in order to avoid exceeding the max_connections cache size. In the worst case, libcurl will create a new socket for every request, even if all requests are going to the same host. See this Tarantool issue on github for details.

Return a new HTTP client instance

Rtype userdata

Example:

```
tarantool> http_client = require('http.client').new({max_connections = 5})
---
...
```

object client_object

client_object:request(method, url, body, opts)

If http_client is an HTTP client instance, http_client:request() will perform an HTTP request and, if there is a successful connection, will return a table with connection information.

Parameters

- method (string) – HTTP method, for example 'GET' or 'POST' or 'PUT'
- url (string) – location, for example 'https://tarantool.org/doc'

- body (string) – optional initial message, for example 'My text string!'
- opts (table) – table of connection options, with any of these components:
  - ca_file - path to an SSL certificate file to verify the peer with
  - ca_path - path to a directory holding one or more certificates to verify the peer with
  - headers - table of HTTP headers
  - keepalive_idle - delay, in seconds, that the operating system will wait while the connection is idle before sending keepalive probes. See also CURLOPT_TCP_KEEPIDLE and the note below about keepalive_interval.
  - keepalive_interval - the interval, in seconds, that the operating system will wait between sending keepalive probes. See also CURLOPT_TCP_KEEPINTVL. If both keepalive_idle and keepalive_interval are set, then Tarantool will also set HTTP keepalive headers: Connection:Keep-Alive and Keep-Alive:timeout=<keepalive_idle>. Otherwise Tarantool will send Connection:close
  - low_speed_limit - set the "low speed limit" – the average transfer speed in bytes per second that the transfer should be below during "low speed time" seconds for the library to consider it to be too slow and abort. See also CURLOPT_LOW_SPEED_LIMIT
  - low_speed_time - set the "low speed time" – the time that the transfer speed should be below the "low speed limit" for the library to consider it too slow and abort. See also CURLOPT_LOW_SPEED_TIME
  - max_header_name_len - the maximal length of a header name. If a header name is bigger than this value, it is truncated to this length. The default value is '32'.
  - follow_location - when the option is set to true (default) and the response has a 3xx code, the HTTP client will automatically issue another request to a location that a server sends in the Location header. If the new response is 3xx again, the HTTP client will issue still another request and so on in a loop until a non-3xx response will be received. This last response will be returned as a result. Setting this option to false allows to disable this behavior. In this case, the HTTP client will return a 3xx response itself.
  - no_proxy - a comma-separated list of hosts that do not require proxies, or '*', or ''. Set no_proxy = host [, host ...] to specify hosts that can be reached without requiring a proxy, even if proxy has been set to a non-blank value and/or if a proxy-related environment variable has been set. Set no__proxy = `'*'` to specify that all hosts can be reached without requiring a proxy, which is equivalent to setting proxy=`''`. Set no_proxy = `''` to specify that no hosts can be reached without requiring a proxy, even if a proxy-related environment variable (HTTP_PROXY) is used. If no_proxy is not set, then a proxy-related environment variable (HTTP_PROXY) may be used. See also CURLOPT_NOPROXY
  - proxy - a proxy server host or IP address, or ''. If proxy is a host or IP address, then it may begin with a scheme, for example 'https://' for an https proxy or 'http:// for an http proxy. If proxy is set to '' an empty string, then proxy use is disabled, and no proxy-related environment variable will be used. If proxy is not set, then a proxy-related environment variable may be used, such as HTTP_PROXY or HTTPS_PROXY or FTP_PROXY, or ALL_PROXY if the protocol can be any protocol. See also CURLOPT_PROXY

- proxy_port – a proxy server port. The default is 443 for an https proxy and 1080 for a non-https proxy. See also CURLOPT_PROXYPORT
- proxy_user_pwd – a proxy server user name and/or password. Format: proxy_user_pwd = user_name: or proxy_user_pwd = :password or proxy_user_pwd = user_name:password. See also CURLOPT_USERPWD
- ssl_cert - path to a SSL client certificate file. See also CURLOPT_SSLCERT
- ssl_key - path to a private key file for a TLS and SSL client certificate. See also CURLOPT_SSLKEY
- timeout - number of seconds to wait for a curl API read request before timing out
- unix_socket - a socket name to use instead of an Internet address, for a local connection. The Tarantool server must be built with libcurl 7.40 or later. See the second example later in this section.
- verbose - set on/off verbose mode
- verify_host - set on/off verification of the certificate's name (CN) against host. See also CURLOPT_SSL_VERIFYHOST
- verify_peer - set on/off verification of the peer's SSL certificate. See also CURLOPT_SSL_VERIFYPEER
- accept_encoding - enables automatic decompression of HTTP responses by setting the contents of the Accept-Encoding: header sent in an HTTP request and enabling decoding of a response when the Content-Encoding: header is received. This option specifies what encoding to use. It can be an empty string which means the Accept-Encoding: header will contain all supported built-in encodings. Four encodings are supported: identity, meaning non-compressed, deflate which requests the server to compress its response using the zlib algorithm, gzip which requests the gzip algorithm and br which is brotli. Provide them in the string as a comma-separated list of accepted encodings, like: "br, gzip, deflate". For details of the option, refer to CURLOPT_ACCEPT_ENCODING

Return connection information, with all of these components:

- status - HTTP response status
- reason - HTTP response status text
- headers - a Lua table with normalized HTTP headers
- body - response body
- proto - protocol version

Rtype table

The cookies component contains a Lua table where the key is a cookie name. The value is an array of two elements where the first one is the cookie value and the second one is an array with the cookie's options. Possible options are: "Expires", "Max-Age", "Domain", "Path", "Secure", "HttpOnly", "SameSite". Note that an option is a string with '=' splitting the option's name and its value. Here you can find more info.

Example

You can use cookies information like this:

```
tarantool> require('http.client').get('https://www.tarantool.io/en/').cookies
---
- csrftoken:
  - bWJVkBybvX9LdJ8uLPOTVrit5P3VbRjE3potYVOuUnsSjYT5ahghDV06tXRkfnOl
  - - Max-Age=31449600
    - Path=/
...

tarantool> cookies = require('http.client').get('https://www.tarantool.io/en/').cookies
---
...

tarantool> options = cookies['csrftoken'][2]
---
...

tarantool> for _, option in ipairs(options) do
         > if option:startswith('csrftoken cookie's Max-Age = ') then
         > print(option)
         > end
         > end

csrftoken cookie's Max-Age = 31449600
---
...

tarantool>
```

The following “shortcuts” exist for requests:

- http_client:get(url, options) - shortcut for http_client:request("GET", url, nil, opts)
- http_client:post (url, body, options) - shortcut for http_client:request("POST", url, body, opts)
- http_client:put(url, body, options) - shortcut for http_client:request("PUT", url, body, opts)
- http_client:patch(url, body, options) - shortcut for http_client:request("PATCH", url, body, opts)
- http_client:options(url, options) - shortcut for http_client:request("OPTIONS", url, nil, opts)
- http_client:head(url, options) - shortcut for http_client:request("HEAD", url, nil, opts)
- http_client:delete(url, options) - shortcut for http_client:request("DELETE", url, nil, opts)
- http_client:trace(url, options) - shortcut for http_client:request("TRACE", url, nil, opts)
- http_client:connect:(url, options) - shortcut for http_client:request("CONNECT", url, nil, opts)

Requests may be influenced by environment variables, for example users can set up an http proxy by setting HTTP_PROXY=proxy before initiating any requests, unless a proxy connection option has priority. See the web page document Environment variables libcurl understands.

client_object:stat()

The http_client:stat() function returns a table with statistics:

- active_requests - number of currently executing requests
- sockets_added - total number of sockets added into an event loop

- sockets_deleted - total number of sockets sockets from an event loop
- total_requests - total number of requests
- http_200_responses - total number of requests which have returned code HTTP 200
- http_other_responses - total number of requests which have not returned code HTTP 200
- failed_requests - total number of requests which have failed including system errors, curl errors, and HTTP errors

Example 1:

Connect to an HTTP server, look at the size of the response for a 'GET' request, and look at the statistics for the session.

```
tarantool> http_client = require('http.client').new()
---
...
tarantool> r = http_client:request('GET','http://tarantool.org')
---
...
tarantool> string.len(r.body)
---
- 21725
...
tarantool> http_client:stat()
---
- total_requests: 1
  sockets_deleted: 2
  failed_requests: 0
  active_requests: 0
  http_other_responses: 0
  http_200_responses: 1
  sockets_added: 2
```

Example 2:

Start two Tarantool instances on the same computer.

On the first Tarantool instance, listen on a Unix socket:

```
box.cfg{listen='/tmp/unix_domain_socket.sock'}
```

On the second Tarantool instance, send via http_client:

```
box.cfg{}
http_client = require('http.client').new({5})
http_client:put('http://localhost/','body',{unix_socket = '/tmp/unix_domain_socket.sock'})
```

Terminal #1 will show an error message: "Invalid MsgPack". This is not useful but demonstrates the syntax and demonstrates that was sent was received.

5.2.14 Module iconv

Overview

The iconv module provides a way to convert a string with one encoding to a string with another encoding, for example from ASCII to UTF-8. It is based on the POSIX iconv routines.

An exact list of the available encodings may depend on environment. Typically the list includes ASCII, BIG5, KOI8R, LATIN8, MS-GREEK, SJIS, and about 100 others. For a complete list, type iconv --list on a terminal.

Index

Below is a list of all iconv functions.

Name	Use
iconv.new()	Create an iconv instance
iconv.converter()	Perform conversion on a string

iconv.new(to, from)

Construct a new iconv instance.

Parameters

- to (string) – the name of the encoding that we will convert to.
- from (string) – the name of the encoding that we will convert from.

Return a new iconv instance – in effect, a callable function

Rtype userdata

If either parameter is not a valid name, there will be an error message.

Example:

```
tarantool> converter = require('iconv').new('UTF8', 'ASCII')
---
...
```

iconv.converter(input-string)

Convert.

param string input-string the string to be converted (the “from” string)

return the string that results from the conversion (the “to” string)

If anything in input-string cannot be converted, there will be an error message and the result string will be unchanged.

Example:

We know that the Unicode code point for “Д” (CYRILLIC CAPITAL LETTER DE) is hexadecimal 0414 according to the character database of Unicode. Therefore that is what it will look like in UTF-16. We know that Tarantool typically uses the UTF-8 character set. So make a from-UTF-8-to-UTF-16 converter, use string.hex(‘Д’) to show what Д’s encoding looks like in the UTF-8 source, and use string.hex(‘Д’-after-conversion) to show what it looks like in the UTF-16 target. Since the result is 0414, we see that iconv conversion works. (Different iconv implementations might use different names, for example UTF-16BE instead of UTF16BE.)

```
tarantool> string.hex('Д')
---
- d094
...
```

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```
tarantool> converter = require('iconv').new('UTF16BE', 'UTF8')
---
...

tarantool> utf16_string = converter('Д')
---
...

tarantool> string.hex(utf16_string)
---
- '0414'
...
```

5.2.15 Module json

Overview

The json module provides JSON manipulation routines. It is based on the Lua-CJSON module by Mark Pulford. For a complete manual on Lua-CJSON please read the official documentation.

Index

Below is a list of all json functions and members.

Name	Use
json.encode()	Convert a Lua object to a JSON string
json.decode()	Convert a JSON string to a Lua object
__serialize parameter	Output structure specification
json.cfg()	Change configuration
json.NULL	Analog of Lua's "nil"

json.encode(lua-value[, configuration])

Convert a Lua object to a JSON string.

Parameters

- lua_value – either a scalar value or a Lua table value.
- configuration – see json.cfg

Return the original value reformatted as a JSON string.

Rtype string

Example:

```
tarantool> json=require('json')
---
...
tarantool> json.encode(123)
---
- '123'
...
tarantool> json.encode({123})
```

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```
---
- '[123]'
...
tarantool> json.encode({123, 234, 345})
---
- '[123,234,345]'
...
tarantool> json.encode({abc = 234, cde = 345})
---
- '{"cde":345,"abc":234}'
...
tarantool> json.encode({hello = {'world'}})
---
- '{"hello":["world"]}'
...
```

json.decode(string[, configuration])

Convert a JSON string to a Lua object.

Parameters

- string (string) – a string formatted as JSON.
- configuration – see json.cfg

Return the original contents formatted as a Lua table.

Rtype table

Example:

```
tarantool> json = require('json')
---
...
tarantool> json.decode('123')
---
- 123
...
tarantool> json.decode('[123, "hello"]')
---
- [123, 'hello']
...
tarantool> json.decode('{"hello": "world"}').hello
---
- world
...
```

See the tutorial Sum a JSON field for all tuples to see how json.decode() can fit in an application.

__serialize parameter:

The JSON output structure can be specified with __serialize:

- 'seq', 'sequence', 'array' - table encoded as an array
- 'map', 'mapping' - table encoded as a map
- function - the meta-method called to unpack serializable representation of table, cdata or userdata objects

Serializing 'A' and 'B' with different __serialize values brings different results:

```
tarantool> json.encode(setmetatable({'A', 'B'}, { __serialize="seq"}))
---
- '["A","B"]'
...
tarantool> json.encode(setmetatable({'A', 'B'}, { __serialize="map"}))
---
- '{"1":"A","2":"B"}'
...
tarantool> json.encode({setmetatable({f1 = 'A', f2 = 'B'}, { __serialize="map"})})
---
- '[{"f2":"B","f1":"A"}]'
...
tarantool> json.encode({setmetatable({f1 = 'A', f2 = 'B'}, { __serialize="seq"})})
---
- '[[]]'
...
```

json.cfg(table)

Set values that affect the behavior of json.encode and json.decode.

The values are all either integers or boolean true/false.

Option	Default	Use
cfg.encode_max_depth	128	Max recursion depth for encoding
cfg.encode_deep_as_nil	false	A flag saying whether to crop tables with nesting level deeper than cfg.encode_max_depth. Not-encoded fields are replaced with one null. If not set, too deep nesting is considered an error.
cfg.encode_invalid_numbers	true	A flag saying whether to enable encoding of NaN and Inf numbers
cfg.encode_number_precision	14	Precision of floating point numbers
cfg.encode_load_metatables	true	A flag saying whether the serializer will follow __serialize metatable field
cfg.encode_use_tostring	false	A flag saying whether to use tostring() for unknown types
cfg.encode_invalid_as_nil	false	A flag saying whether use NULL for non-recognized types
cfg.encode_sparse_convert	true	A flag saying whether to handle excessively sparse arrays as maps. See detailed description below.
cfg.encode_sparse_ratio	2	1/encode_sparse_ratio is the permissible percentage of missing values in a sparse array.
cfg.encode_sparse_safe	10	A limit ensuring that small Lua arrays are always encoded as sparse arrays (instead of generating an error or encoding as a map)
cfg.decode_invalid_numbers	true	A flag saying whether to enable decoding of NaN and Inf numbers
cfg.decode_save_metatables	true	A flag saying whether to set metatables for all arrays and maps
cfg.decode_max_depth	128	Max recursion depth for decoding

Sparse arrays features:

During encoding, the JSON encoder tries to classify a table into one of four kinds:

- map - at least one table index is not unsigned integer
- regular array - all array indexes are available
- sparse array - at least one array index is missing
- excessively sparse array - the number of values missing exceeds the configured ratio

An array is excessively sparse when all the following conditions are met:

- encode_sparse_ratio > 0
- max(table) > encode_sparse_safe
- max(table) > count(table) * encode_sparse_ratio

The JSON encoder will never consider an array to be excessively sparse when encode_sparse_ratio = 0. The encode_sparse_safe limit ensures that small Lua arrays are always encoded as sparse arrays. By default, attempting to encode an excessively sparse array will generate an error. If encode_sparse_convert is set to true, excessively sparse arrays will be handled as maps.

json.cfg() example 1:

The following code will encode 0/0 as NaN ("not a number") and 1/0 as Inf ("infinity"), rather than returning nil or an error message:

```
json = require('json')
json.cfg{encode_invalid_numbers = true}
x = 0/0
y = 1/0
json.encode({1, x, y, 2})
```

The result of the json.encode() request will look like this:

```
tarantool> json.encode({1, x, y, 2})
---
- '[1,nan,inf,2]
...
```

json.cfg example 2:

To avoid generating errors on attempts to encode unknown data types as userdata/cdata, you can use this code:

```
tarantool> httpc = require('http.client').new()
---
...

tarantool> json.encode(httpc.curl)
---
- error: unsupported Lua type 'userdata'
...

tarantool> json.encode(httpc.curl, {encode_use_tostring=true})
---
- '"userdata: 0x010a4ef2a0"'
...
```

Note: To achieve the same effect for only one call to json.encode() (i.e. without changing the configuration permanently), you can use json.encode({1, x, y, 2}, {encode_invalid_numbers = true}).

Similar configuration settings exist for MsgPack and YAML.

json.NULL

A value comparable to Lua "nil" which may be useful as a placeholder in a tuple.

Example:

```
-- When nil is assigned to a Lua-table field, the field is null
tarantool> {nil, 'a', 'b'}
---
- - null
  - a
  - b
...
-- When json.NULL is assigned to a Lua-table field, the field is json.NULL
tarantool> {json.NULL, 'a', 'b'}
---
- - null
  - a
  - b
...
-- When json.NULL is assigned to a JSON field, the field is null
tarantool> json.encode({field2 = json.NULL, field1 = 'a', field3 = 'c'})
---
- '{"field2":null,"field1":"a","field3":"c"}'
...
```

5.2.16 Module key_def

The key_def module has a function for making a definition of the field numbers and types of a tuple. The definition is usually used in conjunction with an index definition to extract or compare the index key values.

key_def.new(parts)

Create a new key_def instance.

Parameters

- parts (table) – field numbers and types. There must be at least one part and it must have at least fieldno and type.

Returns key_def-object a key_def object

The parts table has components which are the same as the parts option in Options for space_object:create_index().

fieldno (integer) for example fieldno = 1. It is legal to say field instead of fieldno.

type (string) for example type = 'string'.

Other components are optional.

Example: key_def.new({{type = 'unsigned', fieldno = 1}})

Example: key_def.new({{type = 'string', collation = 'unicode', field = 2}})

object key_def_object

A key_def object is an object returned by key_def.new(). It has methods extract_key(), compare(), compare_with_key(), merge(), totable().

key_def_object:extract_key(tuple)

Return a tuple containing only the fields of the key_def object.

Parameters

- tuple (table) – tuple or Lua table with field contents

Return the fields that were defined for the key_def object

Example #1:

```
-- Suppose that an item has five fields
-- 1, 99.5, 'X', nil, 99.5
-- and the fields that we care about are
-- #3 (a string) and #1 (an integer).
-- We can define those fields with k = key_def.new
-- and extract the values with k:extract_key.

tarantool> key_def = require('key_def')
---
...

tarantool> k = key_def.new({{type = 'string', fieldno = 3},
>                         {type = 'unsigned', fieldno =1 }})
---
...

tarantool> k:extract_key({1, 99.5, 'X', nil, 99.5})
---
- ['X', 1]
...
```

Example #2

```
-- Now suppose that the item is a tuple in a space which
-- has an index on field #3 plus field #1.
-- We can use key_def.new with the index definition
-- instead of filling it out as we did with Example #1.
-- The result will be the same.
key_def = require('key_def')
box.schema.space.create('T')
i = box.space.T:create_index('I',{parts={3,'string',1,'unsigned'}})
box.space.T:insert{1, 99.5, 'X', nil, 99.5}
k = key_def.new(i.parts)
k:extract_key(box.space.T:get({'X', 1}))
```

Example #3

```
-- Iterate through the tuples in a secondary non-unique index.
-- extracting the tuples' primary-key values so they can be deleted
-- using a unique index. This code should be part of a Lua function.
local key_def_lib = require('key_def')
local s = box.schema.space.create('test')
local pk = s:create_index('pk')
local sk = s:create_index('test', {unique = false, parts = {
    {2, 'number', path = 'a'}, {2, 'number', path = 'b'}}})
s:insert{1, {a = 1, b = 1}}
s:insert{2, {a = 1, b = 2}}
local key_def = key_def_lib.new(pk.parts)
for _, tuple in sk:pairs({1})) do
    local key = key_def:extract_key(tuple)
```

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```
    pk:delete(key)
end
```

key_def_object:compare(tuple_1, tuple_2)

Compare the key fields of tuple_1 to the key fields of tuple_2. This is a tuple-by-tuple comparison so users do not have to write code which compares a field at a time. Each field's type and collation wll be taken into account. In effect it is a comparison of extract_key(tuple_1) with extract_key(tuple_2).

Parameters

- tuple1 (table) – tuple or Lua table with field contents
- tuple2 (table) – tuple or Lua table with field contents

Return > 0 if tuple_1 key fields $>$ tuple_2 key fields, $= 0$ if tuple_1 key fields $=$ tuple_2 key fields, < 0 if tuple_1 key fields $<$ tuple_2 key fields

Example:

```
-- This will return 0
key_def = require('key_def')
k = key_def.new({{type='string',fieldno=3,collation='unicode_ci'},
                 {type='unsigned',fieldno=1}})
k:compare({1, 99.5, 'X', nil, 99.5}, {1, 99.5, 'x', nil, 99.5})
```

key_def_object:compare_with_key(tuple_1, tuple_2)

Compare the key fields of tuple_1 to all the fields of tuple_2. This is the same as key_def_object:compare() except that tuple_2 contains only the key fields. In effect it is a comparison of extract_key(tuple_1) with tuple_2.

Parameters

- tuple1 (table) – tuple or Lua table with field contents
- tuple2 (table) – tuple or Lua table with field contents

Return > 0 if tuple_1 key fields $>$ tuple_2 fields, $= 0$ if tuple_1 key fields $=$ tuple_2 fields, < 0 if tuple_1 key fields $<$ tuple_2 fields

Example:

```
-- This will return 0
key_def = require('key_def')
k = key_def.new({{type='string',fieldno=3,collation='unicode_ci'},
                 {type='unsigned',fieldno=1}})
k:compare_with_key({1, 99.5, 'X', nil, 99.5}, {'x', 1})
```

key_def_object:merge(other_key_def_object)

Combine the main key_def_object with other_key_def_object. The return value is a new key_def_object containing all the fields of the main key_def_object, then all the fields of other_key_def_object which are not in the main key_def_object.

Parameters

- other_key_def_object (key_def_object) – definition of fields to add

Return key_def_object

Example:

```
-- This will return a key definition with fieldno=3 and fieldno=1.
key_def = require('key_def')
k = key_def.new({{type = 'string', fieldno = 3}})
k2= key_def.new({{type = 'unsigned', fieldno = 1},
                 {type = 'string', fieldno = 3}})
k:merge(k2)
```

key_def_object:totable()

Return a table containing what is in the key_def_object. This is the reverse of key_def.new():

- key_def.new() takes a table and returns a key_def object,
- key_def_object:totable() takes a key_def object and returns a table.

This is useful for input to _serialize methods.

Return table

Example:

```
-- This will return a table with type='string', fieldno=3
key_def = require('key_def')
k = key_def.new({{type = 'string', fieldno = 3}})
k:totable()
```

5.2.17 Module log

Overview

The Tarantool server puts all diagnostic messages in a log file specified by the log configuration parameter. Diagnostic messages may be either system-generated by the server's internal code, or user-generated with the log.log_level_function_name function.

As explained in the description of log_format configuration setting, there are two possible formats for log entries:

- 'plain' (the default), or
- 'json' (with more detail and with JSON labels).

Here is what a log entry looks like after box.cfg{log_format='plain'}:

```
2017-10-16 11:36:01.508 [18081] main/101/interactive I> set 'log_format' configuration option to "plain"
```

Here is what a log entry looks like after box.cfg{log_format='json'}:

```
{"time": "2017-10-16T11:36:17.996-0600",
"level": "INFO",
"message": "set 'log_format' configuration option to \"json\"",
"pid": 18081,|
"cord_name": "main",
"fiber_id": 101,
"fiber_name": "interactive",
"file": "builtin\/box\/load_cfg.lua",
"line": 317}
```

Index

Below is a list of all log functions.

Name	Use
log.error() log.warn() log.info() log.verbose() log.debug()	Write a user-generated message to a log file
log.logger_pid()	Get the PID of a logger
log.rotate()	Rotate a log file

log.error(message)
log.warn(message)
log.info(message)
log.verbose(message)
log.debug(message)

Output a user-generated message to the log file, given log_level_function_name = error or warn or info or verbose or debug.

As explained in the description of the configuration setting for log_level, there are seven levels of detail:

- 1 – SYSERROR
- 2 – ERROR – this corresponds to log.error(...)
- 3 – CRITICAL
- 4 – WARNING – this corresponds to log.warn(...)
- 5 – INFO – this corresponds to log.info(...)
- 6 – VERBOSE – this corresponds to log.verbose(...)
- 7 – DEBUG – this corresponds to log.debug(...)

For example, if box.cfg.log_level is currently 5 (the default value), then log.error(...), log.warn(...) and log.info(...) messages will go to the log file. However, log.verbose(...) and log.debug(...) messages will not go to the log file, because they correspond to higher levels of detail.

Parameters

- message (any) – Usually a string.

  Messages may contain C-style format specifiers %d or %s, so log.error('...%d...%s', x, y) will work if x is a number and y is a string.

  Less commonly, messages may be other scalar data types, or even tables. So log.error({'x',18.7,true}) will work.

Return nil

The actual output will be a line in the log, containing:

- the current timestamp,
- a module name,
- 'E', 'W', 'I', 'V' or 'D' depending on log_level_function_name, and
- message.

Output will not occur if log_level_function_name is for a type greater than log_level.

log.logger_pid()

Return PID of a logger

log.rotate()

Rotate the log.

Return nil

Example

```
$ tarantool
tarantool> box.cfg{log_level=3, log='tarantool.txt'}
tarantool> log = require('log')
tarantool> log.error('Error')
tarantool> log.info('Info %s', box.info.version)
tarantool> os.exit()
```

```
$ less tarantool.txt
2017-09-20 ... [68617] main/101/interactive C> version 1.7.5-31-ge939c6ea6
2017-09-20 ... [68617] main/101/interactive C> log level 3
2017-09-20 ... [68617] main/101/interactive [C]:-1 E> Error
```

The 'Error' line is visible in tarantool.txt preceded by the letter E.

The 'Info' line is not present because the log_level is 3.

5.2.18 Module merger

Overview

The merger module takes a stream of tuples and provides access to them as tables.

Index

The four functions for creating a merger object instance are:

- merger.new_tuple_source(),
- merger.new_buffer_source(),
- merger.new_table_source,
- merger.new(merger_source…).

The methods for using a merger object are:

- merger_object:select(),
- merger_object:pairs().

merger.new_tuple_source(gen, param, state)

Create a new merger instance from a tuple source.

A tuple source just returns one tuple.

The generator function gen() allows creation of multiple tuples via an iterator.

The gen() function should return:

- state, tuple each time it is called and a new tuple is available,
- nil when no more tuples are available.

Parameters

- gen – function for iteratively returning tuples
- param – parameter for the gen function

Return merger-object a merger object

Example: see merger_object:pairs() method.

merger.new_buffer_source(gen, param, state)
Create a new merger instance from a buffer source.

Parameters and return: same as for merger.new_tuple_source.

To set up a buffer, or a series of buffers, use the buffer module.

merger.new_table_source(gen, param, state)
Create a new merger instance from a table source.

Parameters and return: same as for merger.new_tuple_source.

Example: see merger_object:select() method.

merger.new(key_def, sources, options)
Create a new merger instance from a merger source.

A merger source is created from a key_def object and a set of (tuple or buffer or table or merger) sources. It performs a kind of merge sort. It chooses a source with a minimal / maximal tuple on each step, consumes a tuple from this source, and repeats.

Parameters

- key_def – object created with key_def
- source – parameter for the gen() function
- options – reverse=true if descending, false or nil if ascending

Return merger-object a merger object

A key_def can be cached across requests with the same ordering rules (typically these would be requests accessing the same space).

Example: see merger_object:pairs() method.

object merger_object
A merger object is an object returned by:

- merger.new_tuple_source() or
- merger.new_buffer_source() or
- merger.new_table_source or
- merger.new(merger_source…).

It has methods:

- merger_object:select() or
- merger_object:pairs().

merger_object:select([buffer[, limit]])
Access the contents of a merger object with familiar select syntax.

Parameters

- buffer – as in net.box client conn:select method
- limit – as in net.box client conn:select method

Return a table of tuples, similar to what select would return

Example with new_table_source():

```
-- Source via new_table_source, simple generator function
-- tarantool> s:select()
-- ---
-- - - [100]
--   - [200]
-- ...
merger=require('merger')
k=0
function merger_function(param)
  k = k + 1
  if param[k] == nil then return nil end
  return box.NULL, param[k]
  end
chunks={}
chunks[1] = {{100}} chunks[2] = {{200}} chunks[3] = nil
s = merger.new_table_source(merger_function, chunks)
s:select()
```

merger_object:pairs()

The pairs() method (or the equivalent ipairs() alias method) returns a luafun iterator. It is a Lua iterator, but also provides a set of handy methods to operate in functional style.

Parameters

- tuple (table) – tuple or Lua table with field contents

Return the tuples that can be found with a standard pairs() function

Example with new_tuple_source():

```
-- Source via new_tuple_source, from a space of tables
-- The result will look like this:
-- tarantool> so:pairs():totable()
-- ---
-- - - [100]
--   - [200]
-- ...
merger = require('merger')
box.schema.space.create('s')
box.space.s:create_index('i')
box.space.s:insert({100})
box.space.s:insert({200})
so = merger.new_tuple_source(box.space.s:pairs())
so:pairs():totable()
```

Example with two mergers:

```
-- Source via key_def, and table data

-- Create the key_def object
merger = require('merger')
key_def_lib = require('key_def')
```

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```
key_def = key_def_lib.new({{
    fieldno = 1,
    type = 'string',
}})
-- Create the table source
data = {{'a'}, {'b'}, {'c'}}
source = merger.new_source_fromtable(data)
i1 = merger.new(key_def, {source}):pairs()
i2 = merger.new(key_def, {source}):pairs()
-- t1 will be 'a' (tuple 1 from merger 1)
t1 = i1:head():totable()
-- t3 will be 'c' (tuple 3 from merger 2)
t3 = i2:head():totable()
-- t2 will be 'b' (tuple 2 from merger 1)
t2 = i1:head():totable()
-- i1:is_null() will be true (merger 1 ends)
i1:is_null()
-- i2:is_null() will be true (merger 2 ends)
i2:is_null()
```

More examples:

See https://github.com/Totktonada/tarantool-merger-examples which, in addition to discussing the merger API in detail, shows Lua code for handling many more situations than are in this manual's brief examples.

5.2.19 Module msgpack

Overview

The msgpack module decodes raw MsgPack strings by converting them to Lua objects, and encodes Lua objects by converting them to raw MsgPack strings. Tarantool makes heavy internal use of MsgPack because tuples in Tarantool are stored as MsgPack arrays.

Definitions: MsgPack is short for MessagePack. A "raw MsgPack string" is a byte array formatted according to the MsgPack specification including type bytes and sizes. The type bytes and sizes can be made displayable with string.hex(), or the raw MsgPack strings can be converted to Lua objects with msgpack methods.

Index

Below is a list of all msgpack functions and members.

Name	Use
msgpack.encode(lua_value)	Convert a Lua object to a raw MsgPack string
msgpack.encode(lua_value,ibuf)	Convert a Lua object to a raw MsgPack string in an ibuf
msgpack.decode(msgpack_string)	Convert a raw MsgPack string to a Lua object
msgpack.decode(C_style_string_pointer)	Convert a raw MsgPack string in an ibuf to a Lua object
msgpack.decode_unchecked(mspack_string)	Convert a raw MsgPack string to a Lua object
msgpack.decode_unchecked(C_style_string_pointer)	Convert a raw MsgPack string to a Lua object
msgpack.decode_array_header	Skip array header in a raw MsgPack string
msgpack.decode_map_header	Skip map header in a raw MsgPack string
__serialize parameter	Output structure specification
msgpack.cfg	Change configuration
msgpack.NULL	Analog of Lua's "nil"

msgpack.encode(lua_value)

Convert a Lua object to a raw MsgPack string.

Parameters

- lua_value – either a scalar value or a Lua table value.

Return the original contents formatted as a raw MsgPack string;

Rtype raw MsgPack string

msgpack.encode(lua_value, ibuf)

Convert a Lua object to a raw MsgPack string in an ibuf, which is a buffer such as buffer.ibuf() creates. As with encode(lua_value), the result is a raw MsgPack string, but it goes to the ibuf output instead of being returned.

Parameters

- lua_value (lua-object) – either a scalar value or a Lua table value.
- ibuf (buffer) – (output parameter) where the result raw MsgPack string goes

Return number of bytes in the output

Rtype raw MsgPack string

Example using buffer.ibuf() and ffi.string() and string.hex(): The result will be '91a161' because 91 is the MessagePack encoding of "fixarray size 1", a1 is the MessagePack encoding of "fixstr size 1", and 61 is the UTF-8 encoding of 'a':

```
ibuf = require('buffer').ibuf()
msgpack_string_size = require('msgpack').encode({'a'}, ibuf)
msgpack_string = require('ffi').string(ibuf.rpos, msgpack_string_size)
string.hex(msgpack_string)
```

msgpack.decode(msgpack_string[, start_position])

Convert a raw MsgPack string to a Lua object.

Parameters

- msgpack_string (string) – a raw MsgPack string.
- start_position (integer) – where to start, minimum = 1, maximum = string length, default = 1.

Return

- (if msgpack_string is a valid raw MsgPack string) the original contents of msgpack_string, formatted as a Lua object, usually a Lua table, (otherwise) a scalar value, such as a string or a number;
- "next_start_position". If decode stops after parsing as far as byte N in msgpack_string, then "next_start_position" will equal N + 1, and decode(msgpack_string, next_start_position) will continue parsing from where the previous decode stopped, plus 1. Normally decode parses all of msgpack_string, so "next_start_position" will equal string.len(msgpack_string) + 1.

Rtype Lua object and number

Example: The result will be ['a'] and 4:

```
msgpack_string = require('msgpack').encode({'a'})
require('msgpack').decode(msgpack_string, 1)
```

msgpack.decode(C_style_string_pointer, size)

Convert a raw MsgPack string, whose address is supplied as a C-style string pointer such as the rpos pointer which is inside an ibuf such as buffer.ibuf() creates, to a Lua object. A C-style string pointer may be described as cdata<char *> or cdata<const char *>.

Parameters

- C_style_string_pointer (buffer) – a pointer to a raw MsgPack string.
- size (integer) – number of bytes in the raw MsgPack string

Return

- (if C_style_string_pointer points to a valid raw MsgPack string) the original contents of msgpack_string, formatted as a Lua object, usually a Lua table, (otherwise) a scalar value, such as a string or a number;
- returned_pointer = a C-style pointer to the byte after what was passed, so that C_style_string_pointer + size = returned_pointer

Rtype table and C-style pointer to after what was passed

Example using buffer.ibuf and pointer arithmetic: The result will be ['a'] and 3 and true:

```
ibuf = require('buffer').ibuf()
msgpack_string_size = require('msgpack').encode({'a'}, ibuf)
a, b = require('msgpack').decode(ibuf.rpos, msgpack_string_size)
a, b - ibuf.rpos, msgpack_string_size == b - ibuf.rpos
```

msgpack.decode_unchecked(msgpack_string[, start_position])

Input and output are the same as for decode(string).

msgpack.decode_unchecked(C_style_string_pointer)

Input and output are the same as for decode(C_style_string_pointer), except that size is not needed. Some checking is skipped, and decode_unchecked(C_style_string_pointer) can operate with string pointers to buffers which decode(C_style_string_pointer) cannot handle. For an example see the buffer module.

msgpack.decode_array_header(byte-array, size)

Call the mp_decode_array function in the MsgPuck library and return the array size and a pointer to the first array component. A subsequent call to msgpack_decode can decode the component instead of the whole array.

Parameters

- byte-array – a pointer to a raw MsgPack string.
- size – a number greater than or equal to the string's length

Return

- the size of the array;
- a pointer to after the array header.

```
-- Example of decode_array_header
-- Suppose we have the raw data '\x93\x01\x02\x03'.
-- \x93 is MsgPack encoding for a header of a three-item array.
-- We want to skip it and decode the next three items.
msgpack=require('msgpack'); ffi=require('ffi')
x,y=msgpack.decode_array_header(ffi.cast('char*','\x93\x01\x02\x03'),4)
a=msgpack.decode(y,1);b=msgpack.decode(y+1,1);c=msgpack.decode(y+2,1);
a,b,c
-- The result will be: 1,2,3.
```

msgpack.decode_map_header(byte-array, size)

Call the mp_decode_map function in the MsgPuck library and return the map size and a pointer to the first map component. A subsequent call to msgpack_decode can decode the component instead of the whole map.

Parameters

- byte-array – a pointer to a raw MsgPack string.
- size – a number greater than or equal to the raw MsgPack string's length

Return

- the size of the map;
- a pointer to after the map header.

```
-- Example of decode_map_header
-- Suppose we have the raw data '\x81\xa2\x41\x41\xc3'.
-- \x81 is MsgPack encoding for a header of a one-item map.
-- We want to skip it and decode the next map item.
msgpack=require('msgpack'); ffi=require('ffi')
x,y=msgpack.decode_map_header(ffi.cast('char*','\x81\xa2\x41\x41\xc3'),5)
a=msgpack.decode(y,3);b=msgpack.decode(y+3,1)
x,a,b
-- The result will be: 1,"AA", true.
```

__serialize parameter:

The MsgPack output structure can be specified with __serialize:

- 'seq', 'sequence', 'array' - table encoded as an array
- 'map', 'mappping' - table encoded as a map
- function - the meta-method called to unpack serializable representation of table, cdata or userdata objects

Serializing 'A' and 'B' with different __serialize values brings different results. To show this, here is a routine which encodes {'A','B'} both as an array and as a map, then displays each result in hexadecimal.

```
function hexdump(bytes)
    local result = ''
    for i = 1, #bytes do
        result = result .. string.format("%x", string.byte(bytes, i)) .. ' '
    end
    return result
end

msgpack = require('msgpack')
m1 = msgpack.encode(setmetatable({'A', 'B'}, {
                             __serialize = "seq"
                          }))
m2 = msgpack.encode(setmetatable({'A', 'B'}, {
                             __serialize = "map"
                          }))
print('array encoding: ', hexdump(m1))
print('map encoding: ', hexdump(m2))
```

Result:

```
array encoding: 92 a1 41 a1 42
map encoding:   82 01 a1 41 02 a1 42
```

The MsgPack Specification page explains that the first encoding means:

```
fixarray(2), fixstr(1), "A", fixstr(1), "B"
```

and the second encoding means:

```
fixmap(2), key(1), fixstr(1), "A", key(2), fixstr(2), "B"
```

Here are examples for all the common types, with the Lua-table representation on the left, with the MsgPack format name and encoding on the right.

Common Types and MsgPack Encodings

{}	'fixmap' if metatable is 'map' = 80 otherwise 'fixarray' = 90
'a'	'fixstr' = a1 61
false	'false' = c2
true	'true' = c3
127	'positive fixint' = 7f
65535	'uint 16' = cd ff ff
4294967295	'uint 32' = ce ff ff ff ff
nil	'nil' = c0
msgpack.NULL	same as nil
[0] = 5	'fixmap(1)' + 'positive fixint' (for the key) + 'positive fixint' (for the value) = 81 00 05
[0] = nil	'fixmap(0)' = 80 – nil is not stored when it is a missing map value
1.5	'float 64' = cb 3f f8 00 00 00 00 00 00

msgpack.cfg(table)

Some MsgPack configuration settings can be changed.

The values are all either integers or boolean true/false.

Option	Default	Use
cfg.encode_max_depth	128	Max recursion depth for encoding
cfg.encode_deep_as_nil	false	A flag saying whether to crop tables with nesting level deeper than cfg.encode_max_depth. Not-encoded fields are replaced with one null. If not set, too high nesting is considered an error.
cfg.encode_invalid_numbers	true	A flag saying whether to enable encoding of NaN and Inf numbers
cfg.encode_load_metatables	true	A flag saying whether the serializer will follow __serialize metatable field
cfg.encode_use_tostring	false	A flag saying whether to use tostring() for unknown types
cfg.encode_invalid_as_nil	false	A flag saying whether to use NULL for non-recognized types
cfg.encode_sparse_convert	true	A flag saying whether to handle excessively sparse arrays as maps. See detailed description below
cfg.encode_sparse_ratio	2	1/encode_sparse_ratio is the permissible percentage of missing values in a sparse array
cfg.encode_sparse_safe	10	A limit ensuring that small Lua arrays are always encoded as sparse arrays (instead of generating an error or encoding as a map)
cfg.decode_invalid_numbers	true	A flag saying whether to enable decoding of NaN and Inf numbers
cfg.decode_save_metatables	true	A flag saying whether to set metatables for all arrays and maps

Sparse arrays features:

During encoding, the MsgPack encoder tries to classify tables into one of four kinds:

- map - at least one table index is not unsigned integer
- regular array - all array indexes are available
- sparse array - at least one array index is missing
- excessively sparse array - the number of values missing exceeds the configured ratio

An array is excessively sparse when all the following conditions are met:

- encode_sparse_ratio > 0
- max(table) > encode_sparse_safe
- max(table) > count(table) * encode_sparse_ratio

MsgPack encoder will never consider an array to be excessively sparse when encode_sparse_ratio = 0. The encode_sparse_safe limit ensures that small Lua arrays are always encoded as sparse arrays. By default, attempting to encode an excessively sparse array will generate an error. If encode_sparse_convert is set to true, excessively sparse arrays will be handled as maps.

msgpack.cfg() example 1:

If msgpack.cfg.encode_invalid_numbers = true (the default), then NaN and Inf are legal values. If that is not desirable, then ensure that msgpack.encode() will not accept them, by saying msgpack.cfg{encode_invalid_numbers = false}, thus:

```
tarantool> msgpack = require('msgpack'); msgpack.cfg{encode_invalid_numbers = true}
---
...
tarantool> msgpack.decode(msgpack.encode{1, 0 / 0, 1 / 0, false})
---
- [1, -nan, inf, false]
- 22
...
tarantool> msgpack.cfg{encode_invalid_numbers = false}
---
...
tarantool> msgpack.decode(msgpack.encode{1, 0 / 0, 1 / 0, false})
---
- error: ... number must not be NaN or Inf'
...
```

msgpack.cfg example 2:

To avoid generating errors on attempts to encode unknown data types as userdata/cdata, you can use this code:

```
tarantool> httpc = require('http.client').new()
---
...

tarantool> msgpack.encode(httpc.curl)
---
- error: unsupported Lua type 'userdata'
...

tarantool> msgpack.encode(httpc.curl, {encode_use_tostring=true})
---
- '"userdata: 0x010a4ef2a0"'
...
```

Note: To achieve the same effect for only one call to msgpack.encode() (i.e. without changing the configuration permanently), you can use msgpack.encode({1, x, y, 2}, {encode_invalid_numbers = true}).

Similar configuration settings exist for JSON and YAML.

msgpack.NULL

A value comparable to Lua "nil" which may be useful as a placeholder in a tuple.

Example

```
tarantool> msgpack = require('msgpack')
---
...
tarantool> y = msgpack.encode({'a',1,'b',2})
---
...
tarantool> z = msgpack.decode(y)
---
...
tarantool> z[1], z[2], z[3], z[4]
---
```

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```
- a
- 1
- b
- 2
...
tarantool> box.space.tester:insert{20, msgpack.NULL, 20}
---
- [20, null, 20]
...
```

5.2.20 Module net.box

Overview

The net.box module contains connectors to remote database systems. One variant, to be discussed later, is for connecting to MySQL or MariaDB or PostgreSQL (see SQL DBMS modules reference). The other variant, which is discussed in this section, is for connecting to Tarantool server instances via a network.

You can call the following methods:

- require('net.box') to get a net.box object (named net_box for examples in this section),
- net_box.connect() to connect and get a connection object (named conn for examples in this section),
- other net.box() routines, passing conn:, to execute requests on the remote database system,
- conn:close to disconnect.

All net.box methods are fiber-safe, that is, it is safe to share and use the same connection object across multiple concurrent fibers. In fact that is perhaps the best programming practice with Tarantool. When multiple fibers use the same connection, all requests are pipelined through the same network socket, but each fiber gets back a correct response. Reducing the number of active sockets lowers the overhead of system calls and increases the overall server performance. However for some cases a single connection is not enough —- for example, when it is necessary to prioritize requests or to use different authentication IDs.

Most net.box methods allow a final {options} argument, which can be:

- {timeout=...}. For example, a method whose final argument is {timeout=1.5} will stop after 1.5 seconds on the local node, although this does not guarantee that execution will stop on the remote server node.
- {buffer=...}. For an example see buffer module.
- {is_async=...}. For example, a method whose final argument is {is_async=true} will not wait for the result of a request. See the is_async description.
- {on_push=... on_push_ctx=...}. For receiving out-of-band messages. See the box.session.push description.

The diagram below shows possible connection states and transitions:

On this diagram:

- The state machine starts in the 'initial' state.
- net_box.connect() method changes the state to 'connecting' and spawns a worker fiber.
- If authentication and schema upload are required, it's possible later on to re-enter the 'fetch_schema' state from 'active' if a request fails due to a schema version mismatch error, so schema reload is triggered.

- conn.close() method sets the state to 'closed' and kills the worker. If the transport is already in the 'error' state, close() does nothing.

Index

Below is a list of all net.box functions.

Name	Use
net_box.connect() net_box.new() net_box.self	Create a connection
conn:ping()	Execute a PING command
conn:wait_connected()	Wait for a connection to be active or closed
conn:is_connected()	Check if a connection is active or closed
conn:wait_state()	Wait for a target state
conn:close()	Close a connection
conn.space.space-name:select{field-value}	Select one or more tuples
conn.space.space-name:get{field-value}	Select a tuple
conn.space.space-name:insert{field-value}	Insert a tuple
conn.space.space-name:replace{field-value}	Insert or replace a tuple
conn.space.space-name:update{field-value}	Update a tuple
conn.space.space-name:upsert{field-value}	Update a tuple
conn.space.space-name:delete{field-value}	Delete a tuple
conn:eval()	Evaluate and execute the expression in a string
conn:call()	Call a stored procedure
conn:timeout()	Set a timeout
conn:on_connect()	Define a connect trigger
conn:on_disconnect()	Define a disconnect trigger
conn:on_schema_reload()	Define a trigger when schema is modified

net_box.connect(URI[, {option[s]}])

net_box.new(URI[, {option[s]}])

Note: The names connect() and new() are synonyms: connect() is preferred; new() is retained for backward compatibility.

Create a new connection. The connection is established on demand, at the time of the first request. It can be re-established automatically after a disconnect (see reconnect_after option below). The returned conn object supports methods for making remote requests, such as select, update or delete.

Possible options:

- user/password: you have two ways to connect to a remote host: using URI or using the options user and password. For example, instead of connect('username:userpassword@localhost:33301') you can write connect('localhost:33301', {user = 'username', password='userpassword'}).
- wait_connected: by default, connection creation is blocked until the connection is established, but passing wait_connected=false makes it return immediately. Also, passing a timeout makes it wait before returning (e.g. wait_connected=1.5 makes it wait at most 1.5 seconds).

Note: If reconnect_after is greater than zero, then wait_connected ignores transient failures.

The wait completes once the connection is established or is closed explicitly.

- reconnect_after: if reconnect_after is greater than zero, then a net.box instance will try to reconnect if a connection is broken or if a connection attempt fails. This makes transient network failures become transparent to the application. Reconnect happens automatically in the background, so requests that initially fail due to connectivity loss are transparently retried. The number of retries is unlimited, connection attempts are made after each specified interval (for example reconnect_after=5 means try to reconnect every 5 seconds). When a connection is explicitly closed, or when the Lua garbage collector removes it, then reconnect attempts stop. The default value of reconnect_after, as with other connect options, is nil.
- call_16: [since 1.7.2] by default, net.box connections comply with a new binary protocol command for CALL, which is not backward compatible with previous versions. The new CALL no longer restricts a function to returning an array of tuples and allows returning an arbitrary MsgPack/JSON result, including scalars, nil and void (nothing). The old CALL is left intact for backward compatibility. It will be removed in the next major release. All programming language drivers will be gradually changed to use the new CALL. To connect to a Tarantool instance that uses the old CALL, specify call_16=true.
- console: depending on the option's value, the connection supports different methods (as if instances of different classes were returned). With console = true, you can use conn methods close(), is_connected(), wait_state(), eval() (in this case, both binary and Lua console network protocols are supported). With console = false (default), you can also use conn database methods (in this case, only the binary protocol is supported). Deprecation notice: console = true is deprecated, users should use console.connect() instead.
- connect_timeout: number of seconds to wait before returning "error: Connection timed out".

Parameters

- URI (string) – the URI of the target for the connection
- options – possible options are user, password, wait_connected, reconnect_after, call_16, console and connect_timeout

Return conn object

Rtype userdata

Examples:

```
conn = net_box.connect('localhost:3301')
conn = net_box.connect('127.0.0.1:3302', {wait_connected = false})
conn = net_box.connect('127.0.0.1:3303', {reconnect_after = 5, call_16 = true})
```

object self

For a local Tarantool server, there is a pre-created always-established connection object named net_box.self. Its purpose is to make polymorphic use of the net_box API easier. Therefore conn = net_box.connect('localhost:3301') can be replaced by conn = net_box.self.

However, there is an important difference between the embedded connection and a remote one:

- With the embedded connection, requests which do not modify data do not yield. When using a remote connection, due to the implicit rules any request can yield, and the database state may have changed by the time it regains control.
- All the options passed to a request (as is_async, on_push, timeout) will be ignored.

object conn

conn:ping([options])

Execute a PING command.

Parameters

- options (table) – the supported option is timeout=seconds

Return true on success, false on error

Rtype boolean

Example:

```
net_box.self:ping({timeout = 0.5})
```

conn:wait_connected([timeout])

Wait for connection to be active or closed.

Parameters

- timeout (number) – in seconds

Return true when connected, false on failure.

Rtype boolean

Example:

```
net_box.self:wait_connected()
```

conn:is_connected()

Show whether connection is active or closed.

Return true if connected, false on failure.

Rtype boolean

Example:

```
net_box.self:is_connected()
```

conn:wait_state(state[s][, timeout])

[since 1.7.2] Wait for a target state.

Parameters

- states (string) – target states
- timeout (number) – in seconds

Return true when a target state is reached, false on timeout or connection closure

Rtype boolean

Examples:

```
-- wait infinitely for 'active' state:
conn:wait_state('active')

-- wait for 1.5 secs at most:
conn:wait_state('active', 1.5)

```

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```
-- wait infinitely for either `active` or `fetch_schema` state:
conn:wait_state({active=true, fetch_schema=true})
```

conn:close()

Close a connection.

Connection objects are destroyed by the Lua garbage collector, just like any other objects in Lua, so an explicit destruction is not mandatory. However, since close() is a system call, it is good programming practice to close a connection explicitly when it is no longer needed, to avoid lengthy stalls of the garbage collector.

Example:

```
conn:close()
```

conn.space.<space-name>:select({field-value, ...} [, {options}])

conn.space.space-name:select({...}) is the remote-call equivalent of the local call box.space.space-name:select{...} (see details). For an additional option see Module buffer and skip-header.

Example:

```
conn.space.testspace:select({1,'B'}, {timeout=1})
```

Note: Due to the implicit yield rules a local box.space.space-name:select{...} does not yield, but a remote conn.space.space-name:select{...} call does yield, so global variables or database tuples data may change when a remote conn.space.space-name:select{...} occurs.

---

conn.space.<space-name>:get({field-value, ...} [, {options}])

conn.space.space-name:get(...) is the remote-call equivalent of the local call box.space.space-name:get(...) (see details).

Example:

```
conn.space.testspace:get({1})
```

conn.space.<space-name>:insert({field-value, ...} [, {options}])

conn.space.space-name:insert(...) is the remote-call equivalent of the local call box.space.space-name:insert(...) (see details). For an additional option see Module buffer and skip-header.

Example:

```
conn.space.testspace:insert({2,3,4,5}, {timeout=1.1})
```

conn.space.<space-name>:replace({field-value, ...} [, {options}])

conn.space.space-name:replace(...) is the remote-call equivalent of the local call box.space.space-name:replace(...) (see details). For an additional option see Module buffer and skip-header.

Example:

```
conn.space.testspace:replace({5,6,7,8})
```

conn.space.<space-name>:update({field-value, ...} [, {options}])

conn.space.space-name:update(...) is the remote-call equivalent of the local call box.space.space-name:update(...) (see details). For an additional option see Module buffer and skip-header.

Example:

```
conn.space.Q:update({1},{{'=',2,5}}, {timeout=0})
```

conn.space.<space-name>:upsert({field-value, ...} [, {options}])
conn.space.space-name:upsert(...) is the remote-call equivalent of the local call box.space.space-name:upsert(...). (see details) For an additional option see Module buffer and skip-header.

conn.space.<space-name>:delete({field-value, ...} [, {options}])
conn.space.space-name:delete(...) is the remote-call equivalent of the local call box.space.space-name:delete(...) (see details). For an additional option see Module buffer and skip-header.

conn:eval(Lua-string[, {arguments}[, {options}]])
conn:eval(Lua-string) evaluates and executes the expression in Lua-string, which may be any statement or series of statements. An execute privilege is required; if the user does not have it, an administrator may grant it with box.schema.user.grant(username, 'execute', 'universe').

To ensure that the return from conn:eval is whatever the Lua expression returns, begin the Lua-string with the word "return".

Examples:

```
tarantool> --Lua-string
tarantool> conn:eval('function f5() return 5+5 end; return f5();')
---
- 10
...
tarantool> --Lua-string, {arguments}
tarantool> conn:eval('return ...', {1,2,{3,'x'}})
---
- 1
- 2
- [3, 'x']
...
tarantool> --Lua-string, {arguments}, {options}
tarantool> conn:eval('return {nil,5}', {}, {timeout=0.1})
---
- [null, 5]
...
```

conn:call(function-name[, {arguments}[, {options}]])
conn:call('func', {'1', '2', '3'}) is the remote-call equivalent of func('1', '2', '3'). That is, conn:call is a remote stored-procedure call. The return from conn:call is whatever the function returns.

Limitation: the called function cannot return a function, for example if func2 is defined as function func2 () return func end then conn:call(func2) will return "error: unsupported Lua type 'function'".

Examples:

```
tarantool> -- create 2 functions with conn:eval()
tarantool> conn:eval('function f1() return 5+5 end;')
tarantool> conn:eval('function f2(x,y) return x,y end;')
tarantool> -- call first function with no parameters and no options
tarantool> conn:call('f1')
---
- 10
...
tarantool> -- call second function with two parameters and one option
tarantool> conn:call('f2',{1,'B'},{timeout=99})
```

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```
---
- 1
- B
...
```

conn:timeout(timeout)
timeout(...) is a wrapper which sets a timeout for the request that follows it. Since version 1.7.4 this method is deprecated – it is better to pass a timeout value for a method's {options} parameter.

Example:

```
conn:timeout(0.5).space.tester:update({1}, {{'=', 2, 15}})
```

Although timeout(...) is deprecated, all remote calls support its use. Using a wrapper object makes the remote connection API compatible with the local one, removing the need for a separate timeout argument, which the local version would ignore. Once a request is sent, it cannot be revoked from the remote server even if a timeout expires: the timeout expiration only aborts the wait for the remote server response, not the request itself.

conn:request(... {is_async=...})
{is_async=true|false} is an option which is applicable for all net_box requests including conn:call, conn:eval, and the conn.space.space-name requests.

The default is is_async=false, meaning requests are synchronous for the fiber. The fiber is blocked, waiting until there is a reply to the request or until timeout expires. Before Tarantool version 1.10, the only way to make asynchronous requests was to put them in separate fibers.

The non-default is is_async=true, meaning requests are asynchronous for the fiber. The request causes a yield but there is no waiting. The immediate return is not the result of the request, instead it is an object that the calling program can use later to get the result of the request.

This immediately-returned object, which we'll call "future", has its own methods:

- future:is_ready() which will return true when the result of the request is available,
- future:result() to get the result of the request (returns the response or nil in case it's not ready yet or there has been an error),
- future:wait_result(timeout) to wait until the result of the request is available and then get it, or throw an error if there is no result after the timeout exceeded,
- future:discard() to abandon the object.

Typically a user would say future=request-name(...{is_async=true}), then either loop checking future:is_ready() until it is true and then say request_result=future:result(), or say request_result=future:wait_result(...). Alternatively the client could check for "out-of-band" messages from the server by calling pairs() in a loop – see box.session.push().

A user would say future:discard() to make a connection forget about the response – if a response for a discarded object is received then it will be ignored, so that the size of the requests table will be reduced and other requests will be faster.

Example:

```
tarantool> future = conn.space.tester:insert({900},{is_async=true})
---
...
tarantool> future
---
```

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```
- method: insert
  response: [900]
  cond: cond
  on_push_ctx: []
  on_push: 'function: builtin#91'
...
tarantool> future:is_ready()
---
- true
...
tarantool> future:result()
---
- [900]
...
```

Typically {is_async=true} is used only if the load is large (more than 100,000 requests per second) and latency is large (more than 1 second), or when it is necessary to send multiple requests in parallel then collect responses (sometimes called a "map-reduce" scenario).

Note: Although the final result of an async request is the same as the result of a sync request, it is structured differently: as a table, instead of as the unpacked values.

Triggers

With the net.box module, you can use the following triggers:

conn:on_connect([trigger-function[, old-trigger-function]])

Define a trigger for execution when a new connection is established, and authentication and schema fetch are completed due to an event such as net_box.connect. If the trigger execution fails and an exception happens, the connection's state changes to 'error'. In this case, the connection is terminated, regardless of the reconnect_after option's value. Can be called as many times as reconnection happens, if reconnect_after is greater than zero.

Parameters

- trigger-function (function) – function which will become the trigger function. Takes the conn object as the first argument
- old-trigger-function (function) – existing trigger function which will be replaced by trigger-function

Return nil or function pointer

conn:on_disconnect([trigger-function[, old-trigger-function]])

Define a trigger for execution after a connection is closed. If the trigger function causes an error, the error is logged but otherwise is ignored. Execution stops after a connection is explicitly closed, or once the Lua garbage collector removes it.

Parameters

- trigger-function (function) – function which will become the trigger function. Takes the conn object as the first argument
- old-trigger-function (function) – existing trigger function which will be replaced by trigger-function

Return nil or function pointer

conn:on_schema_reload([trigger-function[, old-trigger-function]])

Define a trigger executed when some operation has been performed on the remote server after schema has been updated. So, if a server request fails due to a schema version mismatch error, schema reload is triggered.

Parameters

- trigger-function (function) – function which will become the trigger function. Takes the conn object as the first argument
- old-trigger-function (function) – existing trigger function which will be replaced by trigger-function

Return nil or function pointer

Note: If the parameters are (nil, old-trigger-function), then the old trigger is deleted.

If both parameters are omitted, then the response is a list of existing trigger functions.

Details about trigger characteristics are in the triggers section.

Example

This example shows the use of most of the net.box methods.

The sandbox configuration for this example assumes that:

- the Tarantool instance is running on localhost 127.0.0.1:3301,
- there is a space named tester with a numeric primary key and with a tuple that contains a key value = 800,
- the current user has read, write and execute privileges.

Here are commands for a quick sandbox setup:

```
box.cfg{listen = 3301}
s = box.schema.space.create('tester')
s:create_index('primary', {type = 'hash', parts = {1, 'unsigned'}})
t = s:insert({800, 'TEST'})
box.schema.user.grant('guest', 'read,write,execute', 'universe')
```

And here starts the example:

```
tarantool> net_box = require('net.box')
---
...
tarantool> function example()
         >   local conn, wtuple
         >   if net_box.self:ping() then
         >     table.insert(ta, 'self:ping() succeeded')
         >     table.insert(ta, '  (no surprise -- self connection is pre-established)')
         >   end
         >   if box.cfg.listen == '3301' then
         >     table.insert(ta,'The local server listen address = 3301')
         >   else
         >     table.insert(ta, 'The local server listen address is not 3301')
```

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```
         >     table.insert(ta, '(  (maybe box.cfg{...listen="3301"...} was not stated)')
         >     table.insert(ta, '(  (so connect will fail)')
         >   end
         >   conn = net_box.connect('127.0.0.1:3301')
         >   conn.space.tester:delete({800})
         >   table.insert(ta, 'conn delete done on tester.')
         >   conn.space.tester:insert({800, 'data'})
         >   table.insert(ta, 'conn insert done on tester, index 0')
         >   table.insert(ta, '  primary key value = 800.')
         >   wtuple = conn.space.tester:select({800})
         >   table.insert(ta, 'conn select done on tester, index 0')
         >   table.insert(ta, '  number of fields = ' .. #wtuple)
         >   conn.space.tester:delete({800})
         >   table.insert(ta, 'conn delete done on tester')
         >   conn.space.tester:replace({800, 'New data', 'Extra data'})
         >   table.insert(ta, 'conn:replace done on tester')
         >   conn.space.tester:update({800}, {{'=', 2, 'Fld#1'}})
         >   table.insert(ta, 'conn update done on tester')
         >   conn:close()
         >   table.insert(ta, 'conn close done')
         > end
---
...
tarantool> ta = {}
---
...
tarantool> example()
---
...
tarantool> ta
---
- - self:ping() succeeded
  - '  (no surprise -- self connection is pre-established)'
  - The local server listen address = 3301
  - conn delete done on tester.
  - conn insert done on tester, index 0
  - '  primary key value = 800.'
  - conn select done on tester, index 0
  - '  number of fields = 1'
  - conn delete done on tester
  - conn:replace done on tester
  - conn update done on tester
  - conn close done
...
```

5.2.21 Module os

Overview

The os module contains the functions execute(), rename(), getenv(), remove(), date(), exit(), time(), clock(), tmpname(), environ(), setenv(), setlocale(), difftime(). Most of these functions are described in the Lua manual Chapter 22 The Operating System Library.

Index

Below is a list of all os functions.

Name	Use
os.execute()	Execute by passing to the shell
os.rename()	Rename a file or directory
os.getenv()	Get an environment variable
os.remove()	Remove a file or directory
os.date()	Get a formatted date
os.exit()	Exit the program
os.time()	Get the number of seconds since the epoch
os.clock()	Get the number of CPU seconds since the program start
os.tmpname()	Get the name of a temporary file
os.environ()	Get a table with all environment variables
os.setenv()	Set an environment variable
os.setlocale()	Change the locale
os.difftime()	Get the number of seconds between two times

os.execute(shell-command)

Execute by passing to the shell.

Parameters

- shell-command (string) – what to execute.

Example:

```
tarantool> os.execute('ls -l /usr')
total 200
drwxr-xr-x   2 root root 65536 Apr 22 15:49 bin
drwxr-xr-x  59 root root 20480 Apr 18 07:58 include
drwxr-xr-x 210 root root 65536 Apr 18 07:59 lib
drwxr-xr-x  12 root root  4096 Apr 22 15:49 local
drwxr-xr-x   2 root root 12288 Jan 31 09:50 sbin
---
...
```

os.rename(old-name, new-name)

Rename a file or directory.

Parameters

- old-name (string) – name of existing file or directory,
- new-name (string) – changed name of file or directory.

Example:

```
tarantool> os.rename('local','foreign')
---
- null
- 'local: No such file or directory'
- 2
...
```

os.getenv(variable-name)

Get environment variable.

Parameters: (string) variable-name = environment variable name.

Example:

```
tarantool> os.getenv('PATH')
---
- /usr/local/sbin:/usr/local/bin:/usr/sbin
...
```

os.remove(name)

Remove file or directory.

Parameters: (string) name = name of file or directory which will be removed.

Example:

```
tarantool> os.remove('file')
---
- true
...
```

os.date(format-string[, time-since-epoch])

Return a formatted date.

Parameters: (string) format-string = instructions; (string) time-since-epoch = number of seconds since 1970-01-01. If time-since-epoch is omitted, it is assumed to be the current time.

Example:

```
tarantool> os.date("%A %B %d")
---
- Sunday April 24
...
```

os.exit()

Exit the program. If this is done on a server instance, then the instance stops.

Example:

```
tarantool> os.exit()
user@user-shell:~/tarantool_sandbox$
```

os.time()

Return the number of seconds since the epoch.

Example:

```
tarantool> os.time()
---
- 1461516945
...
```

os.clock()

Return the number of CPU seconds since the program start.

Example:

```
tarantool> os.clock()
---
- 0.05
...
```

os.tmpname()

Return a name for a temporary file.

Example:

```
tarantool> os.tmpname()
---
- /tmp/lua_7SW1m2
...
```

os.environ()

Return a table containing all environment variables.

Example:

```
tarantool> os.environ()['TERM']..os.environ()['SHELL']
---
- xterm/bin/bash
...
```

os.setenv(variable-name, variable-value)

Set an environment variable.

Example:

```
tarantool> os.setenv('VERSION','99')
---
-
...
```

os.setlocale([new-locale-string])

Change the locale. If new-locale-string is not specified, return the current locale.

Example:

```
tarantool> string.sub(os.setlocale(),1,20)
---
- LC_CTYPE=en_US.UTF-8
...
```

os.difftime(time1, time2)

Return the number of seconds between two times.

Example:

```
tarantool> os.difftime(os.time() - 0)
---
- 1486594859
...
```

5.2.22 Module pickle

Index

Below is a list of all pickle functions.

Name	Use
pickle.pack()	Convert Lua variables to binary format
pickle.unpack()	Convert Lua variables back from binary format

pickle.pack(format, argument[, argument ...])

To use Tarantool binary protocol primitives from Lua, it's necessary to convert Lua variables to binary format. The pickle.pack() helper function is prototyped after Perl 'pack'.

Format specifiers

b, B	converts Lua scalar value to a 1-byte integer, and stores the integer in the resulting string
s, S	converts Lua scalar value to a 2-byte integer, and stores the integer in the resulting string, low byte first
i, I	converts Lua scalar value to a 4-byte integer, and stores the integer in the resulting string, low byte first
l, L	converts Lua scalar value to an 8-byte integer, and stores the integer in the resulting string, low byte first
n	converts Lua scalar value to a 2-byte integer, and stores the integer in the resulting string, big endian,
N	converts Lua scalar value to a 4-byte integer, and stores the integer in the resulting string, big
q, Q	converts Lua scalar value to an 8-byte integer, and stores the integer in the resulting string, big endian,
f	converts Lua scalar value to a 4-byte float, and stores the float in the resulting string
d	converts Lua scalar value to a 8-byte double, and stores the double in the resulting string
a, A	converts Lua scalar value to a sequence of bytes, and stores the sequence in the resulting string

Parameters

- format (string) – string containing format specifiers
- argument(s) (scalar-value) – scalar values to be formatted

Return a binary string containing all arguments, packed according to the format specifiers.

Rtype string

A scalar value can be either a variable or a literal. Remember that large integers should be entered with tonumber64() or LL or ULL suffixes.

Possible errors: unknown format specifier.

Example:

```
tarantool> pickle = require('pickle')
---
...
tarantool> box.space.tester:insert{0, 'hello world'}
---
- [0, 'hello world']
...
tarantool> box.space.tester:update({0}, {{'=', 2, 'bye world'}})
---
- [0, 'bye world']
```

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```
...
tarantool> box.space.tester:update({0}, {
         >   {'=', 2, pickle.pack('iiA', 0, 3, 'hello')}
         > })
---
- [0, "\0\0\0\0\x03\0\0\0hello"]
...
tarantool> box.space.tester:update({0}, {{'=', 2, 4}})
---
- [0, 4]
...
tarantool> box.space.tester:update({0}, {{'+', 2, 4}})
---
- [0, 8]
...
tarantool> box.space.tester:update({0}, {{'^', 2, 4}})
---
- [0, 12]
...
```

pickle.unpack(format, binary-string)

Counterpart to pickle.pack(). Warning: if format specifier 'A' is used, it must be the last item.

Parameters

- format (string) –
- binary-string (string) –

Return A list of strings or numbers.

Rtype table

Example:

```
tarantool> pickle = require('pickle')
---
...
tarantool> tuple = box.space.tester:replace{0}
---
...
tarantool> string.len(tuple[1])
---
- 1
...
tarantool> pickle.unpack('b', tuple[1])
---
- 48
...
tarantool> pickle.unpack('bsi', pickle.pack('bsi', 255, 65535, 4294967295))
---
- 255
- 65535
- 4294967295
...
tarantool> pickle.unpack('ls', pickle.pack('ls', tonumber64('18446744073709551615'), 65535))
---
...
```

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```
tarantool> num, num64, str = pickle.unpack('slA', pickle.pack('slA', 666,
         > tonumber64('666666666666666'), 'string'))
---
...
```

5.2.23 Module socket

Overview

The socket module allows exchanging data via BSD sockets with a local or remote host in connection-oriented (TCP) or datagram-oriented (UDP) mode. Semantics of the calls in the socket API closely follow semantics of the corresponding POSIX calls.

The functions for setting up and connecting are socket, sysconnect, tcp_connect. The functions for sending data are send, sendto, write, syswrite. The functions for receiving data are recv, recvfrom, read. The functions for waiting before sending/receiving data are wait, readable, writable. The functions for setting flags are nonblock, setsockopt. The functions for stopping and disconnecting are shutdown, close. The functions for error checking are errno, error.

Index

Below is a list of all socket functions.

Name	Use
socket()	Create a socket
socket.tcp_connect()	Connect a socket to a remote host
socket.getaddrinfo()	Get information about a remote site
socket.tcp_server()	Make Tarantool act as a TCP server
socket_object:sysconnect()	Connect a socket to a remote host
socket_object:send() socket_object:write()	Send data over a connected socket
socket_object:syswrite()	Write data to the socket buffer if non-blocking
socket_object:recv()	Read from a connected socket
socket_object:sysread()	Read data from the socket buffer if non-blocking
socket_object:bind()	Bind a socket to the given host/port
socket_object:listen()	Start listening for incoming connections
socket_object:accept()	Accept a client connection + create a connected socket
socket_object:sendto()	Send a message on a UDP socket to a specified host
socket_object:recvfrom()	Receive a message on a UDP socket
socket_object:shutdown()	Shut down a reading end, a writing end, or both
socket_object:close()	Close a socket
socket_object:error() socket_object:errno()	Get information about the last error on a socket
socket_object:setsockopt()	Set socket flags
socket_object:getsockopt()	Get socket flags
socket_object:linger()	Set/clear the SO_LINGER flag
socket_object:nonblock()	Set/get the flag value
socket_object:readable()	Wait until something is readable
socket_object:writable()	Wait until something is writable
socket_object:wait()	Wait until something is either readable or writable
socket_object:name()	Get information about the connection's near side
socket_object:peer()	Get information about the connection's far side
socket.iowait()	Wait for read/write activity
LuaSocket wrapper functions	Several methods for emulating the LuaSocket API

Typically a socket session will begin with the setup functions, will set one or more flags, will have a loop with sending and receiving functions, will end with the teardown functions – as an example at the end of this section will show. Throughout, there may be error-checking and waiting functions for synchronization. To prevent a fiber containing socket functions from "blocking" other fibers, the implicit yield rules will cause a yield so that other processes may take over, as is the norm for cooperative multitasking.

For all examples in this section the socket name will be sock and the function invocations will look like sock:function_name(...).

socket.__call(domain, type, protocol)

Create a new TCP or UDP socket. The argument values are the same as in the Linux socket(2) man page.

Return an unconnected socket, or nil.

Rtype userdata

Example:

```
socket('AF_INET', 'SOCK_STREAM', 'tcp')
```

socket.tcp_connect(host[, port[, timeout]])

Connect a socket to a remote host.

Parameters

- host (string) – URL or IP address
- port (number) – port number
- timeout (number) – timeout

Return a connected socket, if no error.

Rtype userdata

Example:

```
socket.tcp_connect('127.0.0.1', 3301)
```

socket.getaddrinfo(host, port[, timeout[, {option-list}]])

socket.getaddrinfo(host, port[, {option-list}])

The socket.getaddrinfo() function is useful for finding information about a remote site so that the correct arguments for sock:sysconnect() can be passed. This function may use the worker_pool_threads configuration parameter.

Parameters

- host (string) – URL or IP address
- port (number) – port number or a string pointing to a port
- timeout (number) – maximum number of seconds to wait
- options (table) –
  - type – preferred socket type
  - family – desired address family for the returned addresses
  - protocol
  - flags – additional options (see details here)

Return A table containing these fields: "host", "family", "type", "protocol", "port".

Rtype table

Example:

```
tarantool> socket.getaddrinfo('tarantool.org', 'http')
---
- - host: 188.93.56.70
    family: AF_INET
    type: SOCK_STREAM
    protocol: tcp
    port: 80
  - host: 188.93.56.70
    family: AF_INET
    type: SOCK_DGRAM
    protocol: udp
    port: 80
...
-- To find the available values for the options use the following:
tarantool> socket.internal.AI_FLAGS -- or SO_TYPE, or DOMAIN
---
- AI_ALL: 256
  AI_PASSIVE: 1
  AI_NUMERICSERV: 4096
```

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```
  AI_NUMERICHOST: 4
  AI_V4MAPPED: 2048
  AI_ADDRCONFIG: 1024
  AI_CANONNAME: 2
...
```

socket.tcp_server(host, port, handler-function-or-table[, timeout])

The socket.tcp_server() function makes Tarantool act as a server that can accept connections. Usually the same objective is accomplished with box.cfg{listen=. . . }.

Parameters

- host (string) – host name or IP
- port (number) – host port, may be 0
- handler-function-or-table (function/table) – what to execute when a connection occurs
- timeout (number) – number of seconds to wait before timing out

The handler-function-or-table parameter may be simply a function name / function declaration: handler_function. Or it may be a table: {handler = handler_function [, prepare = prepare_function] [, name = name] }. handler_function is mandatory; it may have a parameter = the socket; it is executed once after accept() happens (once per connection); it is for continuous operation after the connection is made. prepare_function is optional; it may have parameters = the socket object and a table with client information; it should return either a backlog value or nothing; it is executed only once before bind() on the listening socket (not once per connection). Examples:

```
socket.tcp_server('localhost', 3302, function (s) loop_loop() end)
socket.tcp_server('localhost', 3302, {handler=hfunc, name='name'})
socket.tcp_server('localhost', 3302, {handler=hfunc, prepare=pfunc})
```

For fuller examples see Use tcp_server to accept file contents sent with socat and Use tcp_server with handler and prepare.

object socket_object

socket_object:sysconnect(host, port)

Connect an existing socket to a remote host. The argument values are the same as in tcp_connect(). The host must be an IP address.

Parameters:

- Either:
  - host - a string representation of an IPv4 address or an IPv6 address;
  - port - a number.
- Or:
  - host - a string containing "unix/";
  - port - a string containing a path to a unix socket.
- Or:
  - host - a number, 0 (zero), meaning "all local interfaces";

- port - a number. If a port number is 0 (zero), the socket will be bound to a random local port.

Return the socket object value may change if sysconnect() succeeds.

Rtype boolean

Example:

```
socket = require('socket')
sock = socket('AF_INET', 'SOCK_STREAM', 'tcp')
sock:sysconnect(0, 3301)
```

socket_object:send(data)
socket_object:write(data)
Send data over a connected socket.

Parameters

- data (string) – what is to be sent

Return the number of bytes sent.

Rtype number

Possible errors: nil on error.

socket_object:syswrite(size)
Write as much data as possible to the socket buffer if non-blocking. Rarely used. For details see this description.

socket_object:recv(size)
Read size bytes from a connected socket. An internal read-ahead buffer is used to reduce the cost of this call.

Parameters

- size (integer) – maximum number of bytes to receive. See Recommended size.

Return a string of the requested length on success.

Rtype string

Possible errors: On error, returns an empty string, followed by status, errno, errstr. In case the writing side has closed its end, returns the remainder read from the socket (possibly an empty string), followed by “eof” status.

socket_object:read(limit[, timeout])
socket_object:read(delimiter[, timeout])
socket_object:read({options}[, timeout])
Read from a connected socket until some condition is true, and return the bytes that were read. Reading goes on until limit bytes have been read, or a delimiter has been read, or a timeout has expired. Unlike socket_object:recv (which uses an internal read-ahead buffer), socket_object:read depends on the socket’s buffer.

Parameters

- limit (integer) – maximum number of bytes to read, for example 50 means “stop after 50 bytes”
- delimiter (string) – separator for example ‘?’ means “stop after a question mark”

- timeout (number) – maximum number of seconds to wait, for example 50 means "stop after 50 seconds".
- options (table) – chunk=limit and/or delimiter=delimiter, for example {chunk=5, delimiter='x'}.

Return an empty string if there is nothing more to read, or a nil value if error, or a string up to limit bytes long, which may include the bytes that matched the delimiter expression.

Rtype string

socket_object:sysread(size)

Return data from the socket buffer if non-blocking. In case the socket is blocking, sysread() can block the calling process. Rarely used. For details, see also this description.

Parameters

- size (integer) – maximum number of bytes to read, for example 50 means "stop after 50 bytes"

Return an empty string if there is nothing more to read, or a nil value if error, or a string up to size bytes long.

Rtype string

socket_object:bind(host[, port])

Bind a socket to the given host/port. A UDP socket after binding can be used to receive data (see socket_object.recvfrom). A TCP socket can be used to accept new connections, after it has been put in listen mode.

Parameters

- host (string) – URL or IP address
- port (number) – port number

Return true for success, false for error. If return is false, use socket_object:errno() or socket_object:error() to see details.

Rtype boolean

socket_object:listen(backlog)

Start listening for incoming connections.

Parameters

- backlog – on Linux the listen backlog backlog may be from /proc/sys/net/core/somaxconn, on BSD the backlog may be SOMAXCONN.

Return true for success, false for error.

Rtype boolean.

socket_object:accept()

Accept a new client connection and create a new connected socket. It is good practice to set the socket's blocking mode explicitly after accepting.

Return new socket if success.

Rtype userdata

Possible errors: nil.

socket_object:sendto(host, port, data)

Send a message on a UDP socket to a specified host.

Parameters

- host (string) – URL or IP address
- port (number) – port number
- data (string) – what is to be sent

Return the number of bytes sent.

Rtype number

Possible errors: on error, returns nil and may return status, errno, errstr.

socket_object:recvfrom(size)
Receive a message on a UDP socket.

Parameters

- size (integer) – maximum number of bytes to receive. See Recommended size.

Return message, a table containing "host", "family" and "port" fields.

Rtype string, table

Possible errors: on error, returns status, errno, errstr.

Example:

After message_content, message_sender = recvfrom(1) the value of message_content might be a string containing 'X' and the value of message_sender might be a table containing

```
message_sender.host = '18.44.0.1'
message_sender.family = 'AF_INET'
message_sender.port = 43065
```

socket_object:shutdown(how)
Shutdown a reading end, a writing end, or both ends of a socket.

Parameters

- how – socket.SHUT_RD, socket.SHUT_WR, or socket.SHUT_RDWR.

Return true or false.

Rtype boolean

socket_object:close()
Close (destroy) a socket. A closed socket should not be used any more. A socket is closed automatically when the Lua garbage collector removes its user data.

Return true on success, false on error. For example, if sock is already closed, sock:close() returns false.

Rtype boolean

socket_object:error()
socket_object:errno()
Retrieve information about the last error that occurred on a socket, if any. Errors do not cause throwing of exceptions so these functions are usually necessary.

Return result for sock:errno(), result for sock:error(). If there is no error, then sock:errno() will return 0 and sock:error().

Rtype number, string

socket_object:setsockopt(level, name, value)

Set socket flags. The argument values are the same as in the Linux getsockopt(2) man page. The ones that Tarantool accepts are:

- SO_ACCEPTCONN
- SO_BINDTODEVICE
- SO_BROADCAST
- SO_DEBUG
- SO_DOMAIN
- SO_ERROR
- SO_DONTROUTE
- SO_KEEPALIVE
- SO_MARK
- SO_OOBINLINE
- SO_PASSCRED
- SO_PEERCRED
- SO_PRIORITY
- SO_PROTOCOL
- SO_RCVBUF
- SO_RCVBUFFORCE
- SO_RCVLOWAT
- SO_SNDLOWAT
- SO_RCVTIMEO
- SO_SNDTIMEO
- SO_REUSEADDR
- SO_SNDBUF
- SO_SNDBUFFORCE
- SO_TIMESTAMP
- SO_TYPE

Setting SO_LINGER is done with sock:linger(active).

socket_object:getsockopt(level, name)

Get socket flags. For a list of possible flags see sock:setsockopt().

socket_object:linger([active])

Set or clear the SO_LINGER flag. For a description of the flag, see the Linux man page.

Parameters

- active (boolean) –

Return new active and timeout values.

socket_object:nonblock([flag])

- sock:nonblock() returns the current flag value.
- sock:nonblock(false) sets the flag to false and returns false.
- sock:nonblock(true) sets the flag to true and returns true.

This function may be useful before invoking a function which might otherwise block indefinitely.

socket_object:readable([timeout])
Wait until something is readable, or until a timeout value expires.

Return true if the socket is now readable, false if timeout expired;

socket_object:writable([timeout])
Wait until something is writable, or until a timeout value expires.

Return true if the socket is now writable, false if timeout expired;

socket_object:wait([timeout])
Wait until something is either readable or writable, or until a timeout value expires.

Return 'R' if the socket is now readable, 'W' if the socket is now writable, 'RW' if the socket is now both readable and writable, '' (empty string) if timeout expired;

socket_object:name()
The sock:name() function is used to get information about the near side of the connection. If a socket was bound to xyz.com:45, then sock:name will return information about [host:xyz.com, port:45]. The equivalent POSIX function is getsockname().

Return A table containing these fields: "host", "family", "type", "protocol", "port".

Rtype table

socket_object:peer()
The sock:peer() function is used to get information about the far side of a connection. If a TCP connection has been made to a distant host tarantool.org:80, sock:peer() will return information about [host:tarantool.org, port:80]. The equivalent POSIX function is getpeername().

Return A table containing these fields: "host", "family", "type", "protocol", "port".

Rtype table

socket.iowait(fd, read-or-write-flags[, timeout])
The socket.iowait() function is used to wait until read-or-write activity occurs for a file descriptor.

Parameters

- fd – file descriptor
- read-or-write-flags – 'R' or 1 = read, 'W' or 2 = write, 'RW' or 3 = read|write.
- timeout – number of seconds to wait

If the fd parameter is nil, then there will be a sleep until the timeout. If the timeout parameter is nil or unspecified, then timeout is infinite.

Ordinarily the return value is the activity that occurred ('R' or 'W' or 'RW' or 1 or 2 or 3). If the timeout period goes by without any reading or writing, the return is an error = ETIMEDOUT.

Example: socket.iowait(sock:fd(), 'r', 1.11)

LuaSocket wrapper functions

The LuaSocket API has functions that are equivalent to the ones described above, with different names and parameters, for example connect() rather than tcp_connect(), as well as getpeername, getsockname, setoption, settimeout. Tarantool supports these functions so that third-party packages which depend on them will work.

The LuaSocket project is on github. The API description is in the LuaSocket manual (click the "introduction" and "reference" links at the bottom of the manual's main page).

A Tarantool example is Use of a socket with LuaSocket wrapper functions.

Recommended size

For recv and recvfrom: use the optional size parameter to limit the number of bytes to receive. A fixed size such as 512 is often reasonable; a pre-calculated size that depends on context – such as the message format or the state of the network – is often better. For recvfrom, be aware that a size greater than the Maximum Transmission Unit can cause inefficient transport. For Mac OS X, be aware that the size can be tuned by changing sysctl net.inet.udp.maxdgram.

If size is not stated: Tarantool will make an extra call to calculate how many bytes are necessary. This extra call takes time, therefore not stating size may be inefficient.

If size is stated: on a UDP socket, excess bytes are discarded. On a TCP socket, excess bytes are not discarded and can be received by the next call.

Examples

Use of a TCP socket over the Internet

In this example a connection is made over the internet between a Tarantool instance and tarantool.org, then an HTTP "head" message is sent, and a response is received: "HTTP/1.1 200 OK" or something else if the site has moved. This is not a useful way to communicate with this particular site, but shows that the system works.

```
tarantool> socket = require('socket')
---
...
tarantool> sock = socket.tcp_connect('tarantool.org', 80)
---
...
tarantool> type(sock)
---
- table
...
tarantool> sock:error()
---
- null
...
tarantool> sock:send("HEAD / HTTP/1.0\r\nHost: tarantool.org\r\n\r\n")
---
- 40
...
tarantool> sock:read(17)
---
```

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```
- HTTP/1.1 302 Move
...
tarantool> sock:close()
---
- true
...
```

Use of a socket with LuaSocket wrapper functions

This is a variation of the earlier example "Use of a TCP socket over the Internet". It uses LuaSocket wrapper functions, with a too-short timeout so that a "Connection timed out" error is likely. The more common way to specify timeout is with an option of tcp_connect().

```
tarantool> socket = require('socket')
---
...
tarantool> sock = socket.connect('tarantool.org', 80)
---
...
tarantool> sock:settimeout(0.001)
---
- 1
...
tarantool> sock:send("HEAD / HTTP/1.0\r\nHost: tarantool.org\r\n\r\n")
---
- 40
...
tarantool> sock:receive(17)
---
- null
- Connection timed out
...
tarantool> sock:close()
---
- 1
...
```

Use of a UDP socket on localhost

Here is an example with datagrams. Set up two connections on 127.0.0.1 (localhost): sock_1 and sock_2. Using sock_2, send a message to sock_1. Using sock_1, receive a message. Display the received message. Close both connections. This is not a useful way for a computer to communicate with itself, but shows that the system works.

```
tarantool> socket = require('socket')
---
...
tarantool> sock_1 = socket('AF_INET', 'SOCK_DGRAM', 'udp')
---
...
tarantool> sock_1:bind('127.0.0.1')
---
```

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```
- true
...
tarantool> sock_2 = socket('AF_INET', 'SOCK_DGRAM', 'udp')
---
...
tarantool> sock_2:sendto('127.0.0.1', sock_1:name().port,'X')
---
- 1
...
tarantool> message = sock_1:recvfrom(512)
---
...
tarantool> message
---
- X
...
tarantool> sock_1:close()
---
- true
...
tarantool> sock_2:close()
---
- true
...
```

Use tcp_server to accept file contents sent with socat

Here is an example of the tcp_server function, reading strings from the client and printing them. On the client side, the Linux socat utility will be used to ship a whole file for the tcp_server function to read.

Start two shells. The first shell will be a server instance. The second shell will be the client.

On the first shell, start Tarantool and say:

```
box.cfg{}
socket = require('socket')
socket.tcp_server('0.0.0.0', 3302,
{
  handler = function(s)
    while true do
      local request
      request = s:read("\n");
      if request == "" or request == nil then
        break
      end
      print(request)
    end
  end,
  prepare = function()
    print('Initialized')
  end
}
)
```

The above code means:

1. Use tcp_server() to wait for a connection from any host on port 3302.
2. When it happens, enter a loop that reads on the socket and prints what it reads. The "delimiter" for the read function is "\n" so each read() will read a string as far as the next line feed, including the line feed.

On the second shell, create a file that contains a few lines. The contents don't matter. Suppose the first line contains A, the second line contains B, the third line contains C. Call this file "tmp.txt".

On the second shell, use the socat utility to ship the tmp.txt file to the server instance's host and port:

```
$ socat TCP:localhost:3302 ./tmp.txt
```

Now watch what happens on the first shell. The strings "A", "B", "C" are printed.

Use tcp_server with handler and prepare

Here is an example of the tcp_server function using handler and prepare.

Start two shells. The first shell will be a server instance. The second shell will be the client.

On the first shell, start Tarantool and say:

```
box.cfg{}
socket = require('socket')
sock = socket.tcp_server(
  '0.0.0.0',
  3302,
  {prepare =
     function(sock)
       print('listening on socket ' .. sock:fd())
       sock:setsockopt('SOL_SOCKET','SO_REUSEADDR',true)
       return 5
     end,
   handler =
    function(sock, from)
      print('accepted connection from: ')
      print('  host: ' .. from.host)
      print('  family: ' .. from.family)
      print('  port: ' .. from.port)
    end
  }
)
```

The above code means:

1. Use tcp_server() to wait for a connection from any host on port 3302.
2. Specify that there will be an initial call to prepare which displays something about the server, then calls setsockopt(...'SO_REUSEADDR'...) (this is the same option that Tarantool would set if there was no prepare), and then returns 5 (this is a rather low backlog queue size).
3. Specify that there will be per-connection calls to handler which display something about the client.

Now watch what happens on the first shell. The display will include something like 'listening on socket 12'.

On the second shell, start Tarantool and say:

```
box.cfg{}
require('socket').tcp_connect('127.0.0.1', 3302)
```

Now watch what happens on the first shell. The display will include something like 'accepted connection from host: 127.0.0.1 family: AF_INET port: 37186'.

5.2.24 Module strict

The strict module has functions for turning "strict mode" on or off. When strict mode is on, an attempt to use an undeclared global variable will cause an error. A global variable is considered "undeclared" if it has never had a value assigned to it. Often this is an indication of a programming error.

By default strict mode is off, unless tarantool was built with the -DCMAKE_BUILD_TYPE=Debug option – see the description of build options in section building-from-source.

Example:

```
tarantool> strict = require('strict')
---
...
tarantool> strict.on()
---
...
tarantool> a = b -- strict mode is on so this will cause an error
---
- error: ... variable ''b'' is not declared'
...
tarantool> strict.off()
---
...
tarantool> a = b -- strict mode is off so this will not cause an error
---
...
```

5.2.25 Module string

Overview

The string module has everything in the standard Lua string library, and some Tarantool extensions.

In this section we only discuss the additional functions that the Tarantool developers have added.

Index

Below is a list of all additional string functions.

Name	Use
string.ljust()	Left-justify a string
string.rjust()	Right-justify a string
string.hex()	Given a string, return hexadecimal values
string.fromhex()	Given hexadecimal values, return a string
string.startswith()	Check if a string starts with a given substring
string.endswith()	Check if a string ends with a given substring
string.lstrip()	Remove characters from the left of a string
string.rstrip()	Remove characters from the right of a string
string.split()	Split a string into a table of strings
string.strip()	Remove spaces on the left and right of a string

string.ljust(input-string, width[, pad-character])
Return the string left-justified in a string of length width.

Parameters

- input-string (string) – the string to left-justify
- width (integer) – the width of the string after left-justifying
- pad-character (string) – a single character, default = 1 space

Return left-justified string (unchanged if width <= string length)

Rtype string

Example:

```
tarantool> string = require('string')
---
...
tarantool> string.ljust(' A', 5)
---
- ' A   '
...
```

string.rjust(input-string, width[, pad-character])
Return the string right-justified in a string of length width.

Parameters

- input-string (string) – the string to right-justify
- width (integer) – the width of the string after right-justifying
- pad-character (string) – a single character, default = 1 space

Return right-justified string (unchanged if width <= string length)

Rtype string

Example:

```
tarantool> string = require('string')
---
...
tarantool> string.rjust('', 5, 'X')
---
- 'XXXXX'
...
```

string.hex(input-string)
Return the hexadecimal value of the input string.

Parameters

- input-string (string) – the string to process

Return hexadecimal, 2 hex-digit characters for each input character

Rtype string

Example:

```
tarantool> string = require('string')
---
...
tarantool> string.hex('ABC ')
---
- '41424320'
...
```

string.fromhex(hexadecimal-input-string)

Given a string containing pairs of hexadecimal digits, return a string with one byte for each pair. This is the reverse of string.hex(). The hexadecimal-input-string must contain an even number of hexadecimal digits.

Parameters

- hexadecimal-input-string (string) – string with pairs of hexadecimal digits

Return string with one byte for each pair of hexadecimal digits

Rtype string

Example:

```
tarantool> string = require('string')
---
...
tarantool> string.fromhex('41424320')
---
- 'ABC '
...
```

string.startswith(input-string, start-string[, start-pos[, end-pos]])

Return True if input-string starts with start-string, otherwise return False.

Parameters

- input-string (string) – the string where start-string should be looked for
- start-string (string) – the string to look for
- start-pos (integer) – position: where to start looking within input-string
- end-pos (integer) – position: where to end looking within input-string

Return true or false

Rtype boolean

start-pos and end-pos may be negative, meaning the position should be calculated from the end of the string.

Example:

```
tarantool> string = require('string')
---
...
tarantool> string.startswith(' A', 'A', 2, 5)
---
- true
...
```

string.endswith(input-string, end-string[, start-pos[, end-pos]])

Return True if input-string ends with end-string, otherwise return False.

Parameters

- input-string (string) – the string where end-string should be looked for
- end-string (string) – the string to look for
- start-pos (integer) – position: where to start looking within input-string
- end-pos (integer) – position: where to end looking within input-string

Return true or false

Rtype boolean

start-pos and end-pos may be negative, meaning the position should be calculated from the end of the string.

Example:

```
tarantool> string = require('string')
---
...
tarantool> string.endswith('Baa', 'aa')
---
- true
...
```

string.lstrip(input-string[, list-of-characters])

Return the value of the input string, after removing characters on the left. The optional list-of-characters parameter is a set not a sequence, so string.lstrip(...,'ABC') does not mean strip 'ABC', it means strip 'A' or 'B' or 'C'.

Parameters

- input-string (string) – the string to process
- list-of-characters (string) – what characters can be stripped. Default = space.

Return result after stripping characters from input string

Rtype string

Example:

```
tarantool> string = require('string')
---
...
tarantool> string.lstrip(' ABC ')
---
- 'ABC '
...
```

string.rstrip(input-string[, list-of-characters])

Return the value of the input string, after removing characters on the right. The optional list-of-characters parameter is a set not a sequence, so string.rstrip(...,'ABC') does not mean strip 'ABC', it means strip 'A' or 'B' or 'C'.

Parameters

- input-string (string) – the string to process
- list-of-characters (string) – what characters can be stripped. Default = space.

Return result after stripping characters from input string

Rtype string

Example:

```
tarantool> string = require('string')
---
...
tarantool> string.rstrip(' ABC ')
---
- ' ABC'
...
```

string.split(input-string[, split-string[, max]])

Split input-string into one or more output strings in a table. The places to split are the places where split-string occurs.

Parameters

- input-string (string) – the string to split
- split-string (integer) – the string to find within input-string. Default = space.
- max (integer) – maximum number of delimiters to process counting from the beginning of the input string. Result will contain max + 1 parts maximum.

Return table of strings that were split from input-string

Rtype table

Example:

```
tarantool> string = require('string')
---
...
tarantool> string.split("A:B:C:D:F", ":", 2)
---
- - A
  - B
  - C:D:F
...
```

string.strip(input-string[, list-of-characters])

Return the value of the input string, after removing characters on the left and the right. The optional list-of-characters parameter is a set not a sequence, so string.strip(...,'ABC') does not mean strip 'ABC', it means strip 'A' or 'B' or 'C'.

Parameters

- input-string (string) – the string to process
- list-of-characters (string) – what characters can be stripped. Default = space.

Return result after stripping characters from input string

Rtype string

Example:

```
tarantool> string = require('string')
---
...
tarantool> string.strip(' ABC ')
```

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```
---
- ABC
...
```

5.2.26 Module swim

Overview

The swim module contains Tarantool's implementation of SWIM – Scalable Weakly-consistent Infection-style Process Group Membership Protocol. It is recommended for any type of Tarantool cluster where the number of nodes can be large. Its job is to discover and monitor the other members in the cluster and keep their information in a "member table". It works by sending and receiving, in a background event loop, periodically, via UDP, messages.

Each message has several parts, including:

- the ping such as "I am checking whether you are alive",
- the event such as "I am joining",
- the anti-entropy such as "I know that another member exists",
- the payload such as "I or another member could have user-generated data".

The maximum message size is about 1500 bytes.

SWIM sends messages periodically to a random subset of the member table. SWIM processes replies from those members asynchronously.

Each entry in the member table has:

- a UUID,
- a status ("alive", "suspected", "dead", or "left").

When a member fails to acknowledge a certain number of pings, its status is changed from "alive" to "suspected", that is, suspected of being dead. But SWIM tries to avoid false positives (misidentifying members as dead) which could happen when a member is overloaded and responds to pings too slowly, or when there is network trouble and packets can not go through some channels. When a member is suspected, SWIM randomly chooses other members and sends requests to them: "please ping this suspected member". This is called an indirect ping. Thus via different routes and additional hops the suspected member gets additional chances to reply, and thus "refute" the suspicion.

Because selection is random there is an even network load of about one message per member per protocol step, regardless of the cluster size. This is a major feature of SWIM. Because the protocol depends on members passing information on, also known as "gossiping", members do not need to broadcast messages to every member, which would cause a network load of N messages per member per protocol step, where N is the number of members in the cluster. However, selection is not entirely random, there is a preference for selecting least-recently-pinged members, like a round-robin.

Regarding the anti-entropy part of a message: this is necessary for maintaining the status in entries of the member table. Consider an example where two members, #1 and #2, are both alive. No events happen so only pings are being sent periodically. Then a third member, #3 appears. It knows about one of the existing members, #2. How can it discover the other member? Certainly #1 could notify #2 and #2 could notify #3, but messages go via UDP, so any notification event can be lost. However, regular messages containing "ping" and/or "event" also can contain an "anti-entropy" section, which is taken from a randomly-chosen part of the member table. So for this example, #2 will eventually randomly add to a regular message the anti-entropy note that #1 is alive, and thus #3 will discover #1 even though it did not receive a direct "I am alive" event message from #1.

Regarding the UUID part of an entry in the member table: this is necessary for stable identification, because UUID changes more rarely than URI (a combination of IP and port number). But if the UUID does change, SWIM will include both the new and old UUID in messages, so all other members will eventually learn about the new UUID and change the member table accordingly.

Regarding the payload part of a message: this is not always necessary, it is a feature which allows passing user-generated information via SWIM instead of via node-to-node communication. The swim module has methods for specifying a "payload", which is arbitrary user data with a maximum size of about 1.2 KB. The payload can be anything, and it will be eventually disseminated over the cluster and available at other members. Each member can have its own payload.

Messages can be encrypted. Encryption may not be necessary in a closed network but is necessary for safety if the cluster is on the public Internet. Users can specify an encryption algorithm, an encryption mode, and a private key. All parts of all messages (including ping, acknowledgment, event, payload, URI, and UUID) will be encrypted with that private key, as well as a random public key generated for each message to prevent pattern attacks.

In theory the event dissemination speed (the number of hops to pass information throughout the cluster) is O(log(cluster_size)). For that and other theoretical information see the Cornell University paper which originally described SWIM.

swim.new([cfg])

Create a new SWIM instance. A SWIM instance maintains a member table and interacts with other members. Multiple SWIM instances can be created in a single Tarantool process.

Parameters

- cfg (table) – an optional configuration parameter.

  If cfg is not specified or is nil, then the new SWIM instance is not bound to a socket and has nil attributes, so it cannot interact with other members and only a few methods are valid until swim_object:cfg() is called.

  If cfg is specified, then the effect is the same as calling s = swim.new() s:cfg(), except for generation. For configuration description see swim_object:cfg().

The generation part of cfg can only be specified during new(), it cannot be specified later during cfg(). Generation is part of incarnation. Usually generation is not specified because the default value (a timestamp) is sufficient, but if there is reason to mistrust timestamps (because the time is changed or because the instance is started on a different machine), then users may say swim.new(generation = {new-value. In that case the latest value should be persisted somehow (for example in a file, or in a space, or in a global service), and the new value must be greater than any previous value of generation.

Return swim-object a swim object

Example:

```
swim_object = swim.new({uri = 3333, uuid = '00000000-0000-1000-8000-000000000001', heartbeat_rate␣
↪= 0.1})
```

object swim_object

A swim object is an object returned by swim.new(). It has methods: cfg(), delete(), is_configured(), size(), quit(), add_member(), remove_member(), probe_member(), broadcast(), set_payload(), set_payload_raw(), set_codec(), self(), member_by_uuid(), pairs().

swim_object:cfg(cfg)

Configure or reconfigure a SWIM instance.

Parameters

- cfg (table) – the options to describe instance behavior

The cfg table may have these components:

- heartbeat_rate (double) – rate of sending round messages, in seconds. Setting heartbeat_rate to X does not mean that every member will be checked every X seconds, instead X is the protocol speed. Protocol period depends on member count and heartbeat_rate. Default = 1.
- ack_timeout (double) – time in seconds after which a ping is considered to be unacknowledged. Default = 30.
- gc_mode (enum) – dead member collection mode.

  If gc_mode == `'off'` then SWIM never removes dead members from the member table (though users may remove them with swim_object:remove_member()), and SWIM will continue to ping them as if they were alive.

  If gc_mode == `'on'` then SWIM removes dead members from the member table after one round.

  Default = `'on'`.
- uri (string or number) – either an `'ip:port'` address, or just a port number (if ip is omitted then 127.0.0.1 is assumed). If port == 0, then the kernel will select any free port for the IP address.
- uuid (string or cdata struct tt_uuid) – a value which should be unique among SWIM instances. Users may choose any value but the recommendation is: use box.cfg.instance_uuid, the Tarantool instance's UUID.

All the cfg components are dynamic – swim_object:cfg() may be called more than once. If it is not being called for the first time and a component is not specified, then the component retains its previous value. If it is being called for the first time then uri and uuid are mandatory, since a SWIM instance cannot operate without URI and UUID.

swim_object:cfg() is atomic – if there is an error, then nothing changes.

Return true if configuration succeeds

Return nil, err if an error occurred. err is an error object

Example:

```
swim_object:cfg({heartbeat_rate = 0.5})
```

After swim_object:cfg(), all other swim_object methods are callable.

.cfg

Expose all non-nil components of the read-only table which was set up or changed by swim_object:cfg().

Example:

```
tarantool> swim_object.cfg
---
- gc_mode: off
  uri: 3333
  uuid: 00000000-0000-1000-8000-000000000001
...
```

swim_object:delete()

Delete a SWIM instance immediately. Its memory is freed, its member table entry is deleted, and it can no longer be used. Other members will treat this member as 'dead'.

After swim_object:delete() any attempt to use the deleted instance will cause an exception to be thrown.

Return none, this method does not fail

Example: swim_object:delete()

swim_object:is_configured()

Return false if a SWIM instance was created via swim.new() without an optional cfg argument, and was not configured with swim_object:cfg(). Otherwise return true.

Return boolean result, true if configured, otherwise false

Example: swim_object:is_configured()

swim_object:size()

Return the size of the member table. It will be at least 1 because the "self" member is included.

Return integer size

Example: swim_object:size()

swim_object:quit()

Leave the cluster.

This is a graceful equivalent of swim_object:delete() – the instance is deleted, but before deletion it sends to each member in its member table a message, that this instance has left the cluster, and should not be considered dead.

Other instances will mark such a member in their tables as 'left', and drop it after one round of dissemination.

Consequences to the caller are the same as after swim_object:delete() – the instance is no longer usable, and an error will be thrown if there is an attempt to use it.

Return none, the method does not fail

Example: swim_object:quit()

swim_object:add_member(cfg)

Explicitly add a member into the member table.

This method is useful when a new member is joining the cluster and does not yet know what members already exist. In that case it can start interaction explicitly by adding the details about an already-existing member into its member table. Subsequently SWIM will discover other members automatically via messages from the already-existing member.

Parameters

- cfg (table) – description of the member

The cfg table has two mandatory components, uuid and uri, which have the same format as uuid and uri in the table for swim_object:cfg().

Return true if member is added

Return nil, err if an error occurred. err is an error object

Example:

```
swim_member_object = swim_object:add_member({uuid = ..., uri = ...})
```

swim_object:remove_member(uuid)

Explicitly and immediately remove a member from the member table.

Parameters

- uuid (string-or-cdata-struct-tt_uuid) – UUID

Return true if member is removed

Return nil, err if an error occurred. err is an error object.

Example: swim_object:delete('00000000-0000-1000-8000-000000000001')

swim_object:probe_member(uri)

Send a ping request to the specified uri address. If another member is listening at that address, it will receive the ping, and respond with an ACK (acknowledgment) message containing information such as UUID. That information will be added to the member table.

swim_object:probe_member() is similar to swim_object:add_member(), but it does not require UUID, and it is not reliable because it uses UDP.

Parameters

- uri (string-or-number) – URI. Format is the same as for uri in swim_object:cfg().

Return true if member is pinged

Return nil, err if an error occurred. err is an error object.

Example: swim_object:probe_member(3333)

swim_object:broadcast([port])

Broadcast a ping request to all the network interfaces in the system.

swim_object:broadcast() is like swim_object:probe_member() to many members at once.

Parameters

- port (number) – All the sent ping requests have this port as destination port in their UDP headers. By default a currently bound port is used.

Return true if broadcast is sent

Return nil, err if an error occurred. err is an error object.

Example:

```
tarantool> fiber = require('fiber')
---
...
tarantool> swim = require('swim')
---
...
tarantool> s1 = swim.new({uri = 3333, uuid = '00000000-0000-1000-8000-000000000001', heartbeat_
↪rate = 0.1})
---
...
tarantool> s2 = swim.new({uri = 3334, uuid = '00000000-0000-1000-8000-000000000002', heartbeat_
↪rate = 0.1})
---
...
```

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```
tarantool> s1:size()
---
- 1
...
tarantool> s1:add_member({uri = s2:self():uri(), uuid = s2:self():uuid()})
---
- true
...
tarantool> s1:size()
---
- 1
...
tarantool> s2:size()
---
- 1
...

tarantool> fiber.sleep(0.2)
---
...
tarantool> s1:size()
---
- 2
...
tarantool> s2:size()
---
- 2
...
tarantool> s1:remove_member(s2:self():uuid()) s2:remove_member(s1:self():uuid())
---
...
tarantool> s1:size()
---
- 1
...
tarantool> s2:size()
---
- 1
...

tarantool> s1:probe_member(s2:self():uri())
---
- true
...
tarantool> fiber.sleep(0.1)
---
...
tarantool> s1:size()
---
- 2
...
tarantool> s2:size()
---
- 2
...
tarantool> s1:remove_member(s2:self():uuid()) s2:remove_member(s1:self():uuid())
```

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```
---
...
tarantool> s1:size()
---
- 1
...
tarantool> s2:size()
---
- 1
...
tarantool> s1:broadcast(3334)
---
- true
...
tarantool> fiber.sleep(0.1)
---
...
tarantool> s1:size()
---
- 2
...

tarantool> s2:size()
---
- 2
...
```

swim_object:set_payload(payload)

Set a payload, as formatted data.

Payload is arbitrary user defined data up to 1200 bytes in size and disseminated over the cluster. So each cluster member will eventually learn what is the payload of other members in the cluster, because it is stored in the member table and can be queried with swim_member_object:payload().

Different members may have different payloads.

Parameters

- payload (object) – Arbitrary Lua object to disseminate. Set to nil to remove the payload, in which case it will be eventually removed on other instances. The object is serialized in MessagePack.

Return true if payload is set

Return nil, err if an error occurred. err is an error object

Example:

```
swim_object:set_payload({field1 = 100, field2 = 200})
```

swim_object:set_payload_raw(payload[, size])

Set a payload, as raw data.

Sometimes a payload does not need to be a Lua object. For example, a user may already have a well formatted MessagePack object and just wants to set it as a payload. Or cdata needs to be exposed.

set_payload_raw allows setting a payload as is, without MessagePack serialization.

Parameters

- payload (string-or-cdata) – any value
- size (number) – Payload size in bytes. If payload is string then size is optional, and if specified, then should not be larger than actual payload size. If size is less than actual payload size, then only the first size bytes of payload are used. If payload is cdata then size is mandatory.

Return true if payload is set

Return nil, err if an error occurred. err is an error object

Example:

```
tarantool> tarantool> ffi = require('ffi')
---
...
tarantool> fiber = require('fiber')
---
...
tarantool> swim = require('swim')
---
...
tarantool> s1 = swim.new({uri = 0, uuid = '00000000-0000-1000-8000-000000000001', heartbeat_
↪rate = 0.1})
---
...
tarantool> s2 = swim.new({uri = 0, uuid = '00000000-0000-1000-8000-000000000002', heartbeat_
↪rate = 0.1})
---
...
tarantool> s1:add_member({uri = s2:self():uri(), uuid = s2:self():uuid()})
---
- true
...
tarantool> s1:set_payload({a = 100, b = 200})
---
- true
...
tarantool> s2:set_payload('any payload')
---
- true
...
tarantool> fiber.sleep(0.2)
---
...
tarantool> s1_view = s2:member_by_uuid(s1:self():uuid())
---
...
tarantool> s2_view = s1:member_by_uuid(s2:self():uuid())
---
...
tarantool> s1_view:payload()
---
- {'a': 100, 'b': 200}
...
tarantool> s2_view:payload()
---
- any payload
...
```

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```
tarantool> cdata = ffi.new('char[?]', 2)
---
...
tarantool> cdata[0] = 1
---
...
tarantool> cdata[1] = 2
---
...
tarantool> s1:set_payload_raw(cdata, 2)
---
- true
...
tarantool> fiber.sleep(0.2)
---
...
tarantool> cdata, size = s1_view:payload_cdata()
---
...
tarantool> cdata[0]
---
- 1
...
tarantool> cdata[1]
---
- 2
...
tarantool> size
---
- 2
...
```

swim_object:set_codec(codec_cfg)

Enable encryption for all following messages.

For a brief description of encryption algorithms see “enum_crypto_algo” and “enum crypto_mode” in the Tarantool source code file crypto.h.

When encryption is enabled, all the messages are encrypted with a chosen private key, and a randomly generated and updated public key.

Parameters

- codec_cfg (table) – description of the encryption

The components of the codec_cfg table may be:

- algo (string) – encryption algorithm name. All the names in module crypto are supported: ‘aes128’, ‘aes192’, ‘aes256’, ‘des’. Specify ‘none’ to disable encryption.
- mode (string) – encryption algorithm mode. All the modes in module crypto are supported: ‘ecb’, ‘cbc’, ‘cfb’, ‘ofb’. Default = ‘cbc’.
- key (cdata or string) – a private secret key which is kept secret and should never be stored hard-coded in source code.
- key_size (integer) – size of the key in bytes.

  key_size is mandatory if key is cdata.

key_size is optional if key is string, and if key_size is shorter than than actual key size then the key is truncated.

All of algo, mode, key, and key_size should be the same for all SWIM instances, so that members can understand each others' messages.

Example;

```
tarantool> tarantool> swim = require('swim')
---
...
tarantool> s1 = swim.new({uri = 0, uuid = '00000000-0000-1000-8000-000000000001'})
---
...
tarantool> s1:set_codec({algo = 'aes128', mode = 'cbc', key = '1234567812345678'})
---
- true
...
```

swim_object:self()

Return a swim member object (of self) from the member table, or from a cache containing earlier results of swim_object:self() or swim_object:member_by_uuid() or swim_object:pairs().

Return swim member object, not nil because self() will not fail

Example: swim_member_object = swim_object:self()

swim_object:member_by_uuid(uuid)

Return a swim member object (given UUID) from the member table, or from a cache containing earlier results of swim_object:self() or swim_object:member_by_uuid() or swim_object:pairs().

Parameters

- uuid (string-or-cdata-struct-tt-uuid) – UUID

Return swim member object, or nil if not found

Example:

```
swim_member_object = swim_object:member_by_uuid('00000000-0000-1000-8000-000000000001')
```

swim_object:pairs()

Set up an iterator for returning swim member objects from the member table, or from a cache containing earlier results of swim_object:self() or swim_object:member_by_uuid() or swim_object:pairs().

swim_object:pairs() should be in a 'for' loop, and there should only be one iterator in operation at one time. (The iterator is implemented in an extra light fashion so only one iterator object is available per SWIM instance.)

Parameters

- generator+object+key (varies) – as for any Lua pairs() iterators. generator function, iterator object (a swim member object), and initial key (a UUID).

Example:

```
tarantool> fiber = require('fiber')
---
...
tarantool> swim = require('swim')
```

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```
---
...
tarantool> s1 = swim.new({uri = 0, uuid = '00000000-0000-1000-8000-000000000001', heartbeat_
↪rate = 0.1})
---
...
tarantool> s2 = swim.new({uri = 0, uuid = '00000000-0000-1000-8000-000000000002', heartbeat_
↪rate = 0.1})
---
...
tarantool> s1:add_member({uri = s2:self():uri(), uuid = s2:self():uuid()})
---
- true
...
tarantool> fiber.sleep(0.2)
---
...
tarantool> s1:self()
---
- uri: 127.0.0.1:55845
  status: alive
  incarnation: cdata {generation = 1569353431853325ULL, version = 1ULL}
  uuid: 00000000-0000-1000-8000-000000000001
  payload_size: 0
...
tarantool> s1:member_by_uuid(s1:self():uuid())
---
- uri: 127.0.0.1:55845
  status: alive
  incarnation: cdata {generation = 1569353431853325ULL, version = 1ULL}
  uuid: 00000000-0000-1000-8000-000000000001
  payload_size: 0
...
tarantool> s1:member_by_uuid(s2:self():uuid())
---
- uri: 127.0.0.1:53666
  status: alive
  incarnation: cdata {generation = 1569353431865138ULL, version = 1ULL}
  uuid: 00000000-0000-1000-8000-000000000002
  payload_size: 0
...
tarantool> t = {}
---
...
tarantool> for k, v in s1:pairs() do table.insert(t, {k, v}) end
---
...
tarantool> t
---
- - - 00000000-0000-1000-8000-000000000002
    - uri: 127.0.0.1:53666
      status: alive
      incarnation: cdata {generation = 1569353431865138ULL, version = 1ULL}
      uuid: 00000000-0000-1000-8000-000000000002
      payload_size: 0
  - - 00000000-0000-1000-8000-000000000001
```

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```
  - uri: 127.0.0.1:55845
    status: alive
    incarnation: cdata {generation = 1569353431853325ULL, version = 1ULL}
    uuid: 00000000-0000-1000-8000-000000000001
    payload_size: 0
...
```

object swim_member_object

Methods swim_object:member_by_uuid(), swim_object:self(), and swim_object:pairs() return swim member objects.

A swim member object has methods for reading its attributes: status(), uuid, uri(), incarnation(), payload_cdata, payload_str(), payload(), is_dropped().

swim_member_object:status()

Return the status, which may be 'alive', 'suspected', 'left', or 'dead'.

Return string 'alive' | 'suspected' | 'left' | dead'

swim_member_object:uuid()

Return the UUID as cdata struct tt_uuid.

Return cdata-struct-tt-uuid UUID

swim_member_object:uri()

Return the URI as a string 'ip:port'. Via this method a user can learn a real assigned port, if port = 0 was specified in swim_object:cfg().

Return string ip:port

swim_member_object:incarnation()

Return a cdata object with the incarnation. The cdata object has two attributes: incarnation().generation and incarnation().version.

Incarnations can be compared to each other with any comparison operator (==, <, >, <=, >=, ~=).

Incarnations, when printed, will appear as strings with both generation and version.

Return cdata incarnation

swim_member_object:payload_cdata()

Return member's payload.

Return pointer-to-cdata payload and size in bytes

swim_member_object:payload_str()

Return payload as a string object. Payload is not decoded. It is just returned as a string instead of cdata. If payload was not specified by swim_object:set_payload() or by swim_object:set_payload_raw(), then its size is 0 and nil is returned.

Return string-object payload, or nil if there is no payload

swim_member_object:payload()

Since the swim module is a Lua module, a user is likely to use Lua objects as a payload – tables, numbers, strings etc. And it is natural to expect that swim_member_object:payload() should return the same object which was passed into swim_object:set_payload() by another instance. swim_member_object:payload() tries to interpret payload as MessagePack, and if that fails then it returns the payload as a string.

swim_member_object:payload() caches its result. Therefore only the first call actually decodes cdata payload. All following calls return a pointer to the same result, unless payload is changed with a new incarnation. If payload was not specified (its size is 0), then nil is returned.

swim_member_object:is_dropped()

Returns true if this member object is a stray reference to a member which has already been dropped from the member table.

Return boolean true if member is dropped, otherwise false

Example:

```
tarantool> swim = require('swim')
---
...
tarantool> s = swim.new({uri = 0, uuid = '00000000-0000-1000-8000-000000000001'})
---
...
tarantool> self = s:self()
---
...
tarantool> self:status()
---
- alive
...
tarantool> self:uuid()
---
- 00000000-0000-1000-8000-000000000001
...
tarantool> self:uri()
---
- 127.0.0.1:56367
...
tarantool> self:incarnation()
---
- - cdata {generation = 1569354463981551ULL, version = 1ULL}
...
tarantool> self:is_dropped()
---
- false
...
tarantool> s:set_payload_raw('123')
---
- true
...
tarantool> self:payload_cdata()
---
- 'cdata<const char *>: 0x0103500050'
- 3
...
tarantool> self:payload_str()
---
- '123'
...
tarantool> s:set_payload({a = 100})
---
- true
...
tarantool> self:payload_cdata()
```

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```
---
- 'cdata<const char *>: 0x0103500050'
- 4
...
tarantool> self:payload_str()
---
- !!binary gaFhZA==
...
tarantool> self:payload()
---
- {'a': 100}
...
```

swim_member_object:on_member_event(trigger-function[, ctx])

Create an "on_member trigger". The trigger-function will be executed when a member in the member table is updated.

Parameters

- trigger-function (function) – this will become the trigger function
- ctx (cdata) – (optional) this will be passed to trigger-function

Return nil or function pointer.

The trigger-function should have three parameter declarations (Tarantool will pass values for them when it invokes the function):

- the member which is having the member event,
- the event object,
- the ctx which will be the same value as what is passed to swim_object:on_member_event.

A member event is any of:

- appearance of a new member,
- drop of an existing member, or
- update of an existing member.

An event object is an object which the trigger-function can use for determining what type of member event has happened. The object's methods – such as is_new_status(), is_new_uri(), is_new_incarnation(), is_new_payload(), is_drop() – return boolean values.

A member event may have more than one associated trigger. Triggers are executed sequentially. Therefore if a trigger function causes yields or sleeps, other triggers may be forced to wait. However, since trigger execution is done in a separate fiber, SWIM itself is not forced to wait.

Example of an on-member trigger function:

```
tarantool> swim = require('swim')

local function on_event(member, event, ctx)
    if event:is_new() then
        ...
    elseif event:is_drop() then
        ...
    end

```

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```
    if event:is_update() then
        -- All next conditions can be
        -- true simultaneously.
        if event:is_new_status() then
...
        end
        if event:is_new_uri() then
...
        end
        if event:is_new_incarnation() then
...
        end
        if event:is_new_payload() then
...
        end
    end
end
```

Notice in the above example that the function is ready for the possibility that multiple events can happen simultaneously for a single trigger activation. is_new() and is_drop() can not both be true, but is_new() and is_update() can both be true, or is_drop() and is_update() can both be true. Multiple simultaneous events are especially likely if there are many events and trigger functions are slow – in that case, for example, a member might be added and then updated after a while, and then after a while there will be a single trigger activation.

Also: is_new() and is_new_payload() can both be true. This case is not due to trigger functions that are slow. It occurs because "omitted payload" and "size-zero payload" are not the same thing. For example: when a ping is received, a new member might be added, but ping messages do not include payload. The payload will appear later in a different message. If that is important for the application, then the function should not assume when is_new() is true that the member already has a payload, and should not assume that payload size says something about the payload's presence or absence.

Also: functions should not assume that is_new() and is_drop() will always be seen. If a new member appears but then is dropped before its appearance has caused a trigger activation, then there will be no trigger activation.

is_new_generation() will be true if the generation part of incarnation changes. is_new_version() will be true if the version part of incarnation changes. is_new_incarnation() will be true if either the generation part or the version part of incarnation changes. For example a combination of these methods can be used within a user-defined trigger to check whether a process has restarted, or a member has changed …

```
swim = require('swim')
s = swim.new()
s:on_member_event(function(m, e)
...
    if e:is_new_incarnation() then
        if e:is_new_generation() then
            -- Process restart.
        end
        if e:is_new_version() then
            -- Process version update. It means
            -- the member is somehow changed.
        end
    end
```

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```
end
```

swim_member_object:on_member_event(nil, old-trigger)

Delete an on-member trigger.

Parameters

- old-trigger (function) – old-trigger

The old-trigger value should be the value returned by on_member_event(trigger-function[, ctx]).

swim_member_object:on_member_event(new-trigger, old-trigger[, ctx])

This is a variation of on_member_event(new-trigger, [, ctx]).

The additional parameter is old-trigger. Instead of adding the new-trigger at the end of a list of triggers, this function will replace the entry in the list of triggers that matches old-trigger. The position within a list may be important because triggers are activated sequentially starting with the first trigger in the list.

The old-trigger value should be the value returned by on_member_event(trigger-function[, ctx]).

swim_member_object:on_member_event()

Return the list of on-member triggers.

SWIM internals

The SWIM internals section is not necessary for programmers who wish to use the SWIM module, it is for programmers who wish to change or replace the SWIM module.

The SWIM wire protocol is open, will be backward compatible in case of any changes, and can be implemented by users who wish to simulate their own SWIM cluster members because they use another language than Lua, or another environment unrelated to Tarantool. The protocol is encoded as MsgPack.

```
SWIM packet structure:

+-----------------Public data, not encrypted------------------+
|                                                             |
|      Initial vector, size depends on chosen algorithm.      |
|                   Next data is encrypted.                   |
|                                                             |
+----------Meta section, handled by transport level-----------+
| map {                                                       |
|     0 = SWIM_META_TARANTOOL_VERSION: uint, Tarantool        |
|                                      version ID,            |
|     1 = SWIM_META_SRC_ADDRESS: uint, ip,                    |
|     2 = SWIM_META_SRC_PORT: uint, port,                     |
|     3 = SWIM_META_ROUTING: map {                            |
|         0 = SWIM_ROUTE_SRC_ADDRESS: uint, ip,               |
|         1 = SWIM_ROUTE_SRC_PORT: uint, port,                |
|         2 = SWIM_ROUTE_DST_ADDRESS: uint, ip,               |
|         3 = SWIM_ROUTE_DST_PORT: uint, port                 |
|     }                                                       |
| }                                                           |
+-------------------Protocol logic section--------------------+
| map {                                                       |
|     0 = SWIM_SRC_UUID: 16 byte UUID,                        |
|                                                             |
```

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```
|               AND                                   |
|                                                     |
|    2 = SWIM_FAILURE_DETECTION: map {                |
|        0 = SWIM_FD_MSG_TYPE: uint, enum swim_fd_msg_type, |
|        1 = SWIM_FD_GENERATION: uint,                |
|        2 = SWIM_FD_VERSION: uint                    |
|    },                                               |
|                                                     |
|               OR/AND                                |
|                                                     |
|    3 = SWIM_DISSEMINATION: array [                  |
|        map {                                        |
|            0 = SWIM_MEMBER_STATUS: uint,            |
|                                enum member_status,  |
|            1 = SWIM_MEMBER_ADDRESS: uint, ip,       |
|            2 = SWIM_MEMBER_PORT: uint, port,        |
|            3 = SWIM_MEMBER_UUID: 16 byte UUID,      |
|            4 = SWIM_MEMBER_GENERATION: uint,        |
|            5 = SWIM_MEMBER_VERSION: uint,           |
|            6 = SWIM_MEMBER_PAYLOAD: bin             |
|        },                                           |
|        ...                                          |
|    ],                                               |
|                                                     |
|               OR/AND                                |
|                                                     |
|    1 = SWIM_ANTI_ENTROPY: array [                   |
|        map {                                        |
|            0 = SWIM_MEMBER_STATUS: uint,            |
|                                enum member_status,  |
|            1 = SWIM_MEMBER_ADDRESS: uint, ip,       |
|            2 = SWIM_MEMBER_PORT: uint, port,        |
|            3 = SWIM_MEMBER_UUID: 16 byte UUID,      |
|            4 = SWIM_MEMBER_GENERATION: uint,        |
|            5 = SWIM_MEMBER_VERSION: uint,           |
|            6 = SWIM_MEMBER_PAYLOAD: bin             |
|        },                                           |
|        ...                                          |
|    ],                                               |
|                                                     |
|               OR/AND                                |
|                                                     |
|    4 = SWIM_QUIT: map {                             |
|        0 = SWIM_QUIT_GENERATION: uint,              |
|        1 = SWIM_QUIT_VERSION: uint                  |
|    }                                                |
| }                                                   |
+-----------------------------------------------------+
```

The Initial vector section appears only when encryption is enabled. This section contains a public key. For example, for AES algorithms it is a 16-byte initial vector stored as is. When no encryption is used, the section size is 0.

The later sections (Meta and Protocol Logic) are encrypted as one big data chunk if encryption is enabled.

The Meta section handles routing and protocol versions compatibility. It works at the 'transport' level of the SWIM protocol, and is always present. Keys in the meta section are:

- SWIM_META_TARANTOOL_VERSION – mandatory field. Tarantool sets here its version as a 3 byte integer:
  - 1 byte for major,
  - 1 byte for minor,
  - 1 byte for patch.

  For example, Tarantool version 2.1.3 would be encoded like this: (((2 << 8) | 1) << 8) | 3;. This field will be used to support multiple versions of the protocol.
- SWIM_META_SRC_ADDRESS and SWIM_META_SRC_PORT – mandatory. source IP address and port. IP is encoded as 4 bytes. "xxx.xxx.xxx.xxx" where each 'xxx' is encoding of one byte. Port is encoded as an integer. Example of how to encode "127.0.0.1:3313":

```
struct in_addr addr;
inet_aton("127.0.0.1", &addr);
pos = mp_encode_uint(pos, SWIM_META_SRC_ADDRESS);
pos = mp_encode_uint(pos, addr->s_addr);
pos = mp_encode_uint(pos, SWIM_META_SRC_PORT);
pos = mp_encode_uint(pos, 3313);
```

- SWIM_META_ROUTING subsection – not mandatory. Responsible for packet forwarding. Used by SWIM suspicion mechanism. Read about suspicion in the SWIM paper.

  If this subsection is present then the following fields are mandatory:
  - SWIM_ROUTE_SRC_ADDRESS and SWIM_ROUTE_SRC_PORT (source IP address and port) (should be an address of the message originator (can differ from
  - SWIM_META_SRC_ADDRESS and from SWIM_META_SRC_ADDRESS_PORT);
  - SWIM_ROUTE_DST_ADDRESS and SWIM_ROUTE_DST_PORT (destination IP address and port, for the the message's final destination).

  If a message was sent indirectly with the help of SWIM_META_ROUTING, then the reply should be sent back by the same route.

  For an example of how SWIM uses routing for indirect pings . . . Assume there are 3 nodes: S1, S2, S3. S1 sends a message to S3 via S2. The following steps are executed in order to deliver the message:

```
S1 -> S2
{ src: S1, routing: {src: S1, dst: S3}, body: ... }
```

  S2 receives the message and sees that routing.dst is not equal to S2, so it is a foreign packet. S2 forwards the packet to S3 preserving all the data including body and routing sections.

```
S2 -> S3
```

  S3 receives the message and sees that routing.dst is equal to S3, so the message is delivered. If S3 wants to answer, it sends a response via the same proxy. It knows that the message was delivered from S2, so it sends an answer via S2.

The Protocol logic section handles SWIM logical protocol steps and actions.

- SWIM_SRC_UUID – mandatory field. SWIM uses UUID as a unique identifier of a member, not IP/port. This field stores UUID of sender. Its type is MP_BIN. Size is always 16 bytes. UUID is encoded in host byte order, no bswaps are needed.

Following SWIM_SRC_UUID there are four possible subsections: SWIM_FAILURE_DETECTION, SWIM_DISSEMINATION, SWIM_ANTI_ENTROPY, SWIM_QUIT. Any or all of these subsections may be present. A connector should be ready to handle any combination.

- SWIM_FAILURE_DETECTION subsection – describes a ping or ACK. In the SWIM_FAILURE_DETECTION subsection are:
  - SWIM_FD_MSG_TYPE (0 is ping, 1 is ack);
  - SWIM_FD_GENERATION + SWIM_FD_VERSION (the incarnation).
- SWIM_DISSEMINATION subsection – a list of changed cluster members. It may include only a subset of changed cluster members if there are too many changes to fit into one UDP packet.

  In the SWIM_DISSEMINATION subsection are:
  - SWIM_MEMBER_STATUS (mandatory) (0 = alive, 1 = suspected, 2 = dead, 3 = left);
  - SWIM_MEMBER_ADDRESS and SWIM_MEMBER_PORT (mandatory) member IP and port;
  - SWIM_MEMBER_UUID (mandatory) (member UUID);
  - SWIM_MEMBER_GENERATION + SWIM_MEMBER_VERSION (mandatory) (the member incarnation);
  - SWIM_MEMBER_PAYLOAD (not mandatory) (member payload) (MessagePack type is MP_BIN).

  Note that absence of SWIM_MEMBER_PAYLOAD means nothing - it is not the same as a payload with zero size.
- SWIM_ANTI_ENTROPY subsection – a helper for the dissemination. It contains all the same fields as the dissemination sub, but all of them are mandatory, including payload even when payload size is 0. Anti-entropy eventually spreads changes which for any reason are not spread by the dissemination.
- SWIM_QUIT subsection – statement that the sender has left the cluster gracefully, for example via swim_object:quit(), and should not be considered dead. Sender status should be changed to 'left'.

  In the SWIM_QUIT subsection are:
  - SWIM_QUIT_GEMERATOPM + SWIM_QUIT_VERSION (the sender incarnation).

The incarnation is a 128-bit cdata value which is part of each member's configuration and is present in most messages. It has two parts: generation and version.

Generation is persistent. By default it has the number of microseconds since the epoch (compare the value returned by clock_realtime64()). Optionally a user can set generation during new().

Version is volatile. It is initially 0. It is incremented automatically every time that a change occurs.

The incarnation, or sometimes the version alone, is useful for deciding to ignore obsolete messages, for updating a member's attributes on remote nodes, and for refuting messages that say a member is dead.

If the member's incarnation is less than the locally stored incarnation, then the message is obsolete. This can happen because UDP allows reordering and duplication.

If the member's incarnation in a message is greater than the locally stored incarnation, then most of its attributes (IP, port, status) should be updated with the values received in the message. However, the payload attribute should not be updated unless it is present in the message. Because of its relatively large size, payload is not always included in every message.

Refutation usually happens when a false-positive failure detection has happened. In such a case the member thought to be dead receives that information from other members, increases its own incarnation, and spreads a message saying the member is alive (a "refutation").

Note: in the original version of Tarantool SWIM, and in the original SWIM specification, there is no generation and the incarnation consists of only the version. Generation was added because it is useful for detecting obsolete messages left over from a previous life of an instance that has restarted.

5.2.27 Module table

The table module has everything in the standard Lua table library, and some Tarantool extensions.

You can see this by saying "table": you will see this list of functions: clear (LuaJIT extension = erase all elements), concat (concatenate), copy (make a copy of an array), deepcopy (see description below), foreach, foreachi, getn (get the number of elements in an array), insert (insert an element into an array), maxn (get largest index) move (move elements between tables), new (LuaJIT extension = return a new table with pre-allocated elements), remove (remove an element from an array), sort (sort the elements of an array).

In this section we only discuss the additional function that the Tarantool developers have added: deepcopy.

table.deepcopy(input-table)

Return a "deep" copy of the table – a copy which follows nested structures to any depth and does not depend on pointers, it copies the contents.

Parameters

- input-table – (table) the table to copy

Return the copy of the table

Rtype table

Example:

```
tarantool> input_table = {1,{'a','b'}}
---
...

tarantool> output_table = table.deepcopy(input_table)
---
...

tarantool> output_table
---
- - 1
  - - a
    - b
...
```

table.sort(input-table[, comparison-function])

Put the input-table contents in sorted order.

The basic Lua table.sort has a default comparison-function: function (a, b) return a < b end.

That is efficient and standard. However, sometimes Tarantool users will want an equivalent to table.sort which has any of these features:

(1) If the table contains nils, except nils at the end, the results must still be correct. That is not the case with the default tarantool_sort, and it cannot be fixed by making a comparison that checks whether a and b are nil. (Before trying certain Internet suggestions, test with {1, nil, 2, -1, 44, 1e308, nil, 2, nil, nil, 0}.

(2) If strings are to be sorted in a language-aware way, there must be a parameter for collation.

(3) If the table has a mix of types, then they must be sorted as booleans, then numbers, then strings, then byte arrays.

Since all those features are available in Tarantool spaces, the solution for Tarantool is simple: make a temporary Tarantool space, put the table contents into it, retrieve the tuples from it in order, and overwrite the table.

Here then is tarantool_sort() which does the same thing as table.sort but has those extra features. It is not fast and it requires a database privilege, so it should only be used if the extra features are necessary.

```
function tarantool_sort(input_table, collation)
    local c = collation or 'binary'
    local tmp_name = 'Temporary_for_tarantool_sort'
    pcall(function() box.space[tmp_name]:drop() end)
    box.schema.space.create(tmp_name, {temporary = true})
    box.space[tmp_name]:create_index('I')
    box.space[tmp_name]:create_index('I2',
                                     {unique = false,
                                      type='tree',
                                      parts={{2, 'scalar',
                                              collation = c,
                                              is_nullable = true}}})
    for i = 1, table.maxn(input_table) do
        box.space[tmp_name]:insert{i, input_table[i]}
    end
    local t = box.space[tmp_name].index.I2:select()
    for i = 1, table.maxn(input_table) do
        input_table[i] = t[i][2]
    end
    box.space[tmp_name]:drop()
  end
```

For example, suppose table t = {1, 'A', -88.3, nil, true, 'b', 'B', nil, 'À'}.
After tarantool_sort(t, 'unicode_ci') t contains {nil, nil, true, -88.3, 1, 'A', 'À', 'b', 'B'}.

5.2.28 Module tap

Overview

The tap module streamlines the testing of other modules. It allows writing of tests in the TAP protocol. The results from the tests can be parsed by standard TAP-analyzers so they can be passed to utilities such as prove. Thus one can run tests and then use the results for statistics, decision-making, and so on.

Index

Name	Use
tap.test()	Initialize
taptest:test()	Create a subtest and print the results
taptest:plan()	Indicate how many tests to perform
taptest:check()	Check the number of tests performed
taptest:diag()	Display a diagnostic message
taptest:ok()	Evaluate the condition and display the message
taptest:fail()	Evaluate the condition and display the message
taptest:skip()	Evaluate the condition and display the message
taptest:is()	Check if the two arguments are equal
taptest:isnt()	Check if the two arguments are different
taptest:is_deeply()	Recursively check if the two arguments are equal
taptest:like()	Check if the argument matches a pattern
taptest:unlike()	Check if the argument does not match a pattern
taptest:isnil() taptest:isstring() taptest:isnumber() taptest:istable() taptest:isboolean() taptest:isudata() taptest:iscdata()	Check if a value has a particular type
taptest.strict	Flag, true if comparisons with nil should be strict

tap.test(test-name)

Initialize.

The result of tap.test is an object, which will be called taptest in the rest of this discussion, which is necessary for taptest:plan() and all the other methods.

Parameters

- test-name (string) – an arbitrary name to give for the test outputs.

Return taptest

Rtype table

```
tap = require('tap')
taptest = tap.test('test-name')
```

object taptest

taptest:test(test-name, func)

Create a subtest (if no func argument specified), or (if all arguments are specified) create a subtest, run the test function and print the result.

See the example.

Parameters

- name (string) – an arbitrary name to give for the test outputs.
- fun (function) – the test logic to run.

Return taptest

Rtype userdata or string

taptest:plan(count)

Indicate how many tests will be performed.

Parameters

- count (number) –

Return nil

taptest:check()

Checks the number of tests performed.

The result will be a display saying # bad plan: ... if the number of completed tests is not equal to the number of tests specified by taptest:plan(...). (This is a purely Tarantool feature: "bad plan" messages are out of the TAP13 standard.)

This check should only be done after all planned tests are complete, so ordinarily taptest:check() will only appear at the end of a script. However, as a Tarantool extension, taptest:check() may appear at the end of any subtest. Therefore there are three ways to cause the check:

- by calling taptest:check() at the end of a script,
- by calling a function which ends with a call to taptest:check(),
- or by calling taptest:test('. . . ', subtest-function-name) where subtest-function-name does not need to end with taptest:check() because it can be called after the subtest is complete.

Return true or false.

Rtype boolean

taptest:diag(message)

Display a diagnostic message.

Parameters

- message (string) – the message to be displayed.

Return nil

taptest:ok(condition, test-name)

This is a basic function which is used by other functions. Depending on the value of condition, print 'ok' or 'not ok' along with debugging information. Displays the message.

Parameters

- condition (boolean) – an expression which is true or false
- test-name (string) – name of the test

Return true or false.

Rtype boolean

Example:

```
tarantool> taptest:ok(true, 'x')
ok - x
---
- true
...
tarantool> tap = require('tap')
---
...
tarantool> taptest = tap.test('test-name')
TAP version 13
---
...
tarantool> taptest:ok(1 + 1 == 2, 'X')
ok - X
---
- true
...
```

taptest:fail(test-name)

taptest:fail('x') is equivalent to taptest:ok(false, 'x'). Displays the message.

Parameters

- test-name (string) – name of the test

Return true or false.

Rtype boolean

taptest:skip(message)

taptest:skip('x') is equivalent to taptest:ok(true, 'x' .. '# skip'). Displays the message.

Parameters

- test-name (string) – name of the test

Return nil

Example:

```
tarantool> taptest:skip('message')
ok - message # skip
---
- true
...
```

taptest:is(got, expected, test-name)

Check whether the first argument equals the second argument. Displays extensive message if the result is false.

Parameters

- got (number) – actual result
- expected (number) – expected result
- test-name (string) – name of the test

Return true or false.

Rtype boolean

taptest:isnt(got, expected, test-name)
This is the negation of taptest:is().

Parameters

- got (number) – actual result
- expected (number) – expected result
- test-name (string) – name of the test

Return true or false.

Rtype boolean

taptest:is_deeply(got, expected, test-name)
Recursive version of taptest:is(...), which can be be used to compare tables as well as scalar values.

Return true or false.

Rtype boolean

Parameters

- got (lua-value) – actual result
- expected (lua-value) – expected result
- test-name (string) – name of the test

taptest:like(got, expected, test-name)
Verify a string against a pattern. Ok if match is found.

Return true or false.

Rtype boolean

Parameters

- got (lua-value) – actual result
- expected (lua-value) – pattern
- test-name (string) – name of the test

```
test:like(tarantool.version, '^[1-9]', "version")
```

taptest:unlike(got, expected, test-name)
This is the negation of taptest:like().

Parameters

- got (number) – actual result
- expected (number) – pattern
- test-name (string) – name of the test

Return true or false.

Rtype boolean

taptest:isnil(value, test-name)
taptest:isstring(value, test-name)
taptest:isnumber(value, test-name)
taptest:istable(value, test-name)
taptest:isboolean(value, test-name)
taptest:isudata(value, test-name)

taptest:iscdata(value, test-name)

Test whether a value has a particular type. Displays a long message if the value is not of the specified type.

Parameters

- value (lua-value) –
- test-name (string) – name of the test

Return true or false.

Rtype boolean

taptest.strict

Set taptest.strict=true if taptest:is() and taptest:isnt() and taptest:is_deeply() must be compared strictly with nil. Set taptest.strict=false if nil and box.NULL both have the same effect. The default is false. For example, if and only if taptest.strict=true has happened, then taptest:is_deeply({a = box.NULL}, {}) will return false.

Example

To run this example: put the script in a file named ./tap.lua, then make tap.lua executable by saying chmod a+x ./tap.lua, then execute using Tarantool as a script processor by saying ./tap.lua.

```
#!/usr/bin/tarantool
local tap = require('tap')
test = tap.test("my test name")
test:plan(2)
test:ok(2 * 2 == 4, "2 * 2 is 4")
test:test("some subtests for test2", function(test)
    test:plan(2)
    test:is(2 + 2, 4, "2 + 2 is 4")
    test:isnt(2 + 3, 4, "2 + 3 is not 4")
end)
test:check()
```

The output from the above script will look approximately like this:

```
TAP version 13
1..2
ok - 2 * 2 is 4
    # Some subtests for test2
    1..2
    ok - 2 + 2 is 4,
    ok - 2 + 3 is not 4
    # Some subtests for test2: end
ok - some subtests for test2
```

5.2.29 Module tarantool

By saying require('tarantool'), one can answer some questions about how the tarantool server was built, such as “what flags were used”, or “what was the version of the compiler”.

Additionally one can see the uptime and the server version and the process id. Those information items can also be accessed with box.info() but use of the tarantool module is recommended.

Example:

```
tarantool> tarantool = require('tarantool')
---
...
tarantool> tarantool
---
- version: 2.3.0-3-g302bb3241
  build:
    target: Linux-x86_64-RelWithDebInfo
    options: cmake . -DCMAKE_INSTALL_PREFIX=/opt/tarantool-install
-DENABLE_BACKTRACE=ON
    mod_format: so
    flags: ' -fexceptions -funwind-tables -fno-omit-frame-pointer
-fno-stack-protector
      -fno-common -fopenmp -msse2 -std=c11 -Wall -Wextra
-Wno-strict-aliasing -Wno-char-subscripts
      -Wno-format-truncation -fno-gnu89-inline -Wno-cast-function-type'
    compiler: /usr/bin/cc /usr/bin/c++
  pid: 'function: 0x40016cd0'
  package: Tarantool
  uptime: 'function: 0x40016cb0'
...
tarantool> tarantool.pid()
---
- 30155
...
tarantool> tarantool.uptime()
---
- 108.64641499519
...
```

5.2.30 Module uuid

Overview

A "UUID" is a Universally unique identifier. If an application requires that a value be unique only within a single computer or on a single database, then a simple counter is better than a UUID, because getting a UUID is time-consuming (it requires a syscall). For clusters of computers, or widely distributed applications, UUIDs are better.

Index

Below is list of all uuid functions and members.

Name	Use
uuid.nil	A nil object
uuid() uuid.bin() uuid.str()	Get a UUID
uuid.fromstr() uuid.frombin() uuid_object:bin() uuid_object:str()	Get a converted UUID
uuid_object:isnil()	Check if a UUID is an all-zero value

uuid.nil

    A nil object

uuid.__call()

Return a UUID

Rtype cdata

uuid.bin()

Return a UUID

Rtype 16-byte string

uuid.str()

Return a UUID

Rtype 36-byte binary string

uuid.fromstr(uuid_str)

Parameters

- uuid_str – UUID in 36-byte hexadecimal string

Return converted UUID

Rtype cdata

uuid.frombin(uuid_bin)

Parameters

- uuid_str – UUID in 16-byte binary string

Return converted UUID

Rtype cdata

object uuid_object

uuid_object:bin([byte-order])

byte-order can be one of next flags:

- 'l' - little-endian,
- 'b' - big-endian,
- 'h' - endianness depends on host (default),
- 'n' - endianness depends on network

Parameters

- byte-order (string) – one of `'l'`, `'b'`, `'h'` or `'n'`.

Return UUID converted from cdata input value.

Rtype 16-byte binary string

uuid_object:str()

Return UUID converted from cdata input value.

Rtype 36-byte hexadecimal string

uuid_object:isnil()

The all-zero UUID value can be expressed as uuid.NULL, or as uuid.fromstr(`'00000000-0000-0000-0000-000000000000'`). The comparison with an all-zero value can also be expressed as uuid_with_type_cdata == uuid.NULL.

Return true if the value is all zero, otherwise false.

Rtype bool

Example

```
tarantool> uuid = require('uuid')
---
...
tarantool> uuid(), uuid.bin(), uuid.str()
---
- 16ffedc8-cbae-4f93-a05e-349f3ab70baa
- !!binary FvG+Vy1MfUC6kIyeM81DYw==
- 67c999d2-5dce-4e58-be16-ac1bcb93160f
...
tarantool> uu = uuid()
---
...
tarantool> #uu:bin(), #uu:str(), type(uu), uu:isnil()
---
- 16
- 36
- cdata
- false
...
```

5.2.31 Module utf8

Overview

utf8 is Tarantool's module for handling UTF-8 strings. It includes some functions which are compatible with ones in Lua 5.3 but Tarantool has much more. For example, because internally Tarantool contains a complete copy of the "International Components For Unicode" library, there are comparison functions which understand the default ordering for Cyrillic (Capital Letter Zhe Ж = Small Letter Zhe ж) and Japanese (Hiragana A = Katakana A).

Name	Use
casecmp and cmp	Comparisons
lower and upper	Case conversions
isalpha, isdigit, islower and isupper	Determine character types
sub	Substrings
len	Length in characters
next	Character-at-a-time iterations

utf8.casecmp(UTF8-string, utf8-string)

Parameters

- string (UTF8-string) – a string encoded with UTF-8

Return -1 meaning "less", 0 meaning "equal", +1 meaning "greater"

Rtype number

Compare two strings with the Default Unicode Collation Element Table (DUCET) for the Unicode Collation Algorithm. Thus 'å' is less than 'B', even though the code-point value of å (229) is greater than the code-point value of B (66), because the algorithm depends on the values in the Collation Element Table, not the code-point values.

The comparison is done with primary weights. Therefore the elements which affect secondary or later weights (such as "case" in Latin or Cyrillic alphabets, or "kana differentiation" in Japanese) are ignored. If asked "is this like a Microsoft case-insensitive accent-insensitive collation" we tend to answer "yes", though the Unicode Collation Algorithm is far more sophisticated than those terms imply.

Example:

```
tarantool> utf8.casecmp('é','e'),utf8.casecmp('E','e')
---
- 0
- 0
...
```

utf8.char(code-point[, code-point ...])

Parameters

- number (code-point) – a Unicode code point value, repeatable

Return a UTF-8 string

Rtype string

The code-point number is the value that corresponds to a character in the Unicode Character Database This is not the same as the byte values of the encoded character, because the UTF-8 encoding scheme is more complex than a simple copy of the code-point number.

Another way to construct a string with Unicode characters is with the \u{hex-digits} escape mechanism, for example '\u{41}\u{42}' and utf8.char(65,66) both produce the string 'AB'.

Example:

```
tarantool> utf8.char(229)
---
- å
...
```

utf8.cmp(UTF8-string, utf8-string)

Parameters

- string (UTF8-string) – a string encoded with UTF-8

Return -1 meaning "less", 0 meaning "equal", +1 meaning "greater"

Rtype number

Compare two strings with the Default Unicode Collation Element Table (DUCET) for the Unicode Collation Algorithm. Thus 'å' is less than 'B', even though the code-point value of å (229) is greater than the code-point value of B (66), because the algorithm depends on the values in the Collation Element Table, not the code values.

The comparison is done with at least three weights. Therefore the elements which affect secondary or later weights (such as "case" in Latin or Cyrillic alphabets, or "kana differentiation" in Japanese) are not ignored. and upper case comes after lower case.

Example:

```
tarantool> utf8.cmp('é','e'),utf8.cmp('E','e')
---
- 1
- 1
...
```

utf8.isalpha(UTF8-character)

Parameters

- string-or-number (UTF8-character) – a single UTF8 character, expressed as a one-byte string or a code point value

Return true or false

Rtype boolean

Return true if the input character is an "alphabetic-like" character, otherwise return false. Generally speaking a character will be considered alphabetic-like provided it is typically used within a word, as opposed to a digit or punctuation. It does not have to be a character in an alphabet.

Example:

```
tarantool> utf8.isalpha('Ж'),utf8.isalpha('å'),utf8.isalpha('9')
---
- true
- true
- false
...
```

utf8.isdigit(UTF8-character)

Parameters

- string-or-number (UTF8-character) – a single UTF8 character, expressed as a one-byte string or a code point value

Return true or false

Rtype boolean

Return true if the input character is a digit, otherwise return false.

Example:

```
tarantool> utf8.isdigit('Ж'),utf8.isdigit('å'),utf8.isdigit('9')
---
- false
- false
- true
...
```

utf8.islower(UTF8-character)

Parameters

- string-or-number (UTF8-character) – a single UTF8 character, expressed as a one-byte string or a code point value

Return true or false

Rtype boolean

Return true if the input character is lower case, otherwise return false.

Example:

```
tarantool> utf8.islower('Ж'),utf8.islower('å'),utf8.islower('9')
---
- false
- true
- false
...
```

utf8.isupper(UTF8-character)

Parameters

- string-or-number (UTF8-character) – a single UTF8 character, expressed as a one-byte string or a code point value

Return true or false

Rtype boolean

Return true if the input character is upper case, otherwise return false.

Example:

```
tarantool> utf8.isupper('Ж'),utf8.isupper('å'),utf8.isupper('9')
---
- true
- false
- false
...
```

utf8.len(UTF8-string[, start-byte[, end-byte]])

Parameters

- string (UTF8-string) – a string encoded with UTF-8
- integer (end-byte) – byte position of the first character
- integer – byte position where to stop

Return the number of characters in the string, or between start and end

Rtype number

Byte positions for start and end can be negative, which indicates "calculate from end of string" rather than "calculate from start of string".

If the string contains a byte sequence which is not valid in UTF-8, each byte in the invalid byte sequence will be counted as one character.

UTF-8 is a variable-size encoding scheme. Typically a simple Latin letter takes one byte, a Cyrillic letter takes two bytes, a Chinese/Japanese character takes three bytes, and the maximum is four bytes.

Example:

```
tarantool> utf8.len('G'),utf8.len('ж')
---
- 1
- 1
...
```

(continues on next page)

(continued from previous page)

```
tarantool> string.len('G'),string.len('ж')
---
- 1
- 2
...
```

utf8.lower(UTF8-string)

Parameters

- string (UTF8-string) – a string encoded with UTF-8

Return the same string, lower case

Rtype string

Example:

```
tarantool> utf8.lower('ÅΓЖABCDEFG')
---
- åγжabcdefg
...
```

utf8.next(UTF8-string[, start-byte])

Parameters

- string (UTF8-string) – a string encoded with UTF-8
- integer (start-byte) – byte position where to start within the string, default is 1

Return byte position of the next character and the code point value of the next character

Rtype table

The next function is often used in a loop to get one character at a time from a UTF-8 string.

Example:

In the string 'åa' the first character is 'å', it starts at position 1, it takes two bytes to store so the character after it will be at position 3, its Unicode code point value is (decimal) 229.

```
tarantool> -- show next-character position + first-character codepoint
tarantool> utf8.next('åa', 1)
---
- 3
- 229
...
tarantool> -- (loop) show codepoint of every character
tarantool> for position,codepoint in utf8.next,'åa' do print(codepoint) end
229
97
...
```

utf8.sub(UTF8-string, start-character[, end-character])

Parameters

- string (UTF8-string) – a string encoded as UTF-8
- number (end-character) – the position of the first character
- number – the position of the last character

Return a UTF-8 string, the "substring" of the input value

Rtype string

Character positions for start and end can be negative, which indicates "calculate from end of string" rather than "calculate from start of string".

The default value for end-character is the length of the input string. Therefore, saying utf8.sub(1, 'abc') will return 'abc', the same as the input string.

Example:

```
tarantool> utf8.sub('åγжabcdefg', 5, 8)
---
- abcd
...
```

utf8.upper(UTF8-string)

Parameters

- string (UTF8-string) – a string encoded with UTF-8

Return the same string, upper case

Rtype string

Note: In rare cases the upper-case result may be longer than the lower-case input, for example utf8.upper('ß') is 'SS'.

Example:

```
tarantool> utf8.upper('åγжabcdefg')
---
- ÅΓЖABCDEFG
...
```

5.2.32 Module uri

Overview

A "URI" is a "Uniform Resource Identifier". The IETF standard says a URI string looks like this:

```
[scheme:]scheme-specific-part[#fragment]
```

A common type, a hierarchical URI, looks like this:

```
[scheme:][//authority][path][?query][#fragment]
```

For example the string 'https://tarantool.org/x.html#y' has three components:

- https is the scheme,
- tarantool.org/x.html is the path,
- y is the fragment.

Tarantool's URI module provides routines which convert URI strings into their components, or turn components into URI strings.

Index

Below is a list of all uri functions.

Name	Use
uri.parse()	Get a table of URI components
uri.format()	Construct a URI from components

uri.parse(URI-string)

Parameters

- URI-string – a Uniform Resource Identifier

Return URI-components-table. Possible components are fragment, host, login, password, path, query, scheme, service.

Rtype Table

Example:

```
tarantool> uri = require('uri')
---
...

tarantool> uri.parse('http://x.html#y')
---
- host: x.html
  scheme: http
  fragment: y
...
```

uri.format(URI-components-table[, include-password])

Parameters

- URI-components-table – a series of name:value pairs, one for each component
- include-password – boolean. If this is supplied and is true, then the password component is rendered in clear text, otherwise it is omitted.

Return URI-string. Thus uri.format() is the reverse of uri.parse().

Rtype string

Example:

```
tarantool> uri.format({host = 'x.html', scheme = 'http', fragment = 'y'})
---
- http://x.html#y
...
```

5.2.33 Module xlog

The xlog module contains one function: pairs(). It can be used to read Tarantool's snapshot files or write-ahead-log (WAL) files. A description of the file format is in section Data persistence and the WAL file format.

xlog.pairs([file-name])

Open a file, and allow iterating over one file entry at a time.

Returns iterator which can be used in a for/end loop.

Rtype iterator

Possible errors: File does not contain properly formatted snapshot or write-ahead-log information.

Example:

This will read the first write-ahead-log (WAL) file that was created in the wal_dir directory in our "Getting started" exercises.

Each result from pairs() is formatted with MsgPack so its structure can be specified with __serialize.

```
xlog = require('xlog')
t = {}
for k, v in xlog.pairs('00000000000000000000.xlog') do
  table.insert(t, setmetatable(v, { __serialize = "map"}))
end
return t
```

The first lines of the result will look like:

```
(...)
---
- - {'BODY':   {'space_id': 272, 'index_base': 1, 'key': ['max_id'],
               'tuple': [['+', 2, 1]]},
     'HEADER': {'type': 'UPDATE', 'timestamp': 1477846870.8541,
               'lsn': 1, 'server_id': 1}}
  - {'BODY':   {'space_id': 280,
                'tuple': [512, 1, 'tester', 'memtx', 0, {}, []]},
     'HEADER': {'type': 'INSERT', 'timestamp': 1477846870.8597,
               'lsn': 2, 'server_id': 1}}
```

5.2.34 Module yaml

Overview

The yaml module takes strings in YAML format and decodes them, or takes a series of non-YAML values and encodes them.

Index

Below is a list of all yaml functions and members.

Name	Use
yaml.encode()	Convert a Lua object to a YAML string
yaml.decode()	Convert a YAML string to a Lua object
__serialize parameter	Output structure specification
yaml.cfg()	Change configuration
yaml.NULL	Analog of Lua's "nil"

yaml.encode(lua_value)

Convert a Lua object to a YAML string.

Parameters

- lua_value – either a scalar value or a Lua table value.

Return the original value reformatted as a YAML string.

Rtype string

yaml.decode(string)

Convert a YAML string to a Lua object.

Parameters

- string – a string formatted as YAML.

Return the original contents formatted as a Lua table.

Rtype table

__serialize parameter:

The YAML output structure can be specified with __serialize:

- 'seq', 'sequence', 'array' - table encoded as an array
- 'map', 'mappping' - table encoded as a map
- function - the meta-method called to unpack serializable representation of table, cdata or userdata objects

'seq' or 'map' also enable the flow (compact) mode for the YAML serializer (flow="[1,2,3]" vs block=" - 1n - 2n - 3n").

Serializing 'A' and 'B' with different __serialize values brings different results:

```
tarantool> yaml.encode(setmetatable({'A', 'B'}, { __serialize="seq"}))
---
- '["A","B"]'
...
tarantool> yaml.encode(setmetatable({'A', 'B'}, { __serialize="map"}))
---
- '{"1":"A","2":"B"}'
...
tarantool> yaml.encode({setmetatable({f1 = 'A', f2 = 'B'}, { __serialize="map"})})
---
- '[{"f2":"B","f1":"A"}]'
...
tarantool> yaml.encode({setmetatable({f1 = 'A', f2 = 'B'}, { __serialize="seq"})})
---
- '[[]]'
...
```

yaml.cfg(table)

Set values affecting the behavior of encode and decode functions.

The values are all either integers or boolean true/false.

Option	Default	Use
cfg. encode_invalid_numbers	true	A flag saying whether to enable encoding of NaN and Inf numbers
cfg. encode_number_precision	14	Precision of floating point numbers
cfg. encode_load_metatables	true	A flag saying whether the serializer will follow __serialize metatable field
cfg. encode_use_tostring	false	A flag saying whether to use tostring() for unknown types
cfg. encode_invalid_as_nil	false	A flag saying whether to use NULL for non-recognized types
cfg. encode_sparse_convert	true	A flag saying whether to handle excessively sparse arrays as maps. See detailed description below
cfg. encode_sparse_ratio	2	1/encode_sparse_ratio is the permissible percentage of missing values in a sparse array
cfg. encode_sparse_safe	10	A limit ensuring that small Lua arrays are always encoded as sparse arrays (instead of generating an error or encoding as map)
cfg. decode_invalid_numbers	true	A flag saying whether to enable decoding of NaN and Inf numbers
cfg. decode_save_metatables	true	A flag saying whether to set metatables for all arrays and maps

Sparse arrays features:

During encoding, The YAML encoder tries to classify table into one of four kinds:

- map - at least one table index is not unsigned integer
- regular array - all array indexes are available
- sparse array - at least one array index is missing
- excessively sparse array - the number of values missing exceeds the configured ratio

An array is excessively sparse when all the following conditions are met:

- encode_sparse_ratio > 0
- max(table) > encode_sparse_safe
- max(table) > count(table) * encode_sparse_ratio

The YAML encoder will never consider an array to be excessively sparse when encode_sparse_ratio = 0. The encode_sparse_safe limit ensures that small Lua arrays are always encoded as sparse arrays. By default, attempting to encode an excessively sparse array will generate an error. If encode_sparse_convert is set to true, excessively sparse arrays will be handled as maps.

yaml.cfg() example 1:

The following code will encode 0/0 as NaN ("not a number") and 1/0 as Inf ("infinity"), rather than returning nil or an error message:

```
yaml = require('yaml')
yaml.cfg{encode_invalid_numbers = true}
x = 0/0
y = 1/0
yaml.encode({1, x, y, 2})
```

The result of the yaml.encode() request will look like this:

```
tarantool> yaml.encode({1, x, y, 2})
---
- '[1,nan,inf,2]
...
```

yaml.cfg example 2:

To avoid generating errors on attempts to encode unknown data types as userdata/cdata, you can use this code:

```
tarantool> httpc = require('http.client').new()
---
...

tarantool> yaml.encode(httpc.curl)
---
- error: unsupported Lua type 'userdata'
...

tarantool> yaml.encode(httpc.curl, {encode_use_tostring=true})
---
- '"userdata: 0x010a4ef2a0"'
...
```

Note: To achieve the same effect for only one call to yaml.encode() (i.e. without changing the configuration permanently), you can use yaml.encode({1, x, y, 2}, {encode_invalid_numbers = true}).

Similar configuration settings exist for JSON and MsgPack.

yaml.NULL
    A value comparable to Lua "nil" which may be useful as a placeholder in a tuple.

Example

```
tarantool> yaml = require('yaml')
---
...
tarantool> y = yaml.encode({'a', 1, 'b', 2})
---
...
tarantool> z = yaml.decode(y)
---
...
tarantool> z[1], z[2], z[3], z[4]
---
- a
- 1
- b
- 2
...
tarantool> if yaml.NULL == nil then print('hi') end
hi
---
...
```

The YAML collection style can be specified with __serialize:

- __serialize="sequence" for a Block Sequence array,
- __serialize="seq" for a Flow Sequence array,
- __serialize="mapping" for a Block Mapping map,
- __serialize="map" for a Flow Mapping map.

Serializing 'A' and 'B' with different __serialize values causes different results:

```
tarantool> yaml = require('yaml')
---
...

tarantool> yaml.encode(setmetatable({'A', 'B'}, { __serialize="sequence"}))
---
- '---

  - A

  - B

  ...

  '
...

tarantool> yaml.encode(setmetatable({'A', 'B'}, { __serialize="seq"}))
---
- '--- [''A'', ''B'']

  ...

  '
...

tarantool> yaml.encode({setmetatable({f1 = 'A', f2 = 'B'}, { __serialize="map"})})
---
- '---

  - {''f2'': ''B'', ''f1'': ''A''}

  ...

  '
...
```

5.2.35 Other package components

All the Tarantool modules are, at some level, inside a package which, appropriately, is named package. There are also miscellaneous functions and variables which are outside all modules.

Name	Use
tonumber64()	Convert a string or a Lua number to a 64-bit integer
dostring()	Parse and execute an arbitrary chunk of Lua code
package.path	Where Tarantool looks for Lua additions
package.cpath	Where Tarantool looks for C additions
package.loaded	What Tarantool has already looked for and found
package.setsearchroot	Set the root path for a directory search
package.searchroot	Get the root path for a directory search

tonumber64(value)

Convert a string or a Lua number to a 64-bit integer. The input value can be expressed in decimal, binary (for example 0b1010), or hexadecimal (for example -0xffff). The result can be used in arithmetic, and the arithmetic will be 64-bit integer arithmetic rather than floating-point arithmetic. (Operations on an unconverted Lua number use floating-point arithmetic.) The tonumber64() function is added by Tarantool; the name is global.

Example:

```
tarantool> type(123456789012345), type(tonumber64(123456789012345))
---
- number
- number
...
tarantool> i = tonumber64('1000000000')
---
...
tarantool> type(i), i / 2, i - 2, i * 2, i + 2, i % 2, i ^ 2
---
- number
- 500000000
- 999999998
- 2000000000
- 1000000002
- 0
- 1000000000000000000
...
```

Warning: There is an underlying LuaJIT library that operates with C rules. Therefore you should expect odd results if you compare unsigned and signed (for example 0ULL > -1LL is false), or if you use numbers outside the 64-bit integer range (for example 9223372036854775808LL is negative). Also you should be aware that type(number-literal-ending-in-ULL) and type(tonumber64(number-with-more-than-14-digits)) is cdata, not a Lua arithmetic type, which prevents direct use with some functions in Lua libraries such as math. See the LuaJIT reference and look for the phrase "64 bit integer arithmetic". and the phrase "64 bit integer comparison". Or see the comments on Issue#4089.

dostring(lua-chunk-string[, lua-chunk-string-argument ...])

Parse and execute an arbitrary chunk of Lua code. This function is mainly useful to define and run Lua code without having to introduce changes to the global Lua environment.

Parameters

- lua-chunk-string (string) – Lua code
- lua-chunk-string-argument (lua-value) – zero or more scalar values which will be appended to, or substitute for, items in the Lua chunk.

Return whatever is returned by the Lua code chunk.

Possible errors: If there is a compilation error, it is raised as a Lua error.

Example:

```
tarantool> dostring('abc')
---
error: '[string "abc"]:1: ''='' expected near ''<eof>'''
...
tarantool> dostring('return 1')
---
- 1
...
tarantool> dostring('return ...', 'hello', 'world')
---
- hello
- world
...
tarantool> dostring([[
         >   local f = function(key)
         >     local t = box.space.tester:select{key}
         >     if t ~= nil then
         >       return t[1]
         >     else
         >       return nil
         >     end
         >   end
         >   return f(...)]], 1)
---
- null
...
```

package.path
This is a string that Tarantool uses to search for Lua modules, especially imporant for require(). See Modules, rocks and applications.

package.cpath
This is a string that Tarantool uses to search for C modules, especially imporant for require(). See Modules, rocks and applications.

package.loaded
This is a string that shows what Lua or C modules Tarantool has loaded, so that their functions and members are available. Initially it has all the pre-loaded modules, which don't need require().

package.setsearchroot([search-root])
Set the search root. The search root is the root directory from which dependencies are loaded.

Parameters

- search-root (string) – the path. Default = current directory.

The search-root string must contain a relative or absolute path. If it is a relative path, then it will be expanded to an absolute path. If search-root is omitted, or is box.NULL, then the search root is reset to the current directory, which is found with debug.sourcedir().

Example:

Suppose that a Lua file myapp/init.lua is the project root. Suppose the current path is /home/tara. Add this as the first line of myapp/init.lua: package.setsearchroot() Start the project with $ tarantool myapp/init.lua The search root will be the default, made absolute: /home/tara/myapp. Within the Lua application all dependencies will be searched relative to /home/tara/myapp.

package.searchroot()
: Return a string with the current search root. After package.setsearchroot('/home') the returned string will be /home'.

5.2.36 Database error codes

In the current version of the binary protocol, error messages, which are normally more descriptive than error codes, are not present in server responses. The actual message may contain a file name, a detailed reason or operating system error code. All such messages, however, are logged in the error log. Below are general descriptions of some popular codes. A complete list of errors can be found in file errcode.h in the source tree.

List of error codes

ER_NONMASTER	(In replication) A server instance cannot modify data unless it is a master.
ER_ILLEGAL_PARAMS	Illegal parameters. Malformed protocol message.
ER_MEMORY_ISSUE	Out of memory: memtx_memory limit has been reached.
ER_WAL_IO	Failed to write to disk. May mean: failed to record a change in the write-ahead log. Some sort of disk error.
ER_KEY_PART_COUNT	Key part count is not the same as index part count
ER_NO_SUCH_SPACE	The specified space does not exist.
ER_NO_SUCH_INDEX	The specified index in the specified space does not exist.
ER_PROC_LUA	An error occurred inside a Lua procedure.
ER_FIBER_STACK	The recursion limit was reached when creating a new fiber. This usually indicates that a stored procedure is recursively invoking itself too often.
ER_UPDATE_FIELD	An error occurred during update of a field.
ER_TUPLE_FOUND	A duplicate key exists in a unique index.

5.2.37 Handling errors

Here are some procedures that can make Lua functions more robust when there are errors, particularly database errors.

1. Invoke with pcall.

   Take advantage of Lua's mechanisms for "Error handling and exceptions", particularly pcall. That is, instead of simply invoking with

   box.space.space-name:function-name()

   say

   if pcall(box.space.space-name.function-name, box.space.space-name) ...

   For some Tarantool box functions, pcall also returns error details including a file-name and line-number within Tarantool's source code. This can be seen by unpacking. For example:

   x, y = pcall(function() box.schema.space.create('') end)

   y:unpack()

   See the tutorial Sum a JSON field for all tuples to see how pcall can fit in an application.

2. Examine and raise with box.error.

   To make a new error and pass it on, the box.error module provides box.error(code, errtext [, errtext ...]).

   To find the last error, the box.error module provides box.error.last(). (There is also a way to find the text of the last operating-system error for certain functions – errno.strerror([code]).)

3. Log.

   Put messages in a log using the log module.

   And filter messages that are automatically generated, with the log configuration parameter.

Generally, for Tarantool built-in functions which are designed to return objects: the result will be an object, or nil, or a Lua error. For example consider the fio_read.lua program in our cookbook:

```
#!/usr/bin/env tarantool

local fio = require('fio')
local errno = require('errno')
local f = fio.open('/tmp/xxxx.txt', {'O_RDONLY' })
if not f then
    error("Failed to open file: "..errno.strerror())
end
local data = f:read(4096)
f:close()
print(data)
```

After a function call that might fail, like fio.open() above, it is common to see syntax like if not f then ... or if f == nil then ..., which check for common failures. But if there had been a syntax error, for example fio.opex instead of fio.open, then there would have been a Lua error and f would not have been changed. If checking for such an obvious error had been a concern, the programmer would probably have used pcall().

All functions in Tarantool modules should work this way, unless the manual explicitly says otherwise.

5.2.38 Debug facilities

Overview

Tarantool users can benefit from built-in debug facilities that are part of:

- Lua (debug library, see details below) and
- LuaJit (debug.* functions).

The debug library provides an interface for debugging Lua programs. All functions in this library reside in the debug table. Those functions that operate on a thread have an optional first parameter that specifies the thread to operate on. The default is always the current thread.

Note: This library should be used only for debugging and profiling and not as a regular programming tool, as the functions provided here can take too long to run. Besides, several of these functions can compromise otherwise secure code.

Index

Below is a list of all debug functions.

Name	Use
debug.debug()	Enter an interactive mode
debug.getfenv()	Get an object's environment
debug.gethook()	Get a thread's current hook settings
debug.getinfo()	Get information about a function
debug.getlocal()	Get a local variable's name and value
debug.getmetatable()	Get an object's metatable
debug.getregistry()	Get the registry table
debug.getupvalue()	Get an upvalue's name and value
debug.setfenv()	Set an object's environment
debug.sethook()	Set a given function as a hook
debug.setlocal()	Assign a value to a local variable
debug.setmetatable()	Set an object's metatable
debug.setupvalue()	Assign a value to an upvalue
debug.sourcedir()	Get the source directory name
debug.sourcefile()	Get the source file name
debug.traceback()	Get a traceback of the call stack

debug.debug()

Enters an interactive mode and runs each string that the user types in. The user can, among other things, inspect global and local variables, change their values and evaluate expressions.

Enter cont to exit this function, so that the caller can continue its execution.

Note: Commands for debug.debug() are not lexically nested within any function and so have no direct access to local variables.

debug.getfenv(object)

Parameters

- object – object to get the environment of

Return the environment of the object

debug.gethook([thread])

Return the current hook settings of the thread as three values:

- the current hook function
- the current hook mask
- the current hook count as set by the debug.sethook() function

debug.getinfo([thread], function[, what])

Parameters

- function – function to get information on
- what (string) – what information on the function to return

Return a table with information about the function

You can pass in a function directly, or you can give a number that specifies a function running at level function of the call stack of the given thread: level 0 is the current function (getinfo() itself), level 1 is the function that called getinfo(), and so on. If function is a number larger than the number of active functions, getinfo() returns nil.

The default for what is to get all information available, except the table of valid lines. If present, the option f adds a field named func with the function itself. If present, the option L adds a field named activelines with the table of valid lines.

debug.getlocal([thread], level, local)

Parameters

- level (number) – level of the stack
- local (number) – index of the local variable

Return the name and the value of the local variable with the index local of the function at level level of the stack or nil if there is no local variable with the given index; raises an error if level is out of range

Note: You can call debug.getinfo() to check whether the level is valid.

debug.getmetatable(object)

Parameters

- object – object to get the metatable of

Return a metatable of the object or nil if it does not have a metatable

debug.getregistry()

Return the registry table

debug.getupvalue(func, up)

Parameters

- func (function) – function to get the upvalue of
- up (number) – index of the function upvalue

Return the name and the value of the upvalue with the index up of the function func or nil if there is no upvalue with the given index

debug.setfenv(object, table)

Sets the environment of the object to the table.

Parameters

- object – object to change the environment of
- table (table) – table to set the object environment to

Return the object

debug.sethook([thread], hook, mask[, count])

Sets the given function as a hook. When called without arguments, turns the hook off.

Parameters

- hook (function) – function to set as a hook
- mask (string) – describes when the hook will be called; may have the following values:
  - c - the hook is called every time Lua calls a function
  - r - the hook is called every time Lua returns from a function
  - l - the hook is called every time Lua enters a new line of code

- count (number) – describes when the hook will be called; when different from zero, the hook is called after every count instructions.

debug.setlocal([thread], level, local, value)

Assigns the value value to the local variable with the index local of the function at level level of the stack.

Parameters

- level (number) – level of the stack
- local (number) – index of the local variable
- value – value to assign to the local variable

Return the name of the local variable or nil if there is no local variable with the given index; raises an error if level is out of range

Note: You can call debug.getinfo() to check whether the level is valid.

debug.setmetatable(object, table)

Sets the metatable of the object to the table.

Parameters

- object – object to change the metatable of
- table (table) – table to set the object metatable to

debug.setupvalue(func, up, value)

Assigns the value value to the upvalue with the index up of the function func.

Parameters

- func (function) – function to set the upvalue of
- up (number) – index of the function upvalue
- value – value to assign to the function upvalue

Return the name of the upvalue or nil if there is no upvalue with the given index

debug.sourcedir([level])

Parameters

- level (number) – the level of the call stack which should contain the path (default is 2)

Return a string with the relative path to the source file directory

Instead of debug.sourcedir() one can say debug.__dir__ which means the same thing.

Determining the real path to a directory is only possible if the function was defined in a Lua file (this restriction may not apply for loadstring() since Lua will store the entire string in debug info).

If debug.sourcedir() is part of a return argument, then it should be inside parentheses: return (debug.sourcedir()).

debug.sourcefile([level])

Parameters

- level (number) – the level of the call stack which should contain the path (default is 2)

Return a string with the relative path to the source file

Instead of debug.sourcefile() one can say debug.__file__ which means the same thing.

Determining the real path to a file is only possible if the function was defined in a Lua file (this restriction may not apply to loadstring() since Lua will store the entire string in debug info).

If debug.sourcefile() is part of a return argument, then it should be inside parentheses: return (debug.sourcefile()).

debug.traceback([thread], [message][, level])

Parameters

- message (string) – an optional message prepended to the traceback
- level (number) – specifies at which level to start the traceback (default is 1)

Return a string with a traceback of the call stack

Debug example:

Make a file in the /tmp directory named example.lua, containing:

```
function w()
  print(debug.sourcedir())
  print(debug.sourcefile())
  print(debug.traceback())
  print(debug.getinfo(1)['currentline'])
end
w()
```

Execute tarantool /tmp/example.lua. Expect to see this:

```
/tmp
/tmp/example.lua
stack traceback:
    /tmp/example.lua:4: in function 'w'
    /tmp/example.lua:7: in main chunk
5
```

5.2.39 JSON paths

Overview

Since version 2.3 Tarantool supports JSON path updates. Now you can update/upsert formatted tuple / space / index fields by name (not only by field number). Updates of nested structures are also supported.

Example:

```
tarantool> box.cfg{};
         > format = {};
         > format[1] = {'field1', 'unsigned'};
         > format[2] = {'field2', 'map'};
         > format[3] = {'field3', 'array'};
         > format[4] = {'field4', 'string', is_nullable = true}
---
...
tarantool> s = box.schema.create_space('test', {format = format});
```

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```
         > _ = s:create_index('pk')
---
...
tarantool> t = {
         >     1,
         >     {
         >         key1 = 'value',
         >         key2 = 10
         >     },
         >     {
         >         2,
         >         3,
         >         {key3 = 20}
         >     }
         > }
---
...
tarantool> t = s:replace(t)
---
...
tarantool> t:update({{'=', 'field2.key1', 'new_value'}})
---
- [1, {'key1': 'new_value', 'key2': 10}, [2, 3, {'key3': 20}]]
...
tarantool> t:update({{'+', 'field3[2]', 1}})
---
- [1, {'key1': 'value', 'key2': 10}, [2, 4, {'key3': 20}]]
...
tarantool> s:update({1}, {{'!', 'field4', 'inserted value'}})
---
- [1, {'key1': 'value', 'key2': 10}, [2, 3, {'key3': 20}], 'inserted value']
...
tarantool> s:update({1}, {{'#', '[2].key2', 1}, {'=', '[3][3].key4', 'value4'}})
---
- [1, {'key1': 'value'}, [2, 3, {'key3': 20, 'key4': 'value4'}], 'inserted value']
...
tarantool> s:upsert({1, {k = 'v'}, {}}, {{'#', '[2].key1', 1}})
---
...
tarantool> s:select{}
---
- - [1, {}, [2, 3, {'key3': 20, 'key4': 'value4'}], 'inserted value']
...
```

Notice that field names that look like JSON paths are processed similarly to accessing tuple fields by JSON: first, the whole path is interpreted as a field name; if such a name does not exist, then it is treated as a path.

For example, for a field name field.name.like.json, this update

object-name:update(..., 'field.name.like.json', ...)

will update this field instead of keys field -> name -> like -> json. If you need such a name as part of a bigger path, then you should wrap it in quotes "" and brackets []:

object-name:update(..., '["field.name.like.json"].next.fields', ...)

There are some rules for JSON updates:

- Operation '!' can't be used to create all intermediate nodes of a path. For example, {'!', 'field1[1].

field3', ...} can't create fields 'field1' and '[1]', they should exist.

- Operation '#', when applied to maps, can't delete more than one key at once. That is, its argument should be always 1 for maps.

  {'#', 'field1.field2', 1} is allowed;

  {'#', 'field1.field2', 10} is not.

  This limitation originates from the problem that keys in a map are not ordered anyhow, and '#' with more than 1 key would lead to undefined behavior.
- Operation '!' on maps can't create a key, if it exists already.
- If a map contains non-string keys (booleans, numbers, maps, arrays - anything), then these keys can't be updated via JSON paths. But it is still allowed to update string keys in such a map.

Why JSON updates are good, and should be preferred when only a part of a tuple needs to be updated:

- They consume less space in WAL, because for an update only its keys, operations, and arguments are stored. It is cheaper to store an update of one deep field than of the whole tuple.
- They are faster. Firstly, this is because they are implemented in C, and have no problems with Lua GC and dynamic typing. Secondly, some cases of JSON paths are highly optimized. For example, an update with a single JSON path costs O(1) memory regardless of how deep that path goes (not counting update arguments).
- They are available from remote clients, as well as any other DML. Before JSON updates became available in Tarantool, to update one deep part of a tuple, it was necessary to download that tuple, update it in memory, and send it back – 2 network hops. With JSON paths, it can be 1 hop when the update can be described in paths.

5.3 Rocks reference

This reference covers third-party Lua modules for Tarantool.

5.3.1 SQL DBMS Modules

The discussion here in the reference is about incorporating and using two modules that have already been created: the "SQL DBMS rocks" for MySQL and PostgreSQL.

To call another DBMS from Tarantool, the essential requirements are: another DBMS, and Tarantool. The module which connects Tarantool to another DBMS may be called a "connector". Within the module there is a shared library which may be called a "driver".

Tarantool supplies DBMS connector modules with the module manager for Lua, LuaRocks. So the connector modules may be called "rocks".

The Tarantool rocks allow for connecting to SQL servers and executing SQL statements the same way that a MySQL or PostgreSQL client does. The SQL statements are visible as Lua methods. Thus Tarantool can serve as a "MySQL Lua Connector" or "PostgreSQL Lua Connector", which would be useful even if that was all Tarantool could do. But of course Tarantool is also a DBMS, so the module also is useful for any operations, such as database copying and accelerating, which work best when the application can work on both SQL and Tarantool inside the same Lua routine. The methods for connect/select/insert/etc. are similar to the ones in the net.box module.

From a user's point of view the MySQL and PostgreSQL rocks are very similar, so the following sections – "MySQL Example" and "PostgreSQL Example" – contain some redundancy.

MySQL Example

This example assumes that MySQL 5.5 or MySQL 5.6 or MySQL 5.7 has been installed. Recent MariaDB versions will also work, the MariaDB C connector is used. The package that matters most is the MySQL client developer package, typically named something like libmysqlclient-dev. The file that matters most from this package is libmysqlclient.so or a similar name. One can use find or whereis to see what directories these files are installed in.

It will be necessary to install Tarantool's MySQL driver shared library, load it, and use it to connect to a MySQL server instance. After that, one can pass any MySQL statement to the server instance and receive results, including multiple result sets.

Installation

Check the instructions for downloading and installing a binary package that apply for the environment where Tarantool was installed. In addition to installing tarantool, install tarantool-dev. For example, on Ubuntu, add the line:

```
$ sudo apt-get install tarantool-dev
```

Now, for the MySQL driver shared library, there are two ways to install:

With LuaRocks

Begin by installing luarocks and making sure that tarantool is among the upstream servers, as in the instructions on rocks.tarantool.org, the Tarantool luarocks page. Now execute this:

```
luarocks install mysql [MYSQL_LIBDIR = path]
                       [MYSQL_INCDIR = path]
                       [--local]
```

For example:

```
$ luarocks install mysql MYSQL_LIBDIR=/usr/local/mysql/lib
```

With GitHub

Go the site github.com/tarantool/mysql. Follow the instructions there, saying:

```
$ git clone https://github.com/tarantool/mysql.git
$ cd mysql && cmake . -DCMAKE_BUILD_TYPE=RelWithDebInfo
$ make
$ make install
```

At this point it is a good idea to check that the installation produced a file named driver.so, and to check that this file is on a directory that is searched by the require request.

Connecting

Begin by making a require request for the mysql driver. We will assume that the name is mysql in further examples.

```
mysql = require('mysql')
```

Now, say:

connection_name = mysql.connect(connection options)

The connection-options parameter is a table. Possible options are:

- host = host-name - string, default value = 'localhost'
- port = port-number - number, default value = 3306
- user = user-name - string, default value is operating-system user name
- password = password - string, default value is blank
- db = database-name - string, default value is blank
- raise = true|false - boolean, default value is false

The option names, except for raise, are similar to the names that MySQL's mysql client uses, for details see the MySQL manual at dev.mysql.com/doc/refman/5.6/en/connecting.html. The raise option should be set to true if errors should be raised when encountered. To connect with a Unix socket rather than with TCP, specify host = `'unix/'` and port = socket-name.

Example, using a table literal enclosed in {braces}:

```
conn = mysql.connect({
    host = '127.0.0.1',
    port = 3306,
    user = 'p',
    password = 'p',
    db = 'test',
    raise = true
})
-- OR
conn = mysql.connect({
    host = 'unix/',
    port = '/var/run/mysqld/mysqld.sock'
})
```

Example, creating a function which sets each option in a separate line:

```
tarantool> -- Connection function. Usage: conn = mysql_connect()
tarantool> function mysql_connection()
         >   local p = {}
         >   p.host = 'widgets.com'
         >   p.db = 'test'
         >   conn = mysql.connect(p)
         >   return conn
         > end
---
...
tarantool> conn = mysql_connect()
---
...
```

We will assume that the name is 'conn' in further examples.

How to ping

To ensure that a connection is working, the request is:

connection-name:ping()

Example:

```
tarantool> conn:ping()
---
- true
...
```

Executing a statement

For all MySQL statements, the request is:

connection-name:execute(sql-statement [, parameters])

where sql-statement is a string, and the optional parameters are extra values that can be plugged in to replace any question marks ("?"s) in the SQL statement.

Example:

```
tarantool> conn:execute('select table_name from information_schema.tables')
---
- - table_name: ALL_PLUGINS
  - table_name: APPLICABLE_ROLES
  - table_name: CHARACTER_SETS
  <...>
- 78
...
```

Closing connection

To end a session that began with mysql.connect, the request is:

connection-name:close()

Example:

```
tarantool> conn:close()
---
...
```

For further information, including examples of rarely-used requests, see the README.md file at github.com/tarantool/mysql.

Example

The example was run on an Ubuntu 12.04 ("precise") machine where tarantool had been installed in a /usr subdirectory, and a copy of MySQL had been installed on ~/mysql-5.5. The mysqld server instance is already running on the local host 127.0.0.1.

```
$ export TMDIR=~/mysql-5.5
$ # Check that the include subdirectory exists by looking
$ # for .../include/mysql.h. (If this fails, there's a chance
$ # that it's in .../include/mysql/mysql.h instead.)
$ [ -f $TMDIR/include/mysql.h ] && echo "OK" || echo "Error"
OK

$ # Check that the library subdirectory exists and has the
$ # necessary .so file.
$ [ -f $TMDIR/lib/libmysqlclient.so ] && echo "OK" || echo "Error"
OK

$ # Check that the mysql client can connect using some factory
$ # defaults: port = 3306, user = 'root', user password = '',
$ # database = 'test'. These can be changed, provided one uses
$ # the changed values in all places.
$ $TMDIR/bin/mysql --port=3306 -h 127.0.0.1 --user=root \
    --password= --database=test
Welcome to the MySQL monitor.  Commands end with ; or \g.
Your MySQL connection id is 25
Server version: 5.5.35 MySQL Community Server (GPL)
...
Type 'help;' or '\h' for help. Type '\c' to clear ...

$ # Insert a row in database test, and quit.
mysql> CREATE TABLE IF NOT EXISTS test (s1 INT, s2 VARCHAR(50));
Query OK, 0 rows affected (0.13 sec)
mysql> INSERT INTO test.test VALUES (1,'MySQL row');
Query OK, 1 row affected (0.02 sec)
mysql> QUIT
Bye

$ # Install luarocks
$ sudo apt-get -y install luarocks | grep -E "Setting up|already"
Setting up luarocks (2.0.8-2) ...

$ # Set up the Tarantool rock list in ~/.luarocks,
$ # following instructions at rocks.tarantool.org
$ mkdir ~/.luarocks
$ echo "rocks_servers = {[[http://rocks.tarantool.org/]]}" >> \
    ~/.luarocks/config.lua

$ # Ensure that the next "install" will get files from Tarantool
$ # master repository. The resultant display is normal for Ubuntu
$ # 12.04 precise
$ cat /etc/apt/sources.list.d/tarantool.list
deb http://tarantool.org/dist/2.1/ubuntu/ precise main
deb-src http://tarantool.org/dist/2.1/ubuntu/ precise main

$ # Install tarantool-dev. The displayed line should show version = 2.1
$ sudo apt-get -y install tarantool-dev | grep -E "Setting up|already"
Setting up tarantool-dev (2.1.0.222.g48b98bb~precise-1) ...
$

$ # Use luarocks to install locally, that is, relative to $HOME
$ luarocks install mysql MYSQL_LIBDIR=/usr/local/mysql/lib --local
Installing http://rocks.tarantool.org/mysql-scm-1.rockspec...
```

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```
... (more info about building the Tarantool/MySQL driver appears here)
mysql scm-1 is now built and installed in ~/.luarocks/

$ # Ensure driver.so now has been created in a place
$ # tarantool will look at
$ find ~/.luarocks -name "driver.so"
~/.luarocks/lib/lua/5.1/mysql/driver.so

$ # Change directory to a directory which can be used for
$ # temporary tests. For this example we assume that the name
$ # of this directory is /home/pgulutzan/tarantool_sandbox.
$ # (Change "/home/pgulutzan" to whatever is the user's actual
$ # home directory for the machine that's used for this test.)
$ cd /home/pgulutzan/tarantool_sandbox

$ # Start the Tarantool server instance. Do not use a Lua initialization file.

$ tarantool
tarantool: version 2.1.0-222-g48b98bb
type 'help' for interactive help
tarantool>
```

Configure tarantool and load mysql module. Make sure that tarantool doesn't reply "error" for the call to "require()".

```
tarantool> box.cfg{}
...
tarantool> mysql = require('mysql')
---
...
```

Create a Lua function that will connect to the MySQL server instance, (using some factory default values for the port and user and password), retrieve one row, and display the row. For explanations of the statement types used here, read the Lua tutorial earlier in the Tarantool user manual.

```
tarantool> function mysql_select ()
         >   local conn = mysql.connect({
         >     host = '127.0.0.1',
         >     port = 3306,
         >     user = 'root',
         >     db = 'test'
         >   })
         >   local test = conn:execute('SELECT * FROM test WHERE s1 = 1')
         >   local row = ''
         >   for i, card in pairs(test) do
         >       row = row .. card.s2 .. ' '
         >       end
         >   conn:close()
         >   return row
         > end
---
...
tarantool> mysql_select()
---
- 'MySQL row '
...
```

Observe the result. It contains "MySQL row". So this is the row that was inserted into the MySQL database. And now it's been selected with the Tarantool client.

PostgreSQL Example

This example assumes that PostgreSQL 8 or PostgreSQL 9 has been installed. More recent versions should also work. The package that matters most is the PostgreSQL developer package, typically named something like libpq-dev. On Ubuntu this can be installed with:

```
$ sudo apt-get install libpq-dev
```

However, because not all platforms are alike, for this example the assumption is that the user must check that the appropriate PostgreSQL files are present and must explicitly state where they are when building the Tarantool/PostgreSQL driver. One can use find or whereis to see what directories PostgreSQL files are installed in.

It will be necessary to install Tarantool's PostgreSQL driver shared library, load it, and use it to connect to a PostgreSQL server instance. After that, one can pass any PostgreSQL statement to the server instance and receive results.

Installation

Check the instructions for downloading and installing a binary package that apply for the environment where Tarantool was installed. In addition to installing tarantool, install tarantool-dev. For example, on Ubuntu, add the line:

```
$ sudo apt-get install tarantool-dev
```

Now, for the PostgreSQL driver shared library, there are two ways to install:

With LuaRocks

Begin by installing luarocks and making sure that tarantool is among the upstream servers, as in the instructions on rocks.tarantool.org, the Tarantool luarocks page. Now execute this:

```
luarocks install pg [POSTGRESQL_LIBDIR = path]
                    [POSTGRESQL_INCDIR = path]
                    [--local]
```

For example:

```
$ luarocks install pg POSTGRESQL_LIBDIR=/usr/local/postgresql/lib
```

With GitHub

Go the site github.com/tarantool/pg. Follow the instructions there, saying:

```
$ git clone https://github.com/tarantool/pg.git
$ cd pg && cmake . -DCMAKE_BUILD_TYPE=RelWithDebInfo
$ make
$ make install
```

At this point it is a good idea to check that the installation produced a file named driver.so, and to check that this file is on a directory that is searched by the require request.

Connecting

Begin by making a require request for the pg driver. We will assume that the name is pg in further examples.

```
pg = require('pg')
```

Now, say:

connection_name = pg.connect(connection options)

The connection-options parameter is a table. Possible options are:

- host = host-name - string, default value = 'localhost'
- port = port-number - number, default value = 5432
- user = user-name - string, default value is operating-system user name
- pass = password or password = password - string, default value is blank
- db = database-name - string, default value is blank

The names are similar to the names that PostgreSQL itself uses.

Example, using a table literal enclosed in {braces}:

```
conn = pg.connect({
    host = '127.0.0.1',
    port = 5432,
    user = 'p',
    password = 'p',
    db = 'test'
})
```

Example, creating a function which sets each option in a separate line:

```
tarantool> function pg_connect()
         >   local p = {}
         >   p.host = 'widgets.com'
         >   p.db = 'test'
         >   p.user = 'postgres'
         >   p.password = 'postgres'
         >   local conn = pg.connect(p)
         >   return conn
         > end
---
...
tarantool> conn = pg_connect()
---
...
```

We will assume that the name is 'conn' in further examples.

How to ping

To ensure that a connection is working, the request is:

connection-name:ping()

Example:

```
tarantool> conn:ping()
---
- true
...
```

Executing a statement

For all PostgreSQL statements, the request is:

connection-name:execute(sql-statement [, parameters])

where sql-statement is a string, and the optional parameters are extra values that can be plugged in to replace any placeholders ($1 $2 $3 etc.) in the SQL statement.

Example:

```
tarantool> conn:execute('select tablename from pg_tables')
---
- - tablename: pg_statistic
  - tablename: pg_type
  - tablename: pg_authid
  <...>
...
```

Closing connection

To end a session that began with pg.connect, the request is:

connection-name:close()

Example:

```
tarantool> conn:close()
---
...
```

For further information, including examples of rarely-used requests, see the README.md file at github.com/tarantool/pg.

Example

The example was run on an Ubuntu 12.04 ("precise") machine where tarantool had been installed in a /usr subdirectory, and a copy of PostgreSQL had been installed on /usr. The PostgreSQL server instance is already running on the local host 127.0.0.1.

```
$ # Check that the include subdirectory exists
$ # by looking for /usr/include/postgresql/libpq-fe-h.
$ [ -f /usr/include/postgresql/libpq-fe.h ] && echo "OK" || echo "Error"
OK

```

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```
$ # Check that the library subdirectory exists and has the necessary .so file.
$ [ -f /usr/lib/x86_64-linux-gnu/libpq.so ] && echo "OK" || echo "Error"
OK

$ # Check that the psql client can connect using some factory defaults:
$ # port = 5432, user = 'postgres', user password = 'postgres',
$ # database = 'postgres'. These can be changed, provided one changes
$ # them in all places. Insert a row in database postgres, and quit.
$ psql -h 127.0.0.1 -p 5432 -U postgres -d postgres
Password for user postgres:
psql (9.3.10)
SSL connection (cipher: DHE-RSA-AES256-SHA, bits: 256)
Type "help" for help.

postgres=# CREATE TABLE test (s1 INT, s2 VARCHAR(50));
CREATE TABLE
postgres=# INSERT INTO test VALUES (1,'PostgreSQL row');
INSERT 0 1
postgres=# \q
$

$ # Install luarocks
$ sudo apt-get -y install luarocks | grep -E "Setting up|already"
Setting up luarocks (2.0.8-2) ...

$ # Set up the Tarantool rock list in ~/.luarocks,
$ # following instructions at rocks.tarantool.org
$ mkdir ~/.luarocks
$ echo "rocks_servers = {[[http://rocks.tarantool.org/]]}" >> \
        ~/.luarocks/config.lua

$ # Ensure that the next "install" will get files from Tarantool master
$ # repository. The resultant display is normal for Ubuntu 12.04 precise
$ cat /etc/apt/sources.list.d/tarantool.list
deb http://tarantool.org/dist/2.0/ubuntu/ precise main
deb-src http://tarantool.org/dist/2.0/ubuntu/ precise main

$ # Install tarantool-dev. The displayed line should show version = 2.0
$ sudo apt-get -y install tarantool-dev | grep -E "Setting up|already"
Setting up tarantool-dev (2.0.4.222.g48b98bb~precise-1) ...
$

$ # Use luarocks to install locally, that is, relative to $HOME
$ luarocks install pg POSTGRESQL_LIBDIR=/usr/lib/x86_64-linux-gnu --local
Installing http://rocks.tarantool.org/pg-scm-1.rockspec...
... (more info about building the Tarantool/PostgreSQL driver appears here)
pg scm-1 is now built and installed in ~/.luarocks/

$ # Ensure driver.so now has been created in a place
$ # tarantool will look at
$ find ~/.luarocks -name "driver.so"
~/.luarocks/lib/lua/5.1/pg/driver.so

$ # Change directory to a directory which can be used for
$ # temporary tests. For this example we assume that the
$ # name of this directory is $HOME/tarantool_sandbox.
```

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```
$ # (Change "$HOME" to whatever is the user's actual
$ # home directory for the machine that's used for this test.)
cd $HOME/tarantool_sandbox

$ # Start the Tarantool server instance. Do not use a Lua initialization file.

$ tarantool
tarantool: version 2.0.4-412-g803b15c
type 'help' for interactive help
tarantool>
```

Configure tarantool and load pg module. Make sure that tarantool doesn't reply "error" for the call to "require()".

```
tarantool> box.cfg{}
...
tarantool> pg = require('pg')
---
...
```

Create a Lua function that will connect to a PostgreSQL server, (using some factory default values for the port and user and password), retrieve one row, and display the row. For explanations of the statement types used here, read the Lua tutorial earlier in the Tarantool user manual.

```
tarantool> function pg_select ()
         >   local conn = pg.connect({
         >     host = '127.0.0.1',
         >     port = 5432,
         >     user = 'postgres',
         >     password = 'postgres',
         >     db = 'postgres'
         >   })
         >   local test = conn:execute('SELECT * FROM test WHERE s1 = 1')
         >   local row = ''
         >   for i, card in pairs(test) do
         >       row = row .. card.s2 .. ' '
         >       end
         >   conn:close()
         >   return row
         > end
---
...
tarantool> pg_select()
---
- 'PostgreSQL row '
...
```

Observe the result. It contains "PostgreSQL row". So this is the row that was inserted into the PostgreSQL database. And now it's been selected with the Tarantool client.

5.3.2 Module expirationd

For a commercial-grade example of a Lua rock that works with Tarantool, let us look at the source code of expirationd, which Tarantool supplies on GitHub with an Artistic license. The expirationd.lua program is lengthy (about 500 lines), so here we will only highlight the matters that will be enhanced by studying the full source later.

```
task.worker_fiber = fiber.create(worker_loop, task)
log.info("expiration: task %q restarted", task.name)
...
fiber.sleep(expirationd.constants.check_interval)
...
```

Whenever one hears "daemon" in Tarantool, one should suspect it's being done with a fiber. The program is making a fiber and turning control over to it so it runs occasionally, goes to sleep, then comes back for more.

```
for _, tuple in scan_space.index[0]:pairs(nil, {iterator = box.index.ALL}) do
...
    expiration_process(task, tuple)
...
    /* expiration_process() contains:
    if task.is_tuple_expired(task.args, tuple) then
    task.expired_tuples_count = task.expired_tuples_count + 1
    task.process_expired_tuple(task.space_id, task.args, tuple) */
```

The "for" instruction can be translated as "iterate through the index of the space that is being scanned", and within it, if the tuple is "expired" (for example, if the tuple has a timestamp field which is less than the current time), process the tuple as an expired tuple.

```
-- default process_expired_tuple function
local function default_tuple_drop(space_id, args, tuple)
    box.space[space_id]:delete(construct_key(space_id, tuple))
end
    /* construct_key() contains:
    local function construct_key(space_id, tuple)
        return fun.map(
            function(x) return tuple[x.fieldno] end,
            box.space[space_id].index[0].parts
        ):totable()
    end */
```

Ultimately the tuple-expiry process leads to default_tuple_drop() which does a "delete" of a tuple from its original space. First the fun fun module is used, specifically fun.map. Remembering that index[0] is always the space's primary key, and index[0].parts[N].fieldno is always the field number for key part N, fun.map() is creating a table from the primary-key values of the tuple. The result of fun.map() is passed to space_object:delete().

```
local function expirationd_run_task(name, space_id, is_tuple_expired, options)
...
```

At this point, if the above explanation is worthwhile, it is clear that expirationd.lua starts a background routine (fiber) which iterates through all the tuples in a space, sleeps cooperatively so that other fibers can operate at the same time, and – whenever it finds a tuple that has expired – deletes it from this space. Now the "expirationd_run_task()" function can be used in a test which creates sample data, lets the daemon run for a while, and prints results.

For those who like to see things run, here are the exact steps to get expirationd through the test.

1. Get expirationd.lua. There are standard ways – it is after all part of a standard rock – but for this purpose just copy the contents of expirationd.lua to a directory on the Lua path (type print(package.path) to see the Lua path).

2. Start the Tarantool server as described before.
3. Execute these requests:

```
fiber = require('fiber')
expd = require('expirationd')
box.cfg{}
e = box.schema.space.create('expirationd_test')
e:create_index('primary', {type = 'hash', parts = {1, 'unsigned'}})
e:replace{1, fiber.time() + 3}
e:replace{2, fiber.time() + 30}
function is_tuple_expired(args, tuple)
  if (tuple[2] < fiber.time()) then return true end
  return false
  end
expd.run_task('expirationd_test', e.id, is_tuple_expired)
retval = {}
fiber.sleep(2)
expd.task_stats()
fiber.sleep(2)
expd.task_stats()
expd.kill_task('expirationd_test')
e:drop()
os.exit()
```

The database-specific requests (cfg, space.create, create_index) should already be familiar.

The function which will be supplied to expirationd is is_tuple_expired, which is saying "if the second field of the tuple is less than the current time , then return true, otherwise return false".

The key for getting the rock rolling is expd = require('expirationd'). The require function is what reads in the program; it will appear in many later examples in this manual, when it's necessary to get a module that's not part of the Tarantool kernel, but is on the Lua path (package.path) or the C path (package.cpath). After the Lua variable expd has been assigned the value of the expirationd module, it's possible to invoke the module's run_task() function.

After sleeping for two seconds, when the task has had time to do its iterations through the spaces, expd.task_stats() will print out a report showing how many tuples have expired – "expired_count: 0".

After sleeping for two more seconds, expd.task_stats() will print out a report showing how many tuples have expired – "expired_count: 1". This shows that the is_tuple_expired() function eventually returned "true" for one of the tuples, because its timestamp field was more than three seconds old.

Of course, expirationd can be customized to do different things by passing different parameters, which will be evident after looking in more detail at the source code. Particularly important are {options} which can be added as a final parameter in expirationd.run_task:

- force (boolean) – run task even on replica. Default: force=false so ordinarily expirationd ignores replicas.
- tuples_per_iteration (integer) – number of tuples that will be checked by one iteration Default: tuples_per_iteration=1024.
- full_scan_time (number) – number of seconds required for full index scan Default: full_scan_time=3600.
- vinyl_assumed_space_len (integer) – assumed size of vinyl space, for the first iteration only. Default: vinyl_assumed_space_len=10000000.
- vinyl_assumed_space_len_factor (integer) – factor for recalculation of size of vinyl space. Default: vinyl_assumed_space_len_factor=2. (The size of a vinyl space cannot be easily calculated, so on the

first iteration it will be the "assumed" size, on the second iteration it will be "assumed" times "factor", on the third iteration it will be "assumed" times "factor" times factor", and so on.)

5.3.3 Module membership

This module is a membership library for Tarantool based on a gossip protocol.

This library builds a mesh from multiple Tarantool instances. The mesh monitors itself, helps members discover everyone else in the group and get notified about their status changes with low latency. It is built upon the ideas from Consul or, more precisely, the SWIM algorithm.

The membership module works over UDP protocol and can operate even before the box.cfg initialization.

Member data structure

A member is represented by the table with the following fields:

- uri (string) is a Uniform Resource Identifier.
- status (string) is a string that takes one of the values below.
  - alive: a member that replies to ping-messages is alive and well.
  - suspect: if any member in the group cannot get a reply from any other member, the first member asks three other alive members to send a ping-message to the member in question. If there is no response, the latter becomes a suspect.
  - dead: a suspect becomes dead after a timeout.
  - left: a member gets the left status after executing the leave() function.

  Note: The gossip protocol guarantees that every member in the group becomes aware of any status change in two communication cycles.

- incarnation (number) is a value incremented every time the instance is becomes a suspect, dead, or updates its payload.
- payload (table) is auxiliary data that can be used by various modules.
- timestamp (number) is a value of fiber.time64() which:
  - corresponds to the last update of status or incarnation;
  - is always local;
  - does not depend on other members' clock setting.

Below is an example of the table:

```
tarantool> membership.myself()
---
uri: localhost:33001
status: alive
incarnation: 1
payload:
    uuid: 2d00c500-2570-4019-bfcc-ab25e5096b73
timestamp: 1522427330993752
...
```

API reference

Below is a list of membership's common, encryption, subscription functions, and options.

Name	Use
Common functions	
init(advertise_host, port)	Initialize the membership module.
myself()	Get the member data structure of the current instance.
get_member(uri)	Get the member data structure for a given URI.
members()	Obtain a table with all members known to the current instance.
pairs()	Shorthand for pairs(membership.members()).
add_member(uri)	Add a member to the group.
probe_uri(uri)	Check if the member is in the group.
broadcast()	Discover members in LAN by sending a UDP broadcast message.
set_payload(key, value)	Update myself().payload and disseminate it.
leave()	Gracefully leave the group.
is_encrypted()	Check if encryption is enabled.
Encryption functions	
set_encryption_key(key)	Set the key for low-level message encryption.
get_encryption_key()	Retrieve the encryption key in use.
Subscription functions	
subscribe()	Subscribe for the members table updates.
unsubscribe()	Remove the subscription.
Options	
PROTOCOL_PERIOD_SECONDS	Direct ping period.
ACK_TIMEOUT_SECONDS	ACK message wait time.
ANTI_ENTROPY_PERIOD_SECONDS	Anti-entropy synchronization period.
SUSPECT_TIMEOUT_SECONDS	Timeout to mark a suspect dead.
NUM_FAILURE_DETECTION_SUBGROUPS	Number of members to ping a suspect indirectly.

Common functions:

membership.init(advertise_host, port)

Initialize the membership module. This binds a UDP socket to 0.0.0.0:<port>, sets the advertise_uri parameter to <advertise_host>:<port>, and incarnation to 1.

The init() function can be called several times, the old socket will be closed and a new one opened.

If the advertise_uri changes during the next init(), the old URI is considered DEAD. In order to leave the group gracefully, use the leave() function.

Parameters

- advertise_host (string) – a hostname or IP address to advertise to other members
- port (number) – a UDP port to bind

Return true

Rtype boolean

Raises socket bind error

membership.myself()

Return the member data structure of the current instance.

Rtype table

membership.get_member(uri)

Parameters

- uri (string) – the given member's advertise_uri

Return the member data structure of the instance with the given URI.

Rtype table

membership.members()

Obtain all members known to the current instance.

Editing this table has no effect.

Return a table with URIs as keys and corresponding member data structures as values.

Rtype table

membership.pairs()

A shorthand for pairs(membership.members()).

Return Lua iterator

It can be used in the following way:

```
for uri, member in memberhip.pairs()
  -- do something
end
```

membership.add_member(uri)

Add a member with the given URI to the group and propagate this event to other members. Adding a member to a single instance is enough as everybody else in the group will receive the update with time. It does not matter who adds whom.

Parameters

- uri (string) – the advertise_uri of the member to add

Return true or nil in case of an error

Rtype boolean

Raises parse error if the URI cannot be parsed

membership.probe_uri(uri)

Send a message to a member to make sure it is in the group. If the member is alive but not in the group, it is added. If it already is in the group, nothing happens.

Parameters

- uri (string) – the advertise_uri of the member to ping

Return true if the member responds within 0.2 seconds, otherwise no response

Rtype boolean

Raises ping was not sent if the hostname could not be resolved

membership.broadcast()

Discover members in local network by sending a UDP broadcast message to all networks discovered by a getifaddrs() C call.

Return true if broadcast was sent, false if getaddrinfo() fails.

Rtype boolean

membership.set_payload(key, value)

Update myself().payload and disseminate it along with the member status.

Increments incarnation.

Parameters

- key (string) – a key to set in payload table
- value – auxiliary data

Return true

Rtype boolean

membership.leave()

Gracefully leave the membership group. The node will be marked with the left status and no other members will ever try to reconnect it.

Return true

Rtype boolean

membership.is_encrypted()

Return true if encryption is enabled, false otherwise.

Rtype boolean

Encryption functions:

membership.set_encryption_key(key)

Set the key used for low-level message encryption. The key is either trimmed or padded automatically to be exactly 32 bytes. If the key value is nil, the encryption is disabled.

The encryption is handled by the crypto.cipher.aes256.cbc Tarantool module.

For proper communication, all members must be configured to use the same encryption key. Otherwise, members report either dead or non-decryptable in their status.

Parameters

- key (string) – encryption key

Return nil.

membership.get_encryption_key()

Retrieve the encryption key that is currently in use.

Return encryption key or nil if the encryption is disabled.

Rtype string

Subscription functions:

membership.subscribe()

Subscribe for updates in the members table.

Return a fiber.cond object broadcasted whenever the members table changes.

Rtype object

membership.unsubscribe(cond)

Remove subscription on cond obtained by the subscribe() function.

The cond's validity is not checked.

Parameters

- cond – the fiber.cond object obtained from subscribe()

Return nil.

Below is a list of membership options. They can be set as follows:

```
options = require('membership.options')
options.<option> = <value>
```

options.PROTOCOL_PERIOD_SECONDS
Period of sending direct pings. Denoted as `T'` in the SWIM protocol.

options.ACK_TIMEOUT_SECONDS
Time to wait for ACK message after a ping. If a member is late to reply, the indirect ping algorithm is invoked.

options.ANTI_ENTROPY_PERIOD_SECONDS
Period to perform the anti-entropy synchronization algorithm of the SWIM protocol.

options.SUSPECT_TIMEOUT_SECONDS
Timeout to mark suspect members as dead.

options.NUM_FAILURE_DETECTION_SUBGROUPS
Number of members to try pinging a suspect indirectly. Denoted as k in the SWIM protocol.

5.3.4 Module vshard

The vshard module introduces an advanced sharding feature based on the concept of virtual buckets and enables horizontal scaling in Tarantool.

Check out the Quick start guide – or dive into the complete vshard documentation:

Summary

Scaling databases in a growing project is often considered one of the most challenging issues. Once a single server cannot withstand the load, scaling methods should be applied.

Sharding is a database architecture that allows for horizontal scaling, which implies that a dataset is partitioned and distributed over multiple servers.

With Tarantool's vshard module, the tuples of a dataset are distributed across multiple nodes, with a Tarantool database server instance on each node. Each instance handles only a subset of the total data, so larger loads can be handled by simply adding more servers. The initial dataset is partitioned into multiple parts, so each part is stored on a separate server.

The vshard module is based on the concept of virtual buckets, where a tuple set is partitioned into a large number of abstract virtual nodes (virtual buckets, further just buckets) rather than into a smaller number of physical nodes.

The dataset is partitioned using sharding keys (bucket id numbers). Hashing a sharding key into a large number of buckets allows seamlessly changing the number of servers in the cluster. The rebalancing mechanism distributes buckets evenly among all shards in case some servers were added or removed.

The buckets have states, so it is easy to monitor the server states. For example, a server instance is active and available for all types of requests, or a failover occurred and the instance accepts only read requests.

The vshard module provides router and storage API (public and internal) for sharding-aware applications.

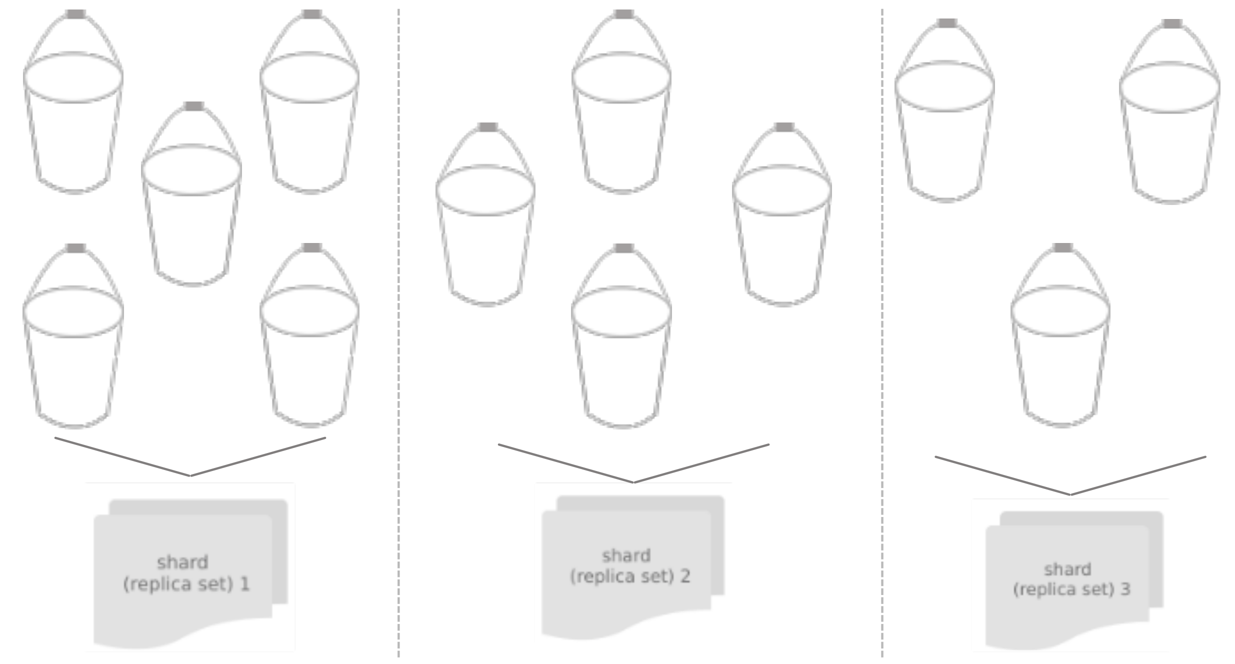
Architecture

Overview

Consider a distributed Tarantool cluster that consists of subclusters called shards, each storing some part of data. Each shard, in its turn, constitutes a replica set consisting of several replicas, one of which serves as a master node that processes all read and write requests.

The whole dataset is logically partitioned into a predefined number of virtual buckets (further just buckets), each assigned a unique number ranging from 1 to N, where N is the total number of buckets. The number of buckets is specifically chosen to be several orders of magnitude larger than the potential number of cluster nodes, even given future cluster scaling. For example, with M projected nodes the dataset may be split into 100 * M or even 1,000 * M buckets. Care should be taken when picking the number of buckets: if too large, it may require extra memory for storing the routing information; if too small, it may decrease the granularity of rebalancing.

Each shard stores a unique subset of buckets, which means that a bucket cannot belong to several shards at once, as illustrated below:



This shard-to-bucket mapping is stored in a table in one of Tarantool's system spaces, with each shard holding only a specific part of the mapping that covers those buckets that were assigned to this shard.

Apart from the mapping table, the bucket id is also stored in a special field of every tuple of every table participating in sharding.

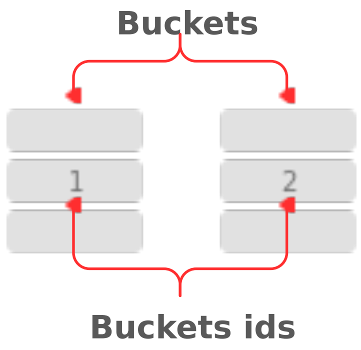
Once a shard receives any request (except for SELECT) from an application, this shard checks the bucket id specified in the request against the table of bucket ids that belong to a given node. If the specified bucket id is invalid, the request gets terminated with the following error: "wrong bucket". Otherwise the request is executed, and all the data created in the process is assigned the bucket id specified in the request. Note that the request should only modify the data that has the same bucket id as the request itself.

Storing bucket ids both in the data itself and the mapping table ensures data consistency regardless of the application logic and makes rebalancing transparent for the application. Storing the mapping table in a system space ensures sharding is performed consistently in case of a failover, as all the replicas in a shard share a common table state.

Virtual buckets

The sharded dataset is partitioned into a large number of abstract nodes called virtual buckets (further just buckets).

The dataset is partitioned using the sharding key (or bucket id, in Tarantool terminology). Bucket id is a number from 1 to N, where N is the total number of buckets.



Each replica set stores a unique subset of buckets. One bucket cannot belong to multiple replica sets at a time.

The total number of buckets is determined by the administrator who sets up the initial cluster configuration.

Every space you plan to shard must have a numeric field containing bucket id-s. This field must comply with the following requirements:

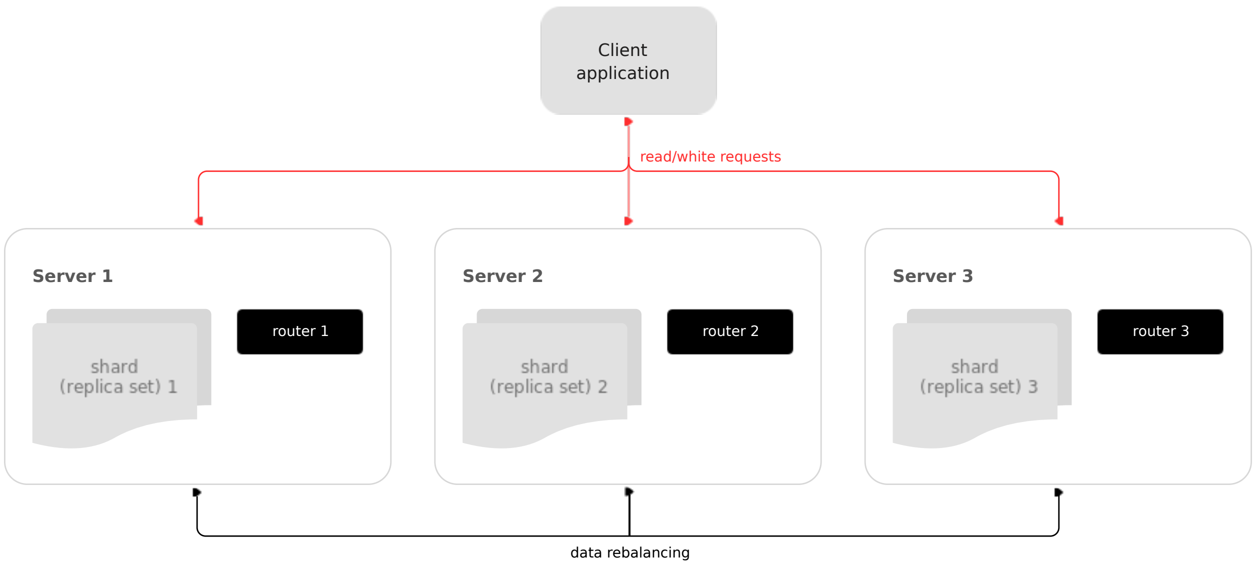
- The field's data type can be: unsigned, number or integer.
- The field must be not nullable.
- The field must be indexed by the shard_index. The default name for this index is bucket_id.

See the configuration example.

Structure

A sharded cluster in Tarantool consists of:

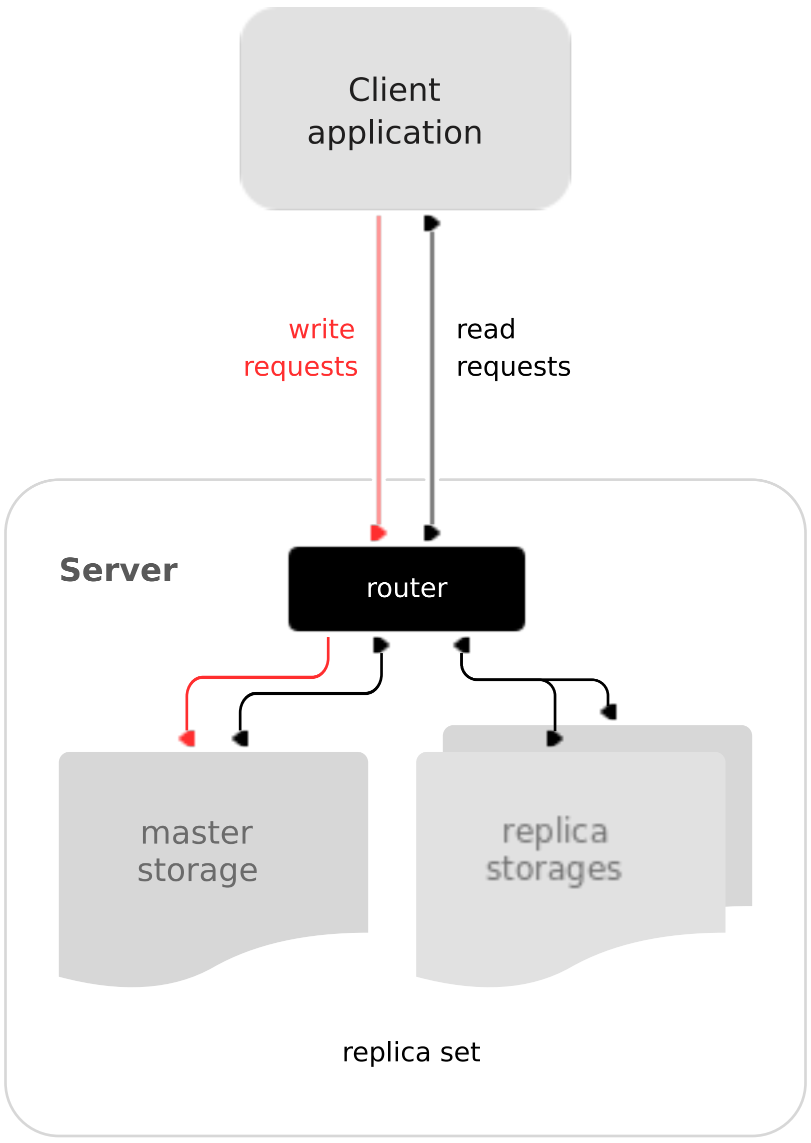
- storages,
- routers,
- and a rebalancer.



Storage

Storage is a node storing a subset of the dataset. Multiple replicated (for redundancy) storages comprise a replica set (also called shard).

Each storage in a replica set has a role, master or replica. A master processes read and write requests. A replica processes read requests but cannot process write requests.



Router

Router is a standalone software component that routes read and write requests from the client application to shards.

All requests from the application come to the sharded cluster through a router. The router keeps the topology of a sharded cluster transparent for the application, thus keeping the application unaware of:

- the number and location of shards,
- data rebalancing process,
- the fact and the process of a failover that occurred after a replica's failure.

A router can also calculate a bucket id on its own provided that the application clearly defines rules for calculating a bucket id based on the request data. To do it, a router needs to be aware of the data schema.

The router does not have a persistent state, nor does it store the cluster topology or balance the data. The router is a standalone software component that can run in the storage layer or application layer depending on the application features.

A router maintains a constant pool of connections to all the storages that is created at startup. Creating it this way helps avoid configuration errors. Once a pool is created, a router caches the current state of the _vbucket table to speed up the routing. In case a bucket id is moved to another storage as a result of data rebalancing, or one of the shards fails over to a replica, a router updates the routing table in a way that's transparent for the application.

Sharding is not integrated into any centralized configuration storage system. It is assumed that the application itself handles all the interactions with such systems and passes sharding parameters. That said, the configuration can be changed dynamically - for example, when adding or deleting one or several shards:

1. To add a new shard to the cluster, a system administrator first changes the configuration of all the routers and then the configuration of all the storages.
2. The new shard becomes available to the storage layer for rebalancing.
3. As a result of rebalancing, one of the vbuckets is moved to the new shard.
4. When trying to access the vbucket, a router receives a special error code that specifies the new vbucket location.

CRUD (create, replace, update, delete) operations

CRUD operations can be:

- executed in a stored procedure inside a storage, or
- initialized by the application.

In any case, the application must include the operation bucket id in a request. When executing an INSERT request, the operation bucket id is stored in a newly created tuple. In other cases, it is checked if the specified operation bucket id matches the bucket id of a tuple being modified.

SELECT requests

Since a storage is not aware of the mapping between a bucket id and a primary key, all the SELECT requests executed in stored procedures inside a storage are only executed locally. Those SELECT requests that were initialized by the application are forwarded to a router. Then, if the application has passed a bucket id, a router uses it for shard calculation.

Calling stored procedures

There are several ways of calling stored procedures in cluster replica sets. Stored procedures can be called:

- on a specific vbucket located in a replica set (in this case, it is necessary to differentiate between read and write procedures, as write procedures are not applicable to vbuckets that are being migrated), or
- without specifying any particular vbucket.

All the routing validity checks performed for sharded DML operations hold true for vbucket-bound stored procedures as well.

Rebalancer

Rebalancer is a background rebalancing process that ensures an even distribution of buckets across the shards. During rebalancing, buckets are being migrated among replica sets.

The rebalancer "wakes up" periodically and redistributes data from the most loaded nodes to less loaded nodes. Rebalancing starts if the disbalance threshold of a replica set exceeds a disbalance threshold specified in the configuration.

The disbalance threshold is calculated as follows:

```
|etalon_bucket_number - real_bucket_number| / etalon_bucket_number * 100
```

Migration of buckets

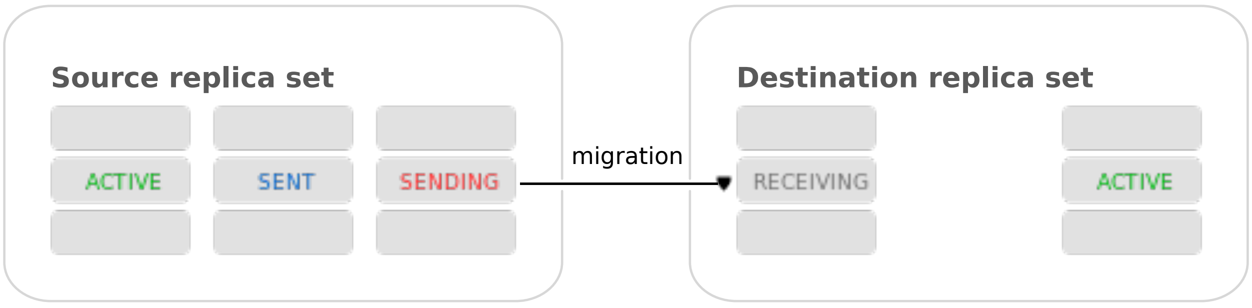
A replica set from which the bucket is being migrated is called a source ; a target replica set to which the bucket is being migrated is called a destination.

A replica set lock makes a replica set invisible to the rebalancer. A locked replica set can neither receive new buckets nor migrate its own buckets.

While a bucket is being migrated, it can have different states:

- ACTIVE – the bucket is available for read and write requests.
- PINNED – the bucket is locked for migrating to another replica set. Otherwise pinned buckets are similar to buckets in the ACTIVE state.
- SENDING – the bucket is currently being copied to the destination replica set; read requests to the source replica set are still processed.
- RECEIVING – the bucket is currently being filled; all requests to it are rejected.
- SENT – the bucket was migrated to the destination replica set. The router uses the SENT state to calculate the new location of the bucket. A bucket in the SENT state goes to the GARBAGE state automatically after BUCKET_SENT_GARBAGE_DELAY seconds, which by default is 0.5 seconds.
- GARBAGE – the bucket was already migrated to the destination replica set during rebalancing; or the bucket was initially in the RECEIVING state, but some error occurred during the migration.

Buckets in the GARBAGE state are deleted by the garbage collector.



Migration is performed as follows:

1. At the destination replica set, a new bucket is created and assigned the RECEIVING state, the data copying starts, and the bucket rejects all requests.
2. The source bucket in the source replica set is assigned the SENDING state, and the bucket continues to process read requests.

3. Once the data is copied, the bucket on the source replica set is assigned the SENT and it starts rejecting all requests.
4. The bucket on the destination replica set is assigned the ACTIVE state and starts accepting all requests.

Note: There is a specific error vshard.error.code.TRANSFER_IS_IN_PROGRESS that returns in case a request tries to perform an action not applicable to a bucket which is being relocated. You need to retry the request in this case.

The _bucket system space

The _bucket system space of each replica set stores the ids of buckets present in the replica set. The space contains the following fields:

- bucket – bucket id
- status – state of the bucket
- destination – UUID of the destination replica set

An example of _bucket.select{}:

```
---
- - [1, ACTIVE, abfe2ef6-9d11-4756-b668-7f5bc5108e2a]
  - [2, SENT, 19f83dcb-9a01-45bc-a0cf-b0c5060ff82c]
...
```

Once the bucket is migrated, the destination replica set identified by UUID is filled in the table. While the bucket is still located on the source replica set, the value of the destination replica set UUID is equal to NULL.

The routing table

A routing table on the router stores the map of all bucket ids to replica sets. It ensures the consistency of sharding in case of failover.

The router keeps a persistent pool of connections to all the storages that are created at startup. This helps prevent configuration errors. Once the connection pool is created, the router caches the current state of the routing table in order to speed up routing. If a bucket migrated to another storage after rebalancing, or a failover occurred and caused one of the shards switching to another replica, the discovery fiber on the router updates the routing table automatically.

As the bucket id is explicitly indicated both in the data and in the mapping table on the router, the data is consistent regardless of the application logic. It also makes rebalancing transparent for the application.

Processing requests

Requests to the database can be performed by the application or using stored procedures. Either way, the bucket id should be explicitly specified in the request.

All requests are forwarded to the router first. The only operation supported by the router is call. The operation is performed via the vshard.router.call() function:

```
result = vshard.router.call(<bucket_id>, <mode>, <function_name>, {<argument_list>}, {<opts>})
```

Requests are processed as follows:

1. The router uses the bucket id to search for a replica set with the corresponding bucket in the routing table.

   If the map of the bucket id to the replica set is not known to the router (the discovery fiber hasn't filled the table yet), the router makes requests to all storages to find out where the bucket is located.

2. Once the bucket is located, the shard checks:

   - whether the bucket is stored in the _bucket system space of the replica set;
   - whether the bucket is ACTIVE or PINNED (for a read request, it can also be SENDING).

3. If all the checks succeed, the request is executed. Otherwise, it is terminated with the error: "wrong bucket".

Glossary

Vertical scaling Adding more power to a single server: using a more powerful CPU, adding more capacity to RAM, adding more storage space, etc.

Horizontal scaling Adding more servers to the pool of resources, then partitioning and distributing a dataset across the servers.

Sharding A database architecture that allows partitioning a dataset using a sharding key and distributing a dataset across multiple servers. Sharding is a special case of horizontal scaling.

Node A virtual or physical server instance.

Cluster A set of nodes that make up a single group.

Storage A node storing a subset of a dataset.

Replica set A set of storage nodes storing copies of a dataset. Each storage in a replica set has a role, master or replica.

Master A storage in a replica set processing read and write requests.

Replica A storage in a replica set processing only read requests.

Read requests Read-only requests, that is, select requests.

Write requests Data-change operations, that is create, replace, update, delete requests.

Buckets (virtual buckets) The abstract virtual nodes into which the dataset is partitioned by the sharding key (bucket id).

Bucket id A sharding key defining which bucket belongs to which replica set. A bucket id may be calculated from a hash key.

Router A proxy server responsible for routing requests from an application to nodes in a cluster.

Administration

Installation

The vshard module is distributed separately from the main Tarantool package. To install it, say this:

```
$ tarantoolctl rocks install vshard
```

Note: The vshard module requires Tarantool version 1.9+, Tarantool development package, git, cmake and gcc packages installed.

Configuration

Any viable sharded cluster consists of:

- one or more replica sets, each containing two or more storage instances,
- one or more router instances.

The number of storage instances in a replica set defines the redundancy factor of the data. The recommended value is 3 or more. The number of router instances is not limited, because routers are completely stateless. We recommend increasing the number of routers when an existing router instance becomes CPU or I/O bound.

vshard supports multiple router instances on a single Tarantool instance. Each router can be connected to any vshard cluster. Multiple router instances can be connected to the same cluster.

As the router and storage applications perform completely different sets of functions, they should be deployed to different Tarantool instances. Although it is technically possible to place the router application on every storage node, this approach is highly discouraged and should be avoided on production deployments.

All storage instances can be deployed using identical instance (configuration) files.

Self-identification is currently performed using tarantoolctl:

```
$ tarantoolctl instance_name
```

All router instances can also be deployed using identical instance (configuration) files.

All cluster nodes must share a common topology. An administrator must ensure that the configurations are identical. We suggest using a configuration management tool like Ansible or Puppet to deploy the cluster.

Sharding is not integrated into any system for centralized configuration management. It is expected that the application itself is responsible for interacting with such a system and passing the sharding parameters.

The configuration example of a simple sharded cluster is available here.

Replica weights

The router sends all read-write requests to the master instance only. Setting replica weights allows sending read-only requests not only to the master instance, but to any available replica that is the 'nearest' to the router. Weights are used to define distances between replicas within a replica set.

Weights can be used, for example, to define the physical distance between the router and each replica in each replica set. In this case read requests are sent to the nearest replica (with the lowest weight).

Setting weights can also help to define the most powerful replicas: the ones that can process the largest number of requests per second.

The idea is to specify the zone for every router and every replica, therefore filling a matrix of relative zone weights. This approach allows setting different weights in different zones for the same replica set.

To set weights, use the zone attribute for each replica during configuration:

```
local cfg = {
  sharding = {
    ['...replicaset_uuid...'] = {
      replicas = {
        ['...replica_uuid...'] = {
          ...,
          zone = <number or string>
        }
      }
    }
  }
}
```

Then, specify relative weights for each zone pair in the weights parameter of vshard.router.cfg. For example:

```
weights = {
   [1] = {
      [2] = 1, -- Routers of the 1st zone see the weight of the 2nd zone as 1.
      [3] = 2, -- Routers of the 1st zone see the weight of the 3rd zone as 2.
      [4] = 3, -- ...
   },
   [2] = {
      [1] = 10,
      [2] = 0,
      [3] = 10,
      [4] = 20,
   },
   [3] = {
      [1] = 100,
      [2] = 200, -- Routers of the 3rd zone see the weight of the 2nd zone as 200.
                 -- Mind that it is not equal to the weight of the 2nd zone visible
                 -- from the 1st zone (= 1).
      [4] = 1000,
   }
}

local cfg = vshard.router.cfg({weights = weights, sharding = ...})
```

Replica set weights

A replica set weight is not the same as the replica weight. The weight of a replica set defines the capacity of the replica set: the larger the weight, the more buckets the replica set can store. The total size of all sharded spaces in the replica set is also its capacity metric.

You can consider replica set weights as the relative amount of data within a replica set. For example, if replicaset_1 = 100, and replicaset_2 = 200, the second replica set stores twice as many buckets as the first one. By default, all weights of all replica sets are equal.

You can use weights, for example, to store the prevailing amount of data on a replica set with more memory space.

Rebalancing process

There is an etalon number of buckets for a replica set. (Etalon in this context means "ideal".) If there is no deviation from this number in the whole replica set, then the buckets are distributed evenly.

The etalon number is calculated automatically considering the number of buckets in the cluster and weights of the replica sets.

Rebalancing starts if the disbalance threshold of a replica set exceeds the disbalance threshold specified in the configuration.

The disbalance threshold of a replica set is calculated as follows:

```
|etalon_bucket_number - real_bucket_number| / etalon_bucket_number * 100
```

For example: The user specified the number of buckets is 3000, and weights of 3 replica sets are 1, 0.5, and 1.5. The resulting etalon numbers of buckets for the replica sets are: 1st replica set – 1000, 2nd replica set – 500, 3rd replica set – 1500.

This approach allows assigning a zero weight to a replica set, which initiates migration of its buckets to the remaining cluster nodes. It also allows adding a new zero-load replica set, which initiates migration of the buckets from the loaded replica sets to the zero-load replica set.

Note: A new zero-load replica set should be assigned a weight for rebalancing to start.

When a new shard is added, the configuration can be updated dynamically:

1. The configuration should be updated on all the routers first, and then on all the storages.
2. The new shard becomes available for rebalancing in the storage layer.
3. As a result of rebalancing, buckets are migrated to the new shard.
4. If a migrated bucket is requested, router receives an error code containing information about the new location of the bucket.

At this time, the new shard is already present in the router's pool of connections, so redirection is transparent for the application.

Parallel rebalancing

Originally, vshard had quite a simple rebalancer – one process on one node that calculated routes which should send buckets, how many, and to whom. The nodes applied these routes one by one sequentially.

Unfortunately, such a simple schema worked not fast enough, especially for Vinyl, where costs of reading disk were comparable with network costs. In fact, with Vinyl the rebalancer routes applier was sleeping most of the time.

Now each node can send multiple buckets in parallel in a round-robin manner to multiple destinations, or to just one.

To set the degree of parallelism, a new option was added – rebalancer_max_sending. You can specify it in a storage configuration in the root table:

```
cfg.rebalancer_max_sending = 5
vshard.storage.cfg(cfg, box.info.uuid)
```

In routers, this option is ignored.

Note: Specifying cfg.rebalancer_max_sending = N probably won't give N times speed up. It depends on network, disk, number of other fibers in the system.

Example #1:

> You have 10 replica sets and a new one is added. Now all the 10 replica sets will try to send buckets to the new one.
>
> Assume that each replica set can send up to 5 buckets at once. In that case, the new replica set will experience a rather big load of 50 buckets being downloaded at once. If the node needs to do some other work, perhaps such a big load is undesirable. Also too many parallel buckets can cause timeouts in the rebalancing process itself.
>
> To fix the problem, you can set a lower value for rebalancer_max_sending for old replica sets, or decrease rebalancer_max_receiving for the new one. In the latter case some workers on old nodes will be throttled, and you will see that in the logs.

rebalancer_max_sending is important, if you have restrictions for the maximal number of buckets that can be read-only at once in the cluster. As you remember, when a bucket is being sent, it does not accept new write requests.

Example #2:

> You have 100000 buckets and each bucket stores ~0.001% of your data. The cluster has 10 replica sets. And you never can afford > 0.1% of data locked on write. Then you should not set rebalancer_max_sending > 10 on these nodes. It guarantees that the rebalancer won't send more than 100 buckets at once in the whole cluster.

If max_sending is too high and max_receiving is too low, then some buckets will try to get relocated – and will fail with that. This problem will consume network resources and time. It is important to configure these parameters to not conflict with each other.

Replica set lock and bucket pin

A replica set lock makes a replica set invisible to the rebalancer: a locked replica set can neither receive new buckets nor migrate its own buckets.

A bucket pin blocks a specific bucket from migrating: a pinned bucket stays on the replica set to which it is pinned, until it is unpinned.

Pinning all replica set buckets is not equivalent to locking a replica set. Even if you pin all buckets, a non-locked replica set can still receive new buckets.

Replica set lock is helpful, for example, to separate a replica set from production replica sets for testing, or to preserve some application metadata that must not be sharded for a while. A bucket pin is used for similar cases but in a smaller scope.

By both locking a replica set and pinning all buckets, one can isolate an entire replica set.

Locked replica sets and pinned buckets affect the rebalancing algorithm as the rebalancer must ignore locked replica sets and consider pinned buckets when attempting to reach the best possible balance.

The issue is not trivial as a user can pin too many buckets to a replica set, so a perfect balance becomes unreachable. For example, consider the following cluster (assume all replica set weights are equal to 1).

The initial configuration:

```
rs1: bucket_count = 150
rs2: bucket_count = 150, pinned_count = 120
```

Adding a new replica set:

```
rs1: bucket_count = 150
rs2: bucket_count = 150, pinned_count = 120
rs3: bucket_count = 0
```

The perfect balance would be 100 - 100 - 100, which is impossible since the rs2 replica set has 120 pinned buckets. The best possible balance here is the following:

```
rs1: bucket_count = 90
rs2: bucket_count = 120, pinned_count 120
rs3: bucket_count = 90
```

The rebalancer moved as many buckets as possible from rs2 to decrease the disbalance. At the same time it respected equal weights of rs1 and rs3.

The algorithms for implementing locks and pins are completely different, although they look similar in terms of functionality.

Replica set lock and rebalancing

Locked replica sets simply do not participate in rebalancing. This means that even if the actual total number of buckets is not equal to the etalon number, the disbalance cannot be fixed due to the lock. When the rebalancer detects that one of the replica sets is locked, it recalculates the etalon number of buckets of the non-locked replica sets as if the locked replica set and its buckets did not exist at all.

Bucket pin and rebalancing

Rebalancing replica sets with pinned buckets requires a more complex algorithm. Here pinned_count[o] is the number of pinned buckets, and etalon_count is the etalon number of buckets for a replica set:

1. The rebalancer calculates the etalon number of buckets as if all buckets were not pinned. Then the rebalancer checks each replica set and compares the etalon number of buckets with the number of pinned buckets in a replica set. If pinned_count < etalon_count, non-locked replica sets (at this point all locked replica sets already are filtered out) with pinned buckets can receive new buckets.
2. If pinned_count > etalon_count, the disbalance cannot be fixed, as the rebalancer cannot move pinned buckets out of this replica set. In such a case the etalon number is updated and set equal to the number of pinned buckets. The replica sets with pinned_count > etalon_count are not processed by the rebalancer, and the number of pinned buckets is subtracted from the total number of buckets. The rebalancer tries to move out as many buckets as possible from such replica sets.
3. This procedure is restarted from step 1 for replica sets with pinned_count >= etalon_count until pinned_count <= etalon_count on all replica sets. The procedure is also restarted when the total number of buckets is changed.

Here is the pseudocode for the algorithm:

```
function cluster_calculate_perfect_balance(replicasets, bucket_count)
        -- rebalance the buckets using weights of the still viable replica sets --
end;

cluster = <all of the non-locked replica sets>;
bucket_count = <the total number of buckets in the cluster>;
can_reach_balance = false
while not can_reach_balance do
        can_reach_balance = true
```

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```
        cluster_calculate_perfect_balance(cluster, bucket_count);
        foreach replicaset in cluster do
                if replicaset.perfect_bucket_count <
                   replicaset.pinned_bucket_count then
                        can_reach_balance = false
                        bucket_count -= replicaset.pinned_bucket_count;
                        replicaset.perfect_bucket_count =
                                replicaset.pinned_bucket_count;
                end;
        end;
end;
cluster_calculate_perfect_balance(cluster, bucket_count);
```

The complexity of the algorithm is O(N^2), where N is the number of replica sets. On each step, the algorithm either finishes the calculation, or ignores at least one new replica set overloaded with the pinned buckets, and updates the etalon number of buckets on other replica sets.

Bucket ref

Bucket ref is an in-memory counter that is similar to the bucket pin, but has the following differences:

1. Bucket ref is not persistent. Refs are intended for forbidding bucket transfer during request execution, but on restart all requests are dropped.
2. There are two types of bucket refs: read-only (RO) and read-write (RW).

   If a bucket has RW refs, it cannot be moved. However, when the rebalancer needs it to be sent, it locks the bucket for new write requests, waits until all current requests are finished, and then sends the bucket.

   If a bucket has RO refs, it can be sent, but cannot be dropped. Such a bucket can even enter GARBAGE or SENT state, but its data is kept until the last reader is gone.

   A single bucket can have both RO and RW refs.
3. Bucket ref is countable.

The vshard.storage.bucket_ref/unref() methods are called automatically when vshard.router.call() or vshard.storage.call() is used. For raw API like r = vshard.router.route() r:callro/callrw you should explicitly call the bucket_ref() method inside the function. Also, make sure that you call bucket_unref() after bucket_ref(), otherwise the bucket cannot be moved from the storage until the instance restart.

To see how many refs there are for a bucket, use vshard.storage.buckets_info([bucket_id]) (the bucket_id parameter is optional).

For example:

```
vshard.storage.buckets_info(1)
---
- 1:
    status: active
    ref_rw: 1
    ref_ro: 1
    ro_lock: true
    rw_lock: true
    id: 1
```

Defining spaces

Database Schema is stored on storages, while routers know nothing about spaces and tuples.

Spaces should be defined within a storage application using box.once(). For example:

```
box.once("testapp:schema:1", function()
    local customer = box.schema.space.create('customer')
    customer:format({
        {'customer_id', 'unsigned'},
        {'bucket_id', 'unsigned'},
        {'name', 'string'},
    })
    customer:create_index('customer_id', {parts = {'customer_id'}})
    customer:create_index('bucket_id', {parts = {'bucket_id'}, unique = false})

    local account = box.schema.space.create('account')
    account:format({
        {'account_id', 'unsigned'},
        {'customer_id', 'unsigned'},
        {'bucket_id', 'unsigned'},
        {'balance', 'unsigned'},
        {'name', 'string'},
    })
    account:create_index('account_id', {parts = {'account_id'}})
    account:create_index('customer_id', {parts = {'customer_id'}, unique = false})
    account:create_index('bucket_id', {parts = {'bucket_id'}, unique = false})
    box.snapshot()

    box.schema.func.create('customer_lookup')
    box.schema.role.grant('public', 'execute', 'function', 'customer_lookup')
    box.schema.func.create('customer_add')
end)
```

Note: Every space you plan to shard must have a field with bucket id numbers, indexed by the shard index.

Adding data

All DML operations with data should be performed via router. The only operation supported by router is CALL via bucket_id:

```
result = vshard.router.call(bucket_id, mode, func, args)
```

vshard.router.call() routes result = func(unpack(args)) call to a shard which serves bucket_id.

bucket_id is just a regular number in the range 1..bucket_count. This number can be assigned in an arbitrary way by the client application. A sharded Tarantool cluster uses this number as an opaque unique identifier to distribute data across replica sets. It is guaranteed that all records with the same bucket_id will be stored on the same replica set.

Bootstrapping and restarting a storage

If a replica set master fails, it is recommended to:

1. Switch one of the replicas into the master mode. This allows the new master to process all the incoming requests.
2. Update the configuration of all the cluster members. This forwards all the requests to the new master.

Monitoring the master and switching the instance modes can be handled by any external utility.

To perform a scheduled downtime of a replica set master, it is recommended to:

1. Update the configuration of the master and wait for the replicas to get into sync. All the requests then are forwarded to a new master.
2. Switch another instance into the master mode.
3. Update the configuration of all the nodes.
4. Shut down the old master.

To perform a scheduled downtime of a replica set, it is recommended to:

1. Migrate all the buckets to the other cluster storages.
2. Update the configuration of all the nodes.
3. Shut down the replica set.

In case a whole replica set fails, some part of the dataset becomes inaccessible. Meanwhile, the router tries to reconnect to the master of the failed replica set. This way, once the replica set is up and running again, the cluster is automatically restored.

Fibers

Searches for buckets, buckets recovery, and buckets rebalancing are performed automatically and do not require manual intervention.

Technically, there are multiple fibers responsible for different types of operations:

- a discovery fiber on the router searches for buckets in the background
- a failover fiber on the router maintains replica connections
- a garbage collector fiber on each master storage removes the contents of buckets that were moved
- a bucket recovery fiber on each master storage recovers buckets in the SENDING and RECEIVING states in case of reboot
- a rebalancer on a single master storage among all replica sets executes the rebalancing process.

See the Rebalancing process and Migration of buckets sections for details.

Garbage collector

A garbage collector fiber runs in the background on the master storages of each replica set. It starts deleting the contents of the bucket in the GARBAGE state part by part. Once the bucket is empty, its record is deleted from the _bucket system space.

Bucket recovery

A bucket recovery fiber runs on the master storages. It helps to recover buckets in the SENDING and RECEIVING states in case of reboot.

Buckets in the SENDING state are recovered as follows:

1. The system first searches for buckets in the SENDING state.
2. If such a bucket is found, the system sends a request to the destination replica set.
3. If the bucket on the destination replica set is ACTIVE, the original bucket is deleted from the source node.

Buckets in the RECEIVING state are deleted without extra checks.

Failover

A failover fiber runs on every router. If a master of a replica set becomes unavailable, the failover fiber redirects read requests to the replicas. Write requests are rejected with an error until the master becomes available.

Quick start guide

For installation instructions, check out the vshard installation manual.

For a pre-configured development cluster, check out the example/ directory in the vshard repository. This example includes 5 Tarantool instances and 2 replica sets:

- router_1 – a router instance
- storage_1_a – a storage instance, the master of the first replica set
- storage_1_b – a storage instance, the replica of the first replica set
- storage_2_a – a storage instance, the master of the second replica set
- storage_2_b – a storage instance, the replica of the second replica set

All instances are managed using the tarantoolctl utility which comes with Tarantool.

Change the directory to example/ and use make to run the development cluster:

```
$ cd example/
$ make
tarantoolctl stop storage_1_a  # stop the first storage instance
Stopping instance storage_1_a...
tarantoolctl stop storage_1_b
<...>
rm -rf data/
tarantoolctl start storage_1_a # start the first storage instance
Starting instance storage_1_a...
Starting configuration of replica 8a274925-a26d-47fc-9e1b-af88ce939412
I am master
Taking on replicaset master role...
Run console at unix/:./data/storage_1_a.control
started
mkdir ./data/storage_1_a
<...>
tarantoolctl start router_1 # start the router
Starting instance router_1...
Starting router configuration
Calling box.cfg()...
<...>
```

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```
Run console at unix/:./data/router_1.control
started
mkdir ./data/router_1
Waiting cluster to start
echo "vshard.router.bootstrap()" | tarantoolctl enter router_1
connected to unix/:./data/router_1.control
unix/:./data/router_1.control> vshard.router.bootstrap()
---
- true
...
unix/:./data/router_1.control>
tarantoolctl enter router_1 # enter the admin console
connected to unix/:./data/router_1.control
unix/:./data/router_1.control>
```

Some tarantoolctl commands:

- tarantoolctl start router_1 – start the router instance
- tarantoolctl enter router_1 – enter the admin console

The full list of tarantoolctl commands for managing Tarantool instances is available in the tarantoolctl reference.

Essential make commands you need to know:

- make start – start all Tarantool instances
- make stop – stop all Tarantool instances
- make logcat – show logs from all instances
- make enter – enter the admin console on router_1
- make clean – clean up all persistent data
- make test – run the test suite (you can also run test-run.py in the test directory)
- make – execute make stop, make clean, make start and make enter

For example, to start all instances, use make start:

```
$ make start
$ ps x|grep tarantool
46564   ??  Ss     0:00.34 tarantool storage_1_a.lua <running>
46566   ??  Ss     0:00.19 tarantool storage_1_b.lua <running>
46568   ??  Ss     0:00.35 tarantool storage_2_a.lua <running>
46570   ??  Ss     0:00.20 tarantool storage_2_b.lua <running>
46572   ??  Ss     0:00.25 tarantool router_1.lua <running>
```

To perform commands in the admin console, use the router's public API:

```
unix/:./data/router_1.control> vshard.router.info()
---
- replicasets:
    ac522f65-aa94-4134-9f64-51ee384f1a54:
      replica: &0
        network_timeout: 0.5
        status: available
        uri: storage@127.0.0.1:3303
        uuid: 1e02ae8a-afc0-4e91-ba34-843a356b8ed7
```

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```
      uuid: ac522f65-aa94-4134-9f64-51ee384f1a54
      master: *0
    cbf06940-0790-498b-948d-042b62cf3d29:
      replica: &1
        network_timeout: 0.5
        status: available
        uri: storage@127.0.0.1:3301
        uuid: 8a274925-a26d-47fc-9e1b-af88ce939412
      uuid: cbf06940-0790-498b-948d-042b62cf3d29
      master: *1
  bucket:
    unreachable: 0
    available_ro: 0
    unknown: 0
    available_rw: 3000
  status: 0
  alerts: []
...
```

Sample configuration

The configuration of a simple sharded cluster can look like this:

```
local cfg = {
    memtx_memory = 100 * 1024 * 1024,
    replication_connect_quorum = 0,
    bucket_count = 10000,
    rebalancer_disbalance_threshold = 10,
    rebalancer_max_receiving = 100,
    sharding = {
        ['cbf06940-0790-498b-948d-042b62cf3d29'] = {
            replicas = {
                ['8a274925-a26d-47fc-9e1b-af88ce939412'] = {
                    uri = 'storage:storage@127.0.0.1:3301',
                    name = 'storage_1_a',
                    master = true
                },
                ['3de2e3e1-9ebe-4d0d-abb1-26d301b84633'] = {
                    uri = 'storage:storage@127.0.0.1:3302',
                    name = 'storage_1_b'
                }
            },
        },
        ['ac522f65-aa94-4134-9f64-51ee384f1a54'] = {
            replicas = {
                ['1e02ae8a-afc0-4e91-ba34-843a356b8ed7'] = {
                    uri = 'storage:storage@127.0.0.1:3303',
                    name = 'storage_2_a',
                    master = true
                },
                ['001688c3-66f8-4a31-8e19-036c17d489c2'] = {
                    uri = 'storage:storage@127.0.0.1:3304',
                    name = 'storage_2_b'
                }
            },
```

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```
        },
    },
}
```

This cluster includes one router instance and two storage instances. Each storage instance includes one master and one replica. The sharding field defines the logical topology of a sharded Tarantool cluster. All the other fields are passed to box.cfg() as they are, without modifications. See the Configuration reference section for details.

On routers, call vshard.router.cfg(cfg):

```
cfg.listen = 3300

-- Start the database with sharding
vshard = require('vshard')
vshard.router.cfg(cfg)
```

On storages, call vshard.storage.cfg(cfg, instance_uuid):

```
-- Get instance name
local MY_UUID = "de0ea826-e71d-4a82-bbf3-b04a6413e417"

-- Call a configuration provider
local cfg = require('localcfg')

-- Start the database with sharding
vshard = require('vshard')
vshard.storage.cfg(cfg, MY_UUID)
```

vshard.storage.cfg() automatically calls box.cfg() and configures the listen port and replication parameters.

For a sample configuration, see router.lua and storage.lua in the example/ directory of the vshard repository.

Configuration reference

Basic parameters

- sharding
- weights
- shard_index
- bucket_count
- collect_bucket_garbage_interval
- collect_lua_garbage
- sync_timeout
- rebalancer_disbalance_threshold
- rebalancer_max_receiving
- rebalancer_max_sending
- discovery_mode

sharding

A field defining the logical topology of the sharded Tarantool cluster.

Type: table

Default: false

Dynamic: yes

weights

A field defining the configuration of relative weights for each zone pair in a replica set. See the Replica weights section.

Type: table

Default: false

Dynamic: yes

shard_index

Name or id of a TREE index over the bucket id. Spaces without this index do not participate in a sharded Tarantool cluster and can be used as regular spaces if needed. It is necessary to specify the first part of the index, other parts are optional.

Type: non-empty string or non-negative integer

Default: "bucket_id"

Dynamic: no

bucket_count

The total number of buckets in a cluster.

This number should be several orders of magnitude larger than the potential number of cluster nodes, considering potential scaling out in the foreseeable future.

Example:

If the estimated number of nodes is M, then the data set should be divided into 100M or even 1000M buckets, depending on the planned scaling out. This number is certainly greater than the potential number of cluster nodes in the system being designed.

Keep in mind that too many buckets can cause a need to allocate more memory to store routing information. On the other hand, an insufficient number of buckets can lead to decreased granularity when rebalancing.

Type: number

Default: 3000

Dynamic: no

collect_bucket_garbage_interval

The interval between garbage collector actions, in seconds.

Type: number
Default: 0.5
Dynamic: yes

collect_lua_garbage
If set to true, the Lua collectgarbage() function is called periodically.

Type: boolean
Default: no
Dynamic: yes

sync_timeout
Timeout to wait for synchronization of the old master with replicas before demotion. Used when switching a master or when manually calling the sync() function.

Type: number
Default: 1
Dynamic: yes

rebalancer_disbalance_threshold
A maximum bucket disbalance threshold, in percent. The threshold is calculated for each replica set using the following formula:

```
|etalon_bucket_count - real_bucket_count| / etalon_bucket_count * 100
```

Type: number
Default: 1
Dynamic: yes

rebalancer_max_receiving
The maximum number of buckets that can be received in parallel by a single replica set. This number must be limited, because when a new replica set is added to a cluster, the rebalancer sends a very large amount of buckets from the existing replica sets to the new replica set. This produces a heavy load on the new replica set.

Example:

Suppose rebalancer_max_receiving is equal to 100, bucket_count is equal to 1000. There are 3 replica sets with 333, 333 and 334 buckets on each respectively. When a new replica set is added, each replica set's etalon_bucket_count becomes equal to 250. Rather than receiving all 250 buckets at once, the new replica set receives 100, 100 and 50 buckets sequentially.

Type: number
Default: 100
Dynamic: yes

rebalancer_max_sending

The degree of parallelism for parallel rebalancing.

Works for storages only, ignored for routers.

The maximum value is 15.

Type: number
Default: 1
Dynamic: yes

discovery_mode

A mode of a bucket discovery fiber: on/off/once. See details below.

Type: string
Default: 'on'
Dynamic: yes

Replica set functions

- uuid
- weight

uuid

A unique identifier of a replica set.

Type:
Default:
Dynamic:

weight

A weight of a replica set. See the Replica set weights section for details.

Type:
Default: 1
Dynamic:

API reference

This section represents public and internal API for the router and the storage.

Subsection	Methods
Router public API	• vshard.router.bootstrap() • vshard.router.cfg(cfg) • vshard.router.new(name, cfg) • vshard.router.call(bucket_id, mode, function_name, {argument_list}, {options}) • vshard.router.callro(bucket_id, function_name, {argument_list}, {options}) • vshard.router.callrw(bucket_id, function_name, {argument_list}, {options}) • vshard.router.callre(bucket_id, function_name, {argument_list}, {options}) • vshard.router.callbro(bucket_id, function_name, {argument_list}, {options}) • vshard.router.callbre(bucket_id, function_name, {argument_list}, {options}) • vshard.router.route(bucket_id) • vshard.router.routeall() • vshard.router.bucket_id_strcrc32(key) • vshard.router.bucket_id_mpcrc32(key) • vshard.router.bucket_count() • vshard.router.sync(timeout) • vshard.router.discovery_wakeup() • vshard.router.discovery_set() • vshard.router.info() • vshard.router.buckets_info() • replicaset_object:call() • replicaset_object:callro() • replicaset_object:callrw() • replicaset_object:callre()
Router internal API	• vshard.router.bucket_discovery(bucket_id)
Storage public API	• vshard.storage.cfg(cfg, name) • vshard.storage.info() • vshard.storage.call(bucket_id, mode, function_name, {argument_list}) • vshard.storage.sync(timeout) • vshard.storage.bucket_pin(bucket_id) • vshard.storage.bucket_unpin(bucket_id) • vshard.storage.bucket_ref(bucket_id, mode) • vshard.storage.bucket_refro() • vshard.storage.bucket_refrw() • vshard.storage.bucket_unref(bucket_id, mode) • vshard.storage.bucket_unrefro() • vshard.storage.bucket_unrefrw() • vshard.storage.find_garbage_bucket(bucket_index, control) • vshard.storage.rebalancer_disable() • vshard.storage.rebalancer_enable() • vshard.storage.is_locked() • vshard.storage.rebalancing_is_in_progress() • vshard.storage.buckets_info() • vshard.storage.buckets_count() • vshard.storage.sharded_spaces()

Router public API

vshard.router.bootstrap()

Perform the initial cluster bootstrap and distribute all buckets across the replica sets.

Parameters

- timeout – a number of seconds before ending a bootstrap attempt as unsuccessful. Recreate the cluster in case of bootstrap timeout.
- if_not_bootstrapped – by default is set to false that means raise an error, when the cluster is already bootstrapped. True means consider an already bootstrapped cluster a success.

Example:

```
vshard.router.bootstrap({timeout = 4, if_not_bootstrapped = true})
```

Note: To detect whether a cluster is bootstrapped, vshard looks for at least one bucket in the whole cluster. If the cluster was bootstrapped only partially (for example, due to an error during the first bootstrap), then it will be considered a bootstrapped cluster on a next bootstrap call with if_not_bootstrapped. So this is still a bad practice. Avoid calling bootstrap() multiple times.

vshard.router.cfg(cfg)

Configure the database and start sharding for the specified router instance. See the sample configuration.

Parameters

- cfg – a configuration table

vshard.router.new(name, cfg)

Create a new router instance. vshard supports multiple routers in a single Tarantool instance. Each router can be connected to any vshard cluster, and multiple routers can be connected to the same cluster.

A router created via vshard.router.new() works in the same way as a static router, but the method name is preceded by a colon (vshard.router:method_name(...)), while for a static router the method name is preceded by a period (vshard.router.method_name(...)).

A static router can be obtained via the vshard.router.static() method and then used like a router created via the vshard.router.new() method.

Note: box.cfg is shared among all the routers of a single instance.

Parameters

- name – a router instance name. This name is used as a prefix in logs of the router and must be unique within the instance
- cfg – a configuration table. See the sample configuration.

Return a router instance, if created successfully; otherwise, nil and an error object

vshard.router.call(bucket_id, mode, function_name, {argument_list}, {options})

Call the function identified by function-name on the shard storing the bucket identified by bucket_id. See the Processing requests section for details on function operation.

Parameters

- bucket_id – a bucket identifier
- mode – either a string = 'read'|'write', or a map with mode='read'|'write' and/or prefer_replica=true|false and/or balance=true|false.
- function_name – a function to execute
- argument_list – an array of the function's arguments
- options –
  - timeout – a request timeout, in seconds. If the router cannot identify a shard with the specified bucket_id, the operation will be repeated until the timeout is reached.
  - other net.box options, such as is_async, buffer, on_push are also supported.

The mode parameter has two possible forms: a string or a map. Examples of the string form are: `'read'`, `'write'`. Examples of the map form are: {mode=`'read'`}, {mode=`'write'`}, {mode=`'read'`, prefer_replica=true}, {mode=`'read'`, balance=true}, {mode=`'read'`, prefer_replica=true, balance=true}.

If `'write'` is specified then the target is the master.

If prefer_replica=true is specified then the preferred target is one of the replicas, but the target is the master if there is no conveniently available replica.

It may be good to specify prefer_replica=true for functions which are expensive in terms of resource use, to avoid slowing down the master.

If balance=true then there is load balancing – reads are distributed over all the nodes in the replica set in round-robin fashion, with a preference for replicas if prefer_replica=true is also set.

Return The original return value of the executed function, or nil and error object. The error object has a type attribute equal to ShardingError or one of the regular Tarantool errors (ClientError, OutOfMemory, SocketError, etc.).

ShardingError is returned on errors specific for sharding: the master is missing, wrong bucket id, etc. It has an attribute code containing one of the values from the vshard.error.code.* LUA table, an optional attribute containing a message with the human-readable error description, and other attributes specific for the error code.

Examples:

To call customer_add function from vshard/example, say:

```
vshard.router.call(100,
                   'write',
                   'customer_add',
                   {{customer_id = 2, bucket_id = 100, name = 'name2', accounts = {}}},
                   {timeout = 5})
-- or, the same thing but with a map for the second argument
vshard.router.call(100,
                   {mode='write'},
                   'customer_add',
                   {{customer_id = 2, bucket_id = 100, name = 'name2', accounts = {}}},
                   {timeout = 5})
```

vshard.router.callro(bucket_id, function_name, {argument_list}, {options})

Call the function identified by function-name on the shard storing the bucket identified by bucket_id, in read-only mode (similar to calling vshard.router.call with mode='read'). See the Processing requests section for details on function operation.

Parameters

- bucket_id – a bucket identifier
- function_name – a function to execute
- argument_list – an array of the function's arguments
- options –
  - timeout – a request timeout, in seconds. In case the router cannot identify a shard with the bucket id, the operation will be repeated until the timeout is reached.
  - other net.box options, such as is_async, buffer, on_push are also supported.

Return

The original return value of the executed function, or nil and error object. The error object has a type attribute equal to ShardingError or one of the regular Tarantool errors (ClientError, OutOfMemory, SocketError, etc.).

ShardingError is returned on errors specific for sharding: the replica set is not available, the master is missing, wrong bucket id, etc. It has an attribute code containing one of the values from the vshard.error.code.* LUA table, an optional attribute containing a message with the human-readable error description, and other attributes specific for this error code.

vshard.router.callrw(bucket_id, function_name, {argument_list}, {options})

Call the function identified by function-name on the shard storing the bucket identified by bucket_id, in read-write mode (similar to calling vshard.router.call with mode='write'). See the Processing requests section for details on function operation.

Parameters

- bucket_id – a bucket identifier
- function_name – a function to execute
- argument_list – an array of the function's arguments
- options –
  - timeout – a request timeout, in seconds. In case the router cannot identify a shard with the bucket id, the operation will be repeated until the timeout is reached.
  - other net.box options, such as is_async, buffer, on_push are also supported.

Return

The original return value of the executed function, or nil and error object. The error object has a type attribute equal to ShardingError or one of the regular Tarantool errors (ClientError, OutOfMemory, SocketError, etc.).

ShardingError is returned on errors specific for sharding: the replica set is not available, the master is missing, wrong bucket id, etc. It has an attribute code containing one of the values from the vshard.error.code.* LUA table, an optional attribute containing a message with the human-readable error description, and other attributes specific for this error code.

vshard.router.callre(bucket_id, function_name, {argument_list}, {options})

Call the function identified by function-name on the shard storing the bucket identified by bucket_id, in read-only mode (similar to calling vshard.router.call with `mode='read'`), with preference for a replica rather than a master (similar to calling vshard.router.call with prefer_replica = true). See the Processing requests section for details on function operation.

Parameters

- bucket_id – a bucket identifier
- function_name – a function to execute
- argument_list – an array of the function's arguments
- options –
  - timeout – a request timeout, in seconds. In case the router cannot identify a shard with the bucket id, the operation will be repeated until the timeout is reached.
  - other net.box options, such as is_async, buffer, on_push are also supported.

Return

The original return value of the executed function, or nil and error object. The error object has a type attribute equal to ShardingError or one of the regular Tarantool errors (ClientError, OutOfMemory, SocketError, etc.).

ShardingError is returned on errors specific for sharding: the replica set is not available, the master is missing, wrong bucket id, etc. It has an attribute code containing one of the values from the vshard.error.code.* LUA table, an optional attribute containing a message with the human-readable error description, and other attributes specific for this error code.

vshard.router.callbro(bucket_id, function_name, {argument_list}, {options})
This has the same effect as vshard.router.call() with mode parameter = {mode=`'read'`, balance=true}.

vshard.router.callbre(bucket_id, function_name, {argument_list}, {options})
This has the same effect as vshard.router.call() with mode parameter = {mode=`'read'`, balance=true, prefer_replica=true}.

vshard.router.route(bucket_id)
Return the replica set object for the bucket with the specified bucket id value.

Parameters

- bucket_id – a bucket identifier

Return a replica set object

Example:

```
replicaset = vshard.router.route(123)
```

vshard.router.routeall()
Return all available replica set objects.

Return a map of the following type: {UUID = replicaset}

Rtype a map of replica set objects

Example:

```
function selectall()
    local resultset = {}
    shards, err = vshard.router.routeall()
    if err ~= nil then
        error(err)
    end
    for uid, replica in pairs(shards) do
        local set = replica:callro('box.space.*space-name*:select', {{}, {limit=10}}, {timeout=5})
        for _, item in ipairs(set) do
```

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```
        table.insert(resultset, item)
      end
    end
    table.sort(resultset, function(a, b) return a[1] < b[1] end)
    return resultset
end
```

vshard.router.bucket_id(key)

Deprecated. Logs a warning when used because it is not consistent for cdata numbers.

In particular, it returns 3 different values for normal Lua numbers like 123, for unsigned long long cdata (like 123ULL, or ffi.cast('unsigned long long',123)), and for signed long long cdata (like 123LL, or ffi.cast('long long', 123)). And it is important.

```
vshard.router.bucket_id(123)
vshard.router.bucket_id(123LL)
vshard.router.bucket_id(123ULL)
```

For float and double cdata (ffi.cast('float', number), ffi.cast('double', number)) these functions return different values even for the same numbers of the same floating point type. This is because tostring() on a floating point cdata number returns not the number, but a pointer at it. Different on each call.

vshard.router.bucket_id_strcrc32() behaves exactly the same, but does not log a warning. In case you need that behavior.

vshard.router.bucket_id_strcrc32(key)

Calculate the bucket id using a simple built-in hash function.

Parameters

- key – a hash key. This can be any Lua object (number, table, string).

Return a bucket identifier

Rtype number

Example:

```
tarantool> vshard.router.bucket_count()
---
- 3000
...

tarantool> vshard.router.bucket_id_strcrc32("18374927634039")
---
- 2032
...

tarantool> vshard.router.bucket_id_strcrc32(18374927634039)
---
- 2032
...

tarantool> vshard.router.bucket_id_strcrc32("test")
---
- 1216
...

tarantool> vshard.router.bucket_id_strcrc32("other")
```

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```
---
- 2284
...
```

Note: Remember that it is not safe. See details in bucket_id()

vshard.router.bucket_id_mpcrc32(key)

This function is safer than bucket_id_strcrc32. It takes a CRC32 from a MessagePack encoded value. That is, bucket id of integers does not depend on their Lua type. In case of a string key, it does not encode it into MessagePack, but takes a hash right from the string.

Parameters

- key – a hash key. This can be any Lua object (number, table, string).

Return a bucket identifier

Rtype number

However it still may return different values for not equal floating point types. That is, ffi.cast('float', number) may be reflected into a bucket id not equal to ffi.cast('double', number). This can't be fixed, because a float value, even being casted to double, may have a garbage tail in its fraction.

Floating point keys should not be used to calculate a bucket id, usually.

Be very careful in case you store floating point types in a space. When data is returned from a space, it is cast to Lua number. And if that value had an empty fraction part, it will be treated as an integer by bucket_id_mpcrc32(). So you need to do explicit casts in such cases. Here is an example of the problem:

```
tarantool> s = box.schema.create_space('test', {format = {{'id', 'double'}}}); _ = s:create_index('pk
↪')
---
...

tarantool> inserted = ffi.cast('double', 1)
---
...

-- Value is stored as double
tarantool> s:replace({inserted})
---
- [1]
...

-- But when returned to Lua, stored as Lua number, not cdata.
tarantool> returned = s:get({inserted}).id
---
...

tarantool> type(returned), returned
---
- number
- 1
...
```

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```
tarantool> vshard.router.bucket_id_mpcrc32(inserted)
---
- 1411
...
tarantool> vshard.router.bucket_id_mpcrc32(returned)
---
- 1614
...
```

vshard.router.bucket_count()

Return the total number of buckets specified in vshard.router.cfg().

Return the total number of buckets

Rtype number

```
tarantool> vshard.router.bucket_count()
---
- 10000
...
```

vshard.router.sync(timeout)

Wait until the dataset is synchronized on replicas.

Parameters

- timeout – a timeout, in seconds

Return true if the dataset was synchronized successfully; or nil and err explaining why the dataset cannot be synchronized.

vshard.router.discovery_wakeup()

Force wakeup of the bucket discovery fiber.

vshard.router.discovery_set(mode)

Turn on/off the background discovery fiber used by the router to find buckets.

Parameters

- mode – working mode of a discovery fiber. There are three modes: on, off and once

When the mode is on (default), the discovery fiber works during all the lifetime of the router. Even after all buckets are discovered, it will still come to storages and download their buckets with some big period (DISCOVERY_IDLE_INTERVAL). This is useful if the bucket topology changes often and the number of buckets is not big. The router will keep its route table up to date even when no requests are processed.

When the mode is off, discovery is disabled completely.

When the mode is once, discovery starts and finds the locations of all buckets, and then the discovery fiber is terminated. This is good for a large bucket count and for clusters, where rebalancing is rare.

The method is good to enable/disable discovery after the router is already started, but discovery is enabled by default. You may want to never enable it even for a short time – then specify the discovery_mode option in the configuration. It takes the same values as vshard.router.discovery_set(mode).

You may decide to turn off discovery or make it once if you have many routers, or tons of buckets (hundreds of thousands and more), and you see that the discovery process consumes notable CPU % on routers and storages. In that case it may be wise to turn off the discovery when there is no rebalancing in the cluster. And turn it on for new routers, as well as for all routers when rebalancing is started.

vshard.router.info()

Return information about each instance.

Return

Replica set parameters:

- replica set uuid
- master instance parameters
- replica instance parameters

Instance parameters:

- uri — URI of the instance
- uuid — UUID of the instance
- status – status of the instance (available, unreachable, missing)
- network_timeout – a timeout for the request. The value is updated automatically on each 10th successful request and each 2nd failed request.

Bucket parameters:

- available_ro – the number of buckets known to the router and available for read requests
- available_rw – the number of buckets known to the router and available for read and write requests
- unavailable – the number of buckets known to the router but unavailable for any requests
- unreachable – the number of buckets whose replica sets are not known to the router

Example:

```
tarantool> vshard.router.info()
---
- replicasets:
    ac522f65-aa94-4134-9f64-51ee384f1a54:
      replica: &0
        network_timeout: 0.5
        status: available
        uri: storage@127.0.0.1:3303
        uuid: 1e02ae8a-afc0-4e91-ba34-843a356b8ed7
      uuid: ac522f65-aa94-4134-9f64-51ee384f1a54
      master: *0
    cbf06940-0790-498b-948d-042b62cf3d29:
      replica: &1
        network_timeout: 0.5
        status: available
        uri: storage@127.0.0.1:3301
        uuid: 8a274925-a26d-47fc-9e1b-af88ce939412
      uuid: cbf06940-0790-498b-948d-042b62cf3d29
      master: *1
  bucket:
    unreachable: 0
    available_ro: 0
    unknown: 0
    available_rw: 3000
  status: 0
  alerts: []
...
```

vshard.router.buckets_info()

Return information about each bucket. Since a bucket map can be huge, only the required range of buckets can be specified.

Parameters

- offset – the offset in a bucket map of the first bucket to show
- limit – the maximum number of buckets to show

Return a map of the following type: {bucket_id = 'unknown'/replicaset_uuid}

```
tarantool> vshard.router.buckets_info()
---
- - uuid: aaaaaaaa-0000-4000-a000-000000000000
    status: available_rw
  - uuid: aaaaaaaa-0000-4000-a000-000000000000
    status: available_rw
  - uuid: aaaaaaaa-0000-4000-a000-000000000000
    status: available_rw
  - uuid: bbbbbbbb-0000-4000-a000-000000000000
    status: available_rw
  - uuid: bbbbbbbb-0000-4000-a000-000000000000
    status: available_rw
  - uuid: bbbbbbbb-0000-4000-a000-000000000000
    status: available_rw
  - uuid: bbbbbbbb-0000-4000-a000-000000000000
    status: available_rw
...
```

object replicaset_object

replicaset_object:call(function_name, {argument_list}, {options})

Call a function on a nearest available master (distances are defined using replica.zone and cfg.weights matrix) with specified arguments.

Note: The replicaset_object:call method is similar to replicaset_object:callrw.

Parameters

- function_name – function to execute
- argument_list – array of the function's arguments
- options –
  - timeout – a request timeout, in seconds. In case the router cannot identify a shard with the bucket id, the operation will be repeated until the timeout is reached.
  - other net.box options, such as is_async, buffer, on_push are also supported.

Return

- result of function_name on success
- nill, err otherwise

replicaset_object:callrw(function_name, {argument_list}, {options})

Call a function on a nearest available master (distances are defined using replica.zone and cfg.weights matrix) with a specified arguments.

Note: The replicaset_object:callrw method is similar to replicaset_object:call.

Parameters

- function_name – function to execute
- argument_list – array of the function's arguments
- options –
  - timeout – a request timeout, in seconds. In case the router cannot identify a shard with the bucket id, the operation will be repeated until the timeout is reached.
  - other net.box options, such as is_async, buffer, on_push are also supported.

Return

- result of function_name on success
- nill, err otherwise

```
tarantool> local bucket = 1; return vshard.router.callrw(
         >     bucket,
         >     'box.space.actors:insert',
         >     {{
         >         1, bucket, 'Renata Litvinova',
         >         {theatre="Moscow Art Theatre"}
         >     }},
         >     {timeout=5}
         > )
```

replicaset_object:callro(function_name, {argument_list}, {options})

Call a function on the nearest available replica (distances are defined using replica.zone and cfg.weights matrix) with specified arguments. It is recommended to use replicaset_object:callro() for calling only read-only functions, as the called functions can be executed not only on a master, but also on replicas.

Parameters

- function_name – function to execute
- argument_list – array of the function's arguments
- options –
  - timeout – a request timeout, in seconds. In case the router cannot identify a shard with the bucket id, the operation will be repeated until the timeout is reached.
  - other net.box options, such as is_async, buffer, on_push are also supported.

Return

- result of function_name on success
- nill, err otherwise

replicaset:callre(function_name, {argument_list}, {options})

Call a function on the nearest available replica (distances are defined using replica.zone and cfg.weights matrix) with specified arguments, with preference for a replica rather than a master (similar to calling vshard.router.call with prefer_replica = true). It is recommended to use replicaset_object:callre() for calling only read-only functions, as the called function can be executed not only on a master, but also on replicas.

Parameters

- function_name – function to execute
- argument_list – array of the function's arguments
- options –
  - timeout – a request timeout, in seconds. In case the router cannot identify a shard with the bucket id, the operation will be repeated until the timeout is reached.
  - other net.box options, such as is_async, buffer, on_push are also supported.

Return

- result of function_name on success
- nill, err otherwise

Router internal API

vshard.router.bucket_discovery(bucket_id)

Search for the bucket in the whole cluster. If the bucket is not found, it is likely that it does not exist. The bucket might also be moved during rebalancing and currently is in the RECEIVING state.

Parameters

- bucket_id – a bucket identifier

Storage public API

vshard.storage.cfg(cfg, name)

Configure the database and start sharding for the specified storage instance.

Parameters

- cfg – a storage configuration
- instance_uuid – UUID of the instance

vshard.storage.info()

Return information about the storage instance in the following format:

```
tarantool> vshard.storage.info()
---
- buckets:
    2995:
      status: active
      id: 2995
    2997:
      status: active
```

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```
      id: 2997
    2999:
      status: active
      id: 2999
  replicasets:
    2dd0a343-624e-4d3a-861d-f45efc571cd3:
      uuid: 2dd0a343-624e-4d3a-861d-f45efc571cd3
      master:
        state: active
        uri: storage:storage@127.0.0.1:3301
        uuid: 2ec29309-17b6-43df-ab07-b528e1243a79
    c7ad642f-2cd8-4a8c-bb4e-4999ac70bba1:
      uuid: c7ad642f-2cd8-4a8c-bb4e-4999ac70bba1
      master:
        state: active
        uri: storage:storage@127.0.0.1:3303
        uuid: 810d85ef-4ce4-4066-9896-3c352fec9e64
...
```

vshard.storage.call(bucket_id, mode, function_name, {argument_list})

Call the specified function on the current storage instance.

Parameters

- bucket_id – a bucket identifier
- mode – a type of the function: 'read' or 'write'
- function_name – function to execute
- argument_list – array of the function's arguments

Return

The original return value of the executed function, or nil and error object.

vshard.storage.sync(timeout)

Wait until the dataset is synchronized on replicas.

Parameters

- timeout – a timeout, in seconds

Return true if the dataset was synchronized successfully; or nil and err explaining why the dataset cannot be synchronized.

vshard.storage.bucket_pin(bucket_id)

Pin a bucket to a replica set. A pinned bucket cannot be moved even if it breaks the cluster balance.

Parameters

- bucket_id – a bucket identifier

Return true if the bucket is pinned successfully; or nil and err explaining why the bucket cannot be pinned

vshard.storage.bucket_unpin(bucket_id)

Return a pinned bucket back into the active state.

Parameters

- bucket_id – a bucket identifier

Return true if the bucket is unpinned successfully; or nil and err explaining why the bucket cannot be unpinned

vshard.storage.bucket_ref(bucket_id, mode)
Create an RO or RW ref.

Parameters

- bucket_id – a bucket identifier
- mode – 'read' or 'write'

Return true if the bucket ref is created successfully; or nil and err explaining why the ref cannot be created

vshard.storage.bucket_refro()
An alias for vshard.storage.bucket_ref in the RO mode.

vshard.storage.bucket_refrw()
An alias for vshard.storage.bucket_ref in the RW mode.

vshard.storage.bucket_unref(bucket_id, mode)
Remove a RO/RW ref.

Parameters

- bucket_id – a bucket identifier
- mode – 'read' or 'write'

Return true if the bucket ref is removed successfully; or nil and err explaining why the ref cannot be removed

vshard.storage.bucket_unrefro()
An alias for vshard.storage.bucket_unref in the RO mode.

vshard.storage.bucket_unrefrw()
An alias for vshard.storage.bucket_unref in the RW mode.

vshard.storage.find_garbage_bucket(bucket_index, control)
Find a bucket which has data in a space but is not stored in a _bucket space; or is in a GARBAGE state.

Parameters

- bucket_index – index of a space with the part of a bucket id
- control – a garbage collector controller. If there is an increased buckets generation, then the search should be interrupted.

Return an identifier of the bucket in the garbage state, if found; otherwise, nil

vshard.storage.buckets_info()
Return information about each bucket located in storage. For example:

```
tarantool> vshard.storage.buckets_info(1)
---
- 1:
    status: active
    ref_rw: 1
    ref_ro: 1
    ro_lock: true
    rw_lock: true
    id: 1
```

vshard.storage.buckets_count()
: Return the number of buckets located in storage.

vshard.storage.recovery_wakeup()
: Immediately wake up a recovery fiber, if it exists.

vshard.storage.rebalancing_is_in_progress()
: Return a flag indicating whether rebalancing is in progress. The result is true if the node is currently applying routes received from a rebalancer node in the special fiber.

vshard.storage.is_locked()
: Return a flag indicating whether storage is invisible to the rebalancer.

vshard.storage.rebalancer_disable()
: Disable rebalancing. A disabled rebalancer sleeps until it is enabled again with vshard.storage.rebalancer_enable().

vshard.storage.rebalancer_enable()
: Enable rebalancing.

vshard.storage.sharded_spaces()
: Show the spaces that are visible to rebalancer and garbage collector fibers.

```
tarantool> vshard.storage.sharded_spaces()
---
- 513:
    engine: memtx
    before_replace: 'function: 0x010e50e738'
    field_count: 0
    id: 513
    on_replace: 'function: 0x010e50e700'
    temporary: false
    index:
      0: &0
        unique: true
        parts:
        - type: number
          fieldno: 1
          is_nullable: false
        id: 0
        type: TREE
        name: primary
        space_id: 513
      1: &1
        unique: false
        parts:
        - type: number
          fieldno: 2
          is_nullable: false
        id: 1
        type: TREE
        name: bucket_id
        space_id: 513
      primary: *0
      bucket_id: *1
    is_local: false
    enabled: true
    name: actors
    ck_constraint: []
...
```

Storage internal API

vshard.storage.bucket_recv(bucket_id, from, data)
Receive a bucket identified by bucket id from a remote replica set.

Parameters

- bucket_id – a bucket identifier
- from – UUID of source replica set
- data – data logically stored in a bucket identified by bucket_id, in the same format as the return value from bucket_collect() <storage_api-bucket_collect>

vshard.storage.bucket_stat(bucket_id)
Return information about the bucket id:

```
tarantool> vshard.storage.bucket_stat(1)
---
- 0
- status: active
  id: 1
...
```

Parameters

- bucket_id – a bucket identifier

vshard.storage.bucket_delete_garbage(bucket_id)
Force garbage collection for the bucket identified by bucket_id in case the bucket was transferred to a different replica set.

Parameters

- bucket_id – a bucket identifier

vshard.storage.bucket_collect(bucket_id)
Collect all the data that is logically stored in the bucket identified by bucket_id:

```
tarantool> vshard.storage.bucket_collect(1)
---
- 0
- - - 514
    - - [10, 1, 1, 100, 'Account 10']
      - [11, 1, 1, 100, 'Account 11']
      - [12, 1, 1, 100, 'Account 12']
      - [50, 5, 1, 100, 'Account 50']
      - [51, 5, 1, 100, 'Account 51']
      - [52, 5, 1, 100, 'Account 52']
  - - 513
    - - [1, 1, 'Customer 1']
      - [5, 1, 'Customer 5']
...
```

Parameters

- bucket_id – a bucket identifier

vshard.storage.bucket_force_create(first_bucket_id, count)
Force creation of the buckets (single or multiple) on the current replica set. Use only for manual emergency recovery or for initial bootstrap.

Parameters

- first_bucket_id – an identifier of the first bucket in a range
- count – the number of buckets to insert (default = 1)

vshard.storage.bucket_force_drop(bucket_id)
Drop a bucket manually for tests or emergency cases.

Parameters

- bucket_id – a bucket identifier

vshard.storage.bucket_send(bucket_id, to)
Send a specified bucket from the current replica set to a remote replica set.

Parameters

- bucket_id – bucket identifier
- to – UUID of a remote replica set

vshard.storage.rebalancer_request_state()
Check all buckets of the host storage that have the SENT or ACTIVE state, return the number of active buckets.

Return the number of buckets in the active state, if found; otherwise, nil

vshard.storage.buckets_discovery()
Collect an array of active bucket identifiers for discovery.

5.3.5 Luatest

More about Luatest API see below.

Overview

Tool for testing tarantool applications. (Build Status).

Highlights:

- executable to run tests in directory or specific files,
- before/after suite hooks,
- before/after test group hooks,
- output capturing,
- helpers for testing tarantool applications,
- luacov integration.

Requirements

- Tarantool (it requires tarantool-specific fio module and ffi from LuaJIT).

Installation

```
tarantoolctl rocks install luatest

.rocks/bin/luatest --help # list available options
```

Usage

Define tests.

```
-- test/feature_test.lua
local t = require('luatest')
local g = t.group('feature')
-- Default name is inferred from caller filename when possible.
-- For `test/a/b/c_d_test.lua` it will be `a.b.c_d`.
-- So `local g = t.group()` works the same way.

-- Tests. All properties with name staring with `test` are treated as test cases.
g.test_example_1 = function() ... end
g.test_example_n = function() ... end

-- Define suite hooks
t.before_suite(function() ... end)
t.before_suite(function() ... end)

-- Hooks to run once for tests group
g.before_all(function() ... end)
g.after_all(function() ... end)

-- Hooks to run for each test in group
g.before_each(function() ... end)
g.after_each(function() ... end)

-- test/other_test.lua
local t = require('luatest')
local g = t.group('other')
-- ...
g.test_example_2 = function() ... end
g.test_example_m = function() ... end
```

Run them.

```
luatest --help                     # list available options
luatest                            # run all in ./test directory
luatest test/feature_test.lua      # run test by file
luatest test/integration           # run all within directory
luatest feature other.test_example_2  # run by group or test name
```

Luatest automatically requires test/helper.lua file if it's present. You can configure luatest or run any bootstrap code there.

See the getting-started example in cartridge-cli repo.

Tests order

Use the --shuffle option to tell luatest how to order the tests. The available ordering schemes are group, all and none.

group shuffles tests within the groups.

all randomizes execution order across all available tests. Be careful: before_all/after_all hooks run always when test group is changed, so it may run multiple time.

none is the default, which executes examples within the group in the order they are defined (eventually they are ordered by functions line numbers).

With group and all you can also specify a seed to reproduce specific order.

```
--shuffle none
--shuffle group
--shuffle all --seed 123
--shuffle all:123 # same as above
```

To change default order use:

```
-- test/helper.lua
local t = require('luatest')
t.configure({shuffle = 'group'})
```

List of luatest functions

Assertions	
assert (value[, message])	Check that value is truthy.
assert_almost_equals (actual, expected, margin[, message])	Check that two floats are close by margin.
assert_covers (actual, expected[, message])	Checks that actual map includes expected
assert_equals (actual, expected[, message[, deep_analysis]])	Check that two values are equal.
assert_error (fn, ...)	Check that calling fn raises an error.
assert_error_msg_contains (expected_partial, fn, ...)	
assert_error_msg_content_equals (expected, fn, ...)	Strips location info from message text.
assert_error_msg_equals (expected, fn, ...)	Checks full error: location and text.
assert_error_msg_matches (pattern, fn, ...)	
assert_eval_to_false (value[, message])	Alias for assert_not.
assert_eval_to_true (value[, message])	Alias for assert.
assert_items_include (actual, expected[, message])	Checks that actual includes all items of ex
assert_is (actual, expected[, message])	Check that values are the same.
assert_is_not (actual, expected[, message])	Check that values are not the same.
assert_items_equals (actual, expected[, message])	Checks equality of tables regardless of the
assert_nan (value[, message])	
assert_not (value[, message])	Check that value is falsy.
assert_not_almost_equals (actual, expected, margin[, message])	Check that two floats are not close by mar
assert_not_covers (actual, expected[, message])	Checks that map does not contain the oth
assert_not_equals (actual, expected[, message])	Check that two values are not equal.
assert_not_nan (value[, message])	
assert_not_str_contains (actual, expected[, is_pattern[, message]])	Case-sensitive strings comparison.
assert_not_str_icontains (value, expected[, message])	Case-insensitive strings comparison.
assert_str_contains (value, expected[, is_pattern[, message]])	Case-sensitive strings comparison.

Conti

Table 6 – continued from previous page

assert_str_icontains (value, expected[, message])	Case-insensitive strings comparison.
assert_str_matches (value, pattern[, start=1[, final=value:len() [, message]]])	Verify a full match for the string.
assert_type (value, expected_type[, message])	Check value’s type.
Flow control	
fail (message)	Stops a test due to a failure.
fail_if (condition, message)	Stops a test due to a failure if condition is
skip (message)	Skip a running test.
skip_if (condition, message)	Skip a running test if condition is met.
success ()	Stops a test with a success.
success_if (condition)	Stops a test with a success if condition is
Suite and groups	
after_suite (fn)	Add after suite hook.
before_suite (fn)	Add before suite hook.
group (name)	Create group of tests.

Capturing output

By default runner captures all stdout/stderr output and shows it only for failed tests. Capturing can be disabled with -c flag.

Test helpers

There are helpers to run tarantool applications and perform basic interaction with it. If application follows configuration conventions it is possible to use options to configure server instance and helpers at the same time. For example http_port is used to perform http request in tests and passed in TARANTOOL_HTTP_PORT to server process.

```lua
local server = luatest.Server:new({
    command = '/path/to/executable.lua',
    -- arguments for process
    args = {'--no-bugs', '--fast'},
    -- additional envars to pass to process
    env = {SOME_FIELD = 'value'},
    -- passed as TARANTOOL_WORKDIR
    workdir = '/path/to/test/workdir',
    -- passed as TARANTOOL_HTTP_PORT, used in http_request
    http_port = 8080,
    -- passed as TARANTOOL_LISTEN, used in connect_net_box
    net_box_port = 3030,
    -- passed to net_box.connect in connect_net_box
    net_box_credentials = {user = 'username', password = 'secret'},
})
server:start()
-- Wait until server is ready to accept connections.
-- This may vary from app to app: for one server:connect_net_box() is enough,
-- for another more complex checks are required.
luatest.helpers.retrying({}, function() server:http_request('get', '/ping') end)

-- http requests
server:http_request('get', '/path')
server:http_request('post', '/path', {body = 'text'})
server:http_request('post', '/path', {json = {field = value}, http = {
    -- http client options
```

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```
    headers = {Authorization = 'Basic ' .. credentials},
    timeout = 1,
}})

-- This method throws error when response status is outside of then range 200..299.
-- To change this behaviour, path `raise = false`:
t.assert_equals(server:http_request('get', '/not_found', {raise = false}).status, 404)
t.assert_error(function() server:http_request('get', '/not_found') end)

-- using net_box
server:connect_net_box()
server.net_box:eval('return do_something(...)', {arg1, arg2})

server:stop()
```

luatest.Process:start(path, args, env) provides low-level interface to run any other application.

There are several small helpers for common actions:

```
luatest.helpers.uuid('ab', 2, 1) == 'abababab-0002-0000-0000-000000000001'

luatest.helpers.retrying({timeout = 1, delay = 0.1}, failing_function, arg1, arg2)
-- wait until server is up
luatest.helpers.retrying({}, function() server:http_request('get', '/status') end)
```

luacov integration

- Install luacov with tarantoolctl rocks install luacov
- Configure it with .luacov file
- Clean old reports rm -f luacov.*.out*
- Run luatest with --coverage option
- Generate report with .rocks/bin/luacov .
- Show summary with grep -A999 '^Summary' luacov.report.out

When running integration tests with coverage collector enabled, luatest automatically starts new tarantool instances with luacov enabled. So coverage is collected from all the instances. However this has some limitations:

- It works only for instances started with Server helper.
- Process command should be executable lua file or tarantool with script argument.
- Instance must be stopped with server:stop(), because this is the point where stats are saved.
- Don't save stats concurrently to prevent corruption.

Development

- Check out the repo.
- Prepare makefile with cmake ..
- Install dependencies with make bootstrap.

- Run it with make lint before committing changes.
- Run tests with bin/luatest.

Contributing

Bug reports and pull requests are welcome on at https://github.com/tarantool/luatest.

License

MIT

API

Module luatest

Functions

Methods

after_suite (fn)

Add after suite hook.

Parameters:

- fn: (func)

before_suite (fn)

Add before suite hook.

Parameters:

- fn: (func)

configure ([options={}])

Update default options. See luatest.runner:run for the list of available options.

Parameters:

- options: (tab) list of options to update (default $(def))

Returns:

options after update

group ([name])

Create group of tests.

Parameters:

- name: (string) (optional)

Returns:

Group object

See also:

- luatest.group

Fields

Server

Class to manage tarantool instances.

See also:

- luatest.server

helpers

Helpers.

See also:

- luatest.helpers

assertions Functions

EPS

EPS is meant to help with Lua's floating point math in simple corner cases like almost_equals(1.1-0.1, 1), which may not work as-is (e.g. on numbers with rational binary representation) if the user doesn't provide some explicit error margin.

The default margin used by almost_equals() in such cases is EPS; and since Lua may be compiled with different numeric precisions (single vs. double), we try to select a useful default for it dynamically. Note: If the initial value is not acceptable, it can be changed by the user to better suit specific needs.

See also: https://en.wikipedia.org/wiki/Machine_epsilon

almost_equals (actual, expected, margin)

Parameters:

- actual: (number)
- expected: (number)

- margin: (number)

assert (value[, message[, ...]])

Check that value is truthy.

Parameters:

- value:
- message: (string) (optional)
- ...: (optional)

Returns:

input values

assert_almost_equals (actual, expected, margin[, message])

Check that two floats are close by margin.

Parameters:

- actual: (number)
- expected: (number)
- margin: (number)
- message: (string) (optional)

assert_covers (actual, expected[, message])

Checks that actual map includes expected one.

Parameters:

- actual: (tab)
- expected: (tab)
- message: (string) (optional)

assert_equals (actual, expected[, message[, deep_analysis]])

Check that two values are equal. Tables are compared by value.

Parameters:

- actual:
- expected:
- message: (string) (optional)
- deep_analysis: (bool) print diff. (optional)

assert_error (fn, ...)

Check that calling fn raises an error.

Parameters:

- fn: (func)
- ...: arguments for function

assert_error_msg_contains (expected_partial, fn, ...)

Parameters:

- expected_partial: (string)
- fn: (func)
- ...: arguments for function

assert_error_msg_content_equals (expected, fn, ...)

Strips location info from message text.

Parameters:

- expected: (string)
- fn: (func)
- ...: arguments for function

assert_error_msg_equals (expected, fn, ...)

Checks full error: location and text.

Parameters:

- expected: (string)
- fn: (func)
- ...: arguments for function

assert_error_msg_matches (pattern, fn, ...)

Parameters:

- pattern: (string)
- fn: (func)
- ...: arguments for function

assert_eval_to_false (value[, message])

Alias for assert_not.

Parameters:

- value:
- message: (string) (optional)

assert_eval_to_true (value[, message])

Alias for assert.

Parameters:

- value:
- message: (string) (optional)

assert_is (actual, expected[, message])

Check that values are the same.

Parameters:

- actual:
- expected:
- message: (string) (optional)

assert_is_not (actual, expected[, message])

Check that values are not the same.

Parameters:

- actual:
- expected:
- message: (string) (optional)

assert_items_equals (actual, expected[, message])

Checks equality of tables regardless of the order of elements.

Parameters:

- actual:
- expected:
- message: (string) (optional)

assert_items_include (actual, expected[, message])

Checks that actual includes all items of expected.

Parameters:

- actual:
- expected:
- message: (string) (optional)

assert_nan (value[, message])

Parameters:

- value:
- message: (string) (optional)

assert_not (value[, message])

Check that value is falsy.

Parameters:

- value:
- message: (string) (optional)

assert_not_almost_equals (actual, expected, margin[, message])

Check that two floats are not close by margin.

Parameters:

- actual: (number)
- expected: (number)
- margin: (number)
- message: (string) (optional)

assert_not_covers (actual, expected[, message])

Checks that map does not contain the other one.

Parameters:

- actual: (tab)
- expected: (tab)
- message: (string) (optional)

assert_not_equals (actual, expected[, message])

Check that two values are not equal. Tables are compared by value.

Parameters:

- actual:
- expected:
- message: (string) (optional)

assert_not_nan (value[, message])

Parameters:

- value:
- message: (string) (optional)

assert_not_str_contains (actual, expected[, is_pattern[, message]])

Case-sensitive strings comparison.

Parameters:

- actual: (string)
- expected: (string)
- is_pattern: (bool) (optional)
- message: (string) (optional)

assert_not_str_icontains (value, expected[, message])

Case-insensitive strings comparison.

Parameters:

- value: (string)
- expected: (string)
- message: (string) (optional)

assert_str_contains (value, expected[, is_pattern[, message]])

Case-sensitive strings comparison.

Parameters:

- value: (string)
- expected: (string)
- is_pattern: (bool) (optional)
- message: (string) (optional)

assert_str_icontains (value, expected[, message])

Case-insensitive strings comparison.

Parameters:

- value: (string)
- expected: (string)
- message: (string) (optional)

assert_str_matches (value, pattern[, start=1[, final=value:len()[, message]]])

Verify a full match for the string.

Parameters:

- value: (string)
- pattern: (string)
- start: (int) (default $(def))
- final: (int) (default $(def))
- message: (string) (optional)

assert_type (value, expected_type[, message[, level]])

Check value's type.

Parameters:

- value: (string)
- expected_type: (string)
- message: (string) (optional)
- level: (int) (optional)

fail (message)

Stops a test due to a failure.

Parameters:

- message: (string)

fail_if (condition, message)

Stops a test due to a failure if condition is met.

Parameters:

- condition:
- message: (string)

skip (message)

Skip a running test.

Parameters:

- message: (string)

skip_if (condition, message)

Skip a running test if condition is met.

Parameters:

- condition:
- message: (string)

success ()

Stops a test with a success.

success_if (condition)

Stops a test with a success if condition is met.

Parameters:

- condition:

Module luatest.helpers

Collection of test helpers.

Functions

Methods

retrying (config, fn, . . .)

Keep calling fn until it returns without error. Throws last error if config.timeout is elapsed. Default options are taken from helpers.RETRYING_TIMEOUT and helpers.RETRYING_DELAY.

```
helpers.retrying({}, fn, arg1, arg2)
helpers.retrying({timeout = 2, delay = 0.5}, fn, arg1, arg2)
```

Parameters:

- config:
  - timeout: (number)
  - delay: (number)

- fn: (func)
- . . . : args

uuid (a, . . .)

Generates uuids from its 5 parts. Strings are repeated and numbers are padded to match required part length. If number of arguments is less than 5 then first and last arguments are used for corresponding parts, missing parts are set to 0.

```
'aaaaaaaa-0000-0000-0000-000000000000' == uuid('a')
'abababab-0000-0000-0000-000000000001' == uuid('ab', 1)
'00000001-0002-0000-0000-000000000003' == uuid(1, 2, 3)
'11111111-2222-0000-0000-333333333333' == uuid('1', '2', '3')
'12121212-3434-5656-7878-909090909090' == uuid('12', '34', '56', '78', '90')
```

Parameters:

- a: first part
- . . . : parts

Class luatest.group

Tests group.

To add new example add function at key starting with test .

Group hooks run always when test group is changed. So it may run multiple times when --shuffle option is used.

Instance methods

Group.mt.after_all (fn)

Add callback to run once after all tests in the group.

Parameters:

- fn:

Group.mt.after_each (fn)

Add callback to run after each test in the group.

Parameters:

- fn:

Group.mt.before_all (fn)

Add callback to run once before all tests in the group.

Parameters:

- fn:

Group.mt.before_each (fn)

Add callback to run before each test in the group.

Parameters:

- fn:

Group.mt:initialize ([name])

Parameters:

- name: (string) Default name is inferred from caller filename when possible.For test/a/b/c_d_test.lua it will be a.b.c_d . (optional)

Returns:

Group instance

Class luatest.http_response

Class to provide helper methods for HTTP responses

Instance getter methods

HTTPResponse.getters

For backward compatibility this methods should be accessed as object's fields (eg., response.json.id).

They are not assigned to object's fields on initialization to be evaluated lazily and to be able to throw errors.

HTTPResponse.getters:json ()

Parse json from body.

Usage:

```
response.json.id
```

HTTPResponse.mt:is_successful ()

Check that status code is 2xx.

Class luatest.runner

Class to run test suite.

Functions

Methods

Runner.is_test_name (s)

Check that string matches the name of a test method. Default rule is that is starts with 'test'

Parameters:

- s:

Runner.run ([args=_G.args[, options]])

Main entrypoint to run test suite.

Parameters:

- args: (tab) List of CLI arguments (default $(def))
- options:
  - verbosity: (int) (optional)
  - fail_fast: (bool) (default $(def))
  - output_file_name: (string) Filename for JUnit report (optional)
  - exe_repeat: (int) Times to repeat each test (optional)
  - tests_pattern: (tab) Patterns to filter tests (optional)
  - tests_names: (tab) List of test names or groups to run (optional)
  - paths: (tab) List of directories to load tests from. (default $(def))
  - load_tests: (func) Function to load tests. Called once for every item in paths . (optional)
  - shuffle: (string) Shuffle method (none, all, group) (default $(def))
  - seed: (int) Random seed for shuffle (optional)
  - output: (string) Output formatter (text, tap, junit, nil) (default $(def))

Runner.split_test_method_name (someName)

Split some.group.name.method into some.group.name and method . Returns nil, input if input value does not have a dot.

Parameters:

- someName:

Runner:expand_group (group)

Exrtact all test methods from group.

Parameters:

- group:

Class luatest.server

Class to run tarantool instance.

Functions

Methods

Server:build_env ()

Generates environment to run process with. The result is merged into os.environ().

Returns:

map

Server:connect_net_box ()

Establish net.box connection. It's available in net_box field.

Server:http_request (method, path[, options])

Perform HTTP request.

Parameters:

- method: (string)
- path: (string)
- options:
  - body: (string) request body (optional)
  - json: data to encode as JSON into request body (optional)
  - http: (tab) other options for HTTP-client (optional)
  - raise: (bool) raise error when status is not in 200..299. Default to true. (optional)

Returns:

response object from HTTP client with helper methods.

Raises:

HTTPRequest error when response status is not 200.

See also:

- luatest.http_response

Server:new (object)

Build server object.

Parameters:

- object:
  - command: (string) Command to start server process.
  - workdir: (string) Value to be passed in TARANTOOL_WORKDIR .
  - chdir: (string) Path to cwd before running a process. (optional)
  - env: (tab) Table to pass as env variables to process. (optional)
  - args: (tab) Args to run command with. (optional)
  - http_port: (int) Value to be passed in TARANTOOL_HTTP_PORT and used to perform HTTP requests. (optional)
  - net_box_port: (int) Value to be passed in TARANTOOL_LISTEN and used for net_box connection. (optional)
  - net_box_credentials: (tab) Override default net_box credentials. (optional)
  - alias: (string) Instance alias. Used to prefix output. (optional)

Returns:

input object.

Server:start ()

Start server process.

Server:stop ()

Stop server process.

Changelog

Unreleased

0.5.2

- Throw parser error when .json is accessed on response with invalid body.
- Set Content-Type: application/json for :http_request(. . . , {json = . . . }) requests.

0.5.1

- Assertions pretty-prints non-string extra messages (useful for custom errors as tables).
- String values in errors are printed as valid Lua strings (with %q formatter).
- Add TARANTOOL_DIR to rockspec build.variables

- Replace –error and –failure options with –fail-fast.
- Fix stripping luatest trace from backtrace.
- Fix luarocks 3 test engine installation.

0.5.0

- assert_is treats box.NULL and nil as different values.
- Add luacov integration.
- Fix assert_items_equals for repeated values. Add support for tuple items.
- Add assert_items_include matcher.
- assert_equals uses same comparison rules for nested values.
- Fix generated group names when running files within specific directory.

0.4.0

- Fix not working –exclude, –pattern options
- Fix error messages for *_covers matchers
- Raise error when group() is called with existing group name.
- Allow dot in group name.
- Prevent using / in group name.
- Decide group name from filename for group() call without args.
- assert returns input values.
- assert[_not]_equals works for Tarantool's box.tuple.
- Print tables in lua-compatible way in errors.
- Fix performance issue with large errors messages.
- Unify hooks definition: group hooks are defined via function calls.
- Keep running other groups when group hook failed.
- Prefix and colorize captured output.
- Fix numeric assertions for cdata values.

0.3.0

- Make –shuffle option accept group, all, none values
- Replace raw option for Server:http_request with raise.
- Remove not documented methods inherited from luaunit.
- Colorize report.

0.2.2

- Fix issue with crashes in capture.
- Do not raise error for 2xx responses in Server:http_request

0.2.1

- Don't run suite hooks when suite is not going to be run.
- Gracefully shutdown even when luanit calls os.exit.
- Show failed tests summary.
- Capture works with large outputs.

0.2.0

- GC'ed processes are killed automatically.
- Print captured output when suite/group hook fails.
- Rename Server:console to Server:net_box.
- Use real time instead of CPU time for duration.
- LDoc comments.
- Make assertions box.NULL aware.
- Luarocks 3 tests engine.
- assert_covers matcher.

0.1.1

- Fix exit code on failure.

0.1.0

- Initial implementation.

5.4 Configuration reference

This reference covers all options and parameters which can be set for Tarantool on the command line or in an initialization file.

Tarantool is started by entering either of the following command:

$ tarantool

$ tarantool options

$ tarantool lua-initialization-file [arguments]

5.4.1 Command options

-h, --help
    Print an annotated list of all available options and exit.

-V, --version
    Print product name and version, for example:

```
$ ./tarantool --version
Tarantool 1.7.0-1216-g73f7154
Target: Linux-x86_64-Debug
...
```

In this example:

"Tarantool" is the name of the reusable asynchronous networking programming framework.

The 3-number version follows the standard <major>-<minor>-<patch> scheme, in which <major> number is changed only rarely, <minor> is incremented for each new milestone and indicates possible incompatible changes, and <patch> stands for the number of bug fix releases made after the start of the milestone. For non-released versions only, there may be a commit number and commit SHA1 to indicate how much this particular build has diverged from the last release.

"Target" is the platform tarantool was built on. Some platform-specific details may follow this line.

Note: Tarantool uses git describe to produce its version id, and this id can be used at any time to check out the corresponding source from our git repository.

5.4.2 URI

Some configuration parameters and some functions depend on a URI, or "Universal Resource Identifier". The URI string format is similar to the generic syntax for a URI schema. So it may contain (in order) a user name for login, a password, a host name or host IP address, and a port number. Only the port number is always mandatory. The password is mandatory if the user name is specified, unless the user name is 'guest'. So, formally, the URI syntax is [host:]port or [username:password@]host:port. If host is omitted, then '0.0.0.0' or '[::]' is assumed, meaning respectively any IPv4 address or any IPv6 address, on the local machine. If username:password is omitted, then 'guest' is assumed. Some examples:

URI fragment	Example
port	3301
host:port	127.0.0.1:3301
username:password@host:port	notguest:sesame@mail.ru:3301

In certain circumstances a Unix domain socket may be used where a URI is expected, for example "unix/:/tmp/unix_domain_socket.sock" or simply "/tmp/unix_domain_socket.sock".

A method for parsing URIs is illustrated in Module uri.

5.4.3 Initialization file

If the command to start Tarantool includes lua-initialization-file, then Tarantool begins by invoking the Lua program in the file, which by convention may have the name "script.lua". The Lua program may get further arguments from the command line or may use operating-system functions, such as getenv(). The

Lua program almost always begins by invoking box.cfg(), if the database server will be used or if ports need to be opened. For example, suppose script.lua contains the lines

```
#!/usr/bin/env tarantool
box.cfg{
    listen              = os.getenv("LISTEN_URI"),
    memtx_memory        = 100000,
    pid_file            = "tarantool.pid",
    wal_max_size        = 2500
}
print('Starting ', arg[1])
```

and suppose the environment variable LISTEN_URI contains 3301, and suppose the command line is ~/tarantool/src/tarantool script.lua ARG. Then the screen might look like this:

```
$ export LISTEN_URI=3301
$ ~/tarantool/src/tarantool script.lua ARG
... main/101/script.lua C> version 1.7.0-1216-g73f7154
... main/101/script.lua C> log level 5
... main/101/script.lua I> mapping 107374184 bytes for a shared arena...
... main/101/script.lua I> recovery start
... main/101/script.lua I> recovering from './00000000000000000000.snap'
... main/101/script.lua I> primary: bound to 0.0.0.0:3301
... main/102/leave_local_hot_standby I> ready to accept requests
Starting  ARG
... main C> entering the event loop
```

If you wish to start an interactive session on the same terminal after initialization is complete, you can use console.start().

5.4.4 Configuration parameters

Configuration parameters have the form:

box.cfg{[key = value [, key = value ...]]}

Since box.cfg may contain many configuration parameters and since some of the parameters (such as directory addresses) are semi-permanent, it's best to keep box.cfg in a Lua file. Typically this Lua file is the initialization file which is specified on the tarantool command line.

Most configuration parameters are for allocating resources, opening ports, and specifying database behavior. All parameters are optional. A few parameters are dynamic, that is, they can be changed at runtime by calling box.cfg{} a second time.

To see all the non-null parameters, say box.cfg (no parentheses). To see a particular parameter, for example the listen address, say box.cfg.listen.

The following sections describe all parameters for basic operation, for storage, for binary logging and snapshots, for replication, for networking, for logging, and for feedback.

Basic parameters

- background
- custom_proc_title
- listen

- memtx_dir
- pid_file
- read_only
- sql_cache_size
- vinyl_dir
- vinyl_timeout
- username
- wal_dir
- work_dir
- worker_pool_threads
- strip_core

background
Since version 1.6.2. Run the server as a background task. The log and pid_file parameters must be non-null for this to work.

Type: boolean
Default: false
Dynamic: no

custom_proc_title
Since version 1.6.7. Add the given string to the server's process title (what's shown in the COMMAND column for ps -ef and top -c commands).

For example, ordinarily ps -ef shows the Tarantool server process thus:

```
$ ps -ef | grep tarantool
1000     14939 14188  1 10:53 pts/2    00:00:13 tarantool <running>
```

But if the configuration parameters include custom_proc_title='sessions' then the output looks like:

```
$ ps -ef | grep tarantool
1000     14939 14188  1 10:53 pts/2    00:00:16 tarantool <running>: sessions
```

Type: string
Default: null
Dynamic: yes

listen
Since version 1.6.4. The read/write data port number or URI (Universal Resource Identifier) string. Has no default value, so must be specified if connections will occur from remote clients that do not use the "admin port". Connections made with listen = URI are called "binary port" or "binary protocol" connections.

A typical value is 3301.

Note: A replica also binds to this port, and accepts connections, but these connections can only serve reads until the replica becomes a master.

Type: integer or string
Default: null
Dynamic: yes

memtx_dir

Since version 1.7.4. A directory where memtx stores snapshot (.snap) files. Can be relative to work_dir. If not specified, defaults to work_dir. See also wal_dir.

Type: string
Default: "."
Dynamic: no

pid_file

Since version 1.4.9. Store the process id in this file. Can be relative to work_dir. A typical value is "tarantool.pid".

Type: string
Default: null
Dynamic: no

read_only

Since version 1.7.1. Say box.cfg{read_only=true...} to put the server instance in read-only mode. After this, any requests that try to change persistent data will fail with error ER_READONLY. Read-only mode should be used for master-replica replication. Read-only mode does not affect data-change requests for spaces defined as temporary. Although read-only mode prevents the server from writing to the WAL, it does not prevent writing diagnostics with the log module.

Type: boolean
Default: false
Dynamic: yes

Setting read_only == true affects spaces differently depending on the options that were used during box.schema.space.create, as summarized by this chart:

Option	Can be created?	Can be written to?	Is replicated?	Is persistent?
(default)	no	no	yes	yes
temporary	no	yes	no	no
is_local	no	yes	no	yes

sql_cache_size

Since version 2.3.1. The maximum number of bytes in the cache for SQL prepared statements. (The number of bytes that are actually used can be seen with box.info.sql().cache.size.)

Type: number
Default: 5242880
Dynamic: yes

vinyl_dir

Since version 1.7.1. A directory where vinyl files or subdirectories will be stored. Can be relative to work_dir. If not specified, defaults to work_dir.

Type: string
Default: "."
Dynamic: no

vinyl_timeout

Since version 1.7.5. The vinyl storage engine has a scheduler which does compaction. When vinyl is low on available memory, the compaction scheduler may be unable to keep up with incoming update requests. In that situation, queries may time out after vinyl_timeout seconds. This should rarely occur, since normally vinyl would throttle inserts when it is running low on compaction bandwidth. Compaction can also be ordered manually with index_object:compact().

Type: float
Default: 60
Dynamic: yes

username

Since version 1.4.9. UNIX user name to switch to after start.

Type: string
Default: null
Dynamic: no

wal_dir

Since version 1.6.2. A directory where write-ahead log (.xlog) files are stored. Can be relative to work_dir. Sometimes wal_dir and memtx_dir are specified with different values, so that write-ahead log files and snapshot files can be stored on different disks. If not specified, defaults to work_dir.

Type: string
Default: "."
Dynamic: no

work_dir

Since version 1.4.9. A directory where database working files will be stored. The server instance switches to work_dir with chdir(2) after start. Can be relative to the current directory. If not specified, defaults to the current directory. Other directory parameters may be relative to work_dir, for example:

```
box.cfg{
    work_dir = '/home/user/A',
    wal_dir = 'B',
    memtx_dir = 'C'
}
```

will put xlog files in /home/user/A/B, snapshot files in /home/user/A/C, and all other files or subdirectories in /home/user/A.

Type: string
Default: null
Dynamic: no

worker_pool_threads

Since version 1.7.5. The maximum number of threads to use during execution of certain internal processes (currently socket.getaddrinfo() and coio_call()).

Type: integer
Default: 4
Dynamic: yes

strip_core

Since version 2.2.2. Whether coredump files should include memory allocated for tuples. (This can be large if Tarantool runs under heavy load.) Setting to true means "do not include". In an older version of Tarantool the default value of this parameter was false.

Type: boolean
Default: true
Dynamic: no

Configuring the storage

- memtx_memory
- memtx_max_tuple_size
- memtx_min_tuple_size
- vinyl_bloom_fpr
- vinyl_cache
- vinyl_max_tuple_size
- vinyl_memory

- vinyl_page_size
- vinyl_range_size
- vinyl_run_count_per_level
- vinyl_run_size_ratio
- vinyl_read_threads
- vinyl_write_threads

memtx_memory

Since version 1.7.4. How much memory Tarantool allocates to actually store tuples. When the limit is reached, INSERT or UPDATE requests begin failing with error ER_MEMORY_ISSUE. The server does not go beyond the memtx_memory limit to allocate tuples, but there is additional memory used to store indexes and connection information. Depending on actual configuration and workload, Tarantool can consume up to 20% more than the memtx_memory limit.

Type: float
Default: 256 * 1024 * 1024 = 268435456 bytes
Dynamic: yes but it cannot be decreased

memtx_max_tuple_size

Since version 1.7.4. Size of the largest allocation unit, for the memtx storage engine. It can be increased if it is necessary to store large tuples. See also: vinyl_max_tuple_size.

Type: integer
Default: 1024 * 1024 = 1048576 bytes
Dynamic: no

memtx_min_tuple_size

Since version 1.7.4. Size of the smallest allocation unit. It can be decreased if most of the tuples are very small. The value must be between 8 and 1048280 inclusive.

Type: integer
Default: 16 bytes
Dynamic: no

vinyl_bloom_fpr

Since version 1.7.4. Bloom filter false positive rate – the suitable probability of the bloom filter to give a wrong result. The vinyl_bloom_fpr setting is a default value for one of the options in the Options for space_object:create_index() chart.

Type: float
Default = 0.05
Dynamic: no

vinyl_cache

Since version 1.7.4. The cache size for the vinyl storage engine. The cache can be resized dynamically.

Type: integer
Default = 128 * 1024 * 1024 = 134217728 bytes
Dynamic: yes

vinyl_max_tuple_size

Since version 1.7.5. Size of the largest allocation unit, for the vinyl storage engine. It can be increased if it is necessary to store large tuples. See also: memtx_max_tuple_size.

Type: integer
Default: 1024 * 1024 = 1048576 bytes
Dynamic: no

vinyl_memory

Since version 1.7.4. The maximum number of in-memory bytes that vinyl uses.

Type: integer
Default = 128 * 1024 * 1024 = 134217728 bytes
Dynamic: yes but it cannot be decreased

vinyl_page_size

Since version 1.7.4. Page size. Page is a read/write unit for vinyl disk operations. The vinyl_page_size setting is a default value for one of the options in the Options for space_object:create_index() chart.

Type: integer
Default = 8 * 1024 = 8192 bytes
Dynamic: no

vinyl_range_size

Since version 1.7.4. The default maximum range size for a vinyl index. The maximum range size affects the decision whether to split a range.

If vinyl_range_size is not nil and not 0, then it is used as the default value for the range_size option in the Options for space_object:create_index() chart.

If vinyl_range_size is nil or 0, and range_size is not specified when the index is created, then Tarantool sets a value later depending on performance considerations. To see the actual value, use index_object:stat().range_size.

In Tarantool versions prior to 1.10.2, vinyl_range_size default value was 1073741824.

Type: integer
Default = nil bytes

Dynamic: no

vinyl_run_count_per_level

Since version 1.7.4. The maximal number of runs per level in vinyl LSM tree. If this number is exceeded, a new level is created. The vinyl_run_count_per_level setting is a default value for one of the options in the Options for space_object:create_index() chart.

Type: integer
Default = 2
Dynamic: no

vinyl_run_size_ratio

Since version 1.7.4. Ratio between the sizes of different levels in the LSM tree. The vinyl_run_size_ratio setting is a default value for one of the options in the Options for space_object:create_index() chart.

Type: float
Default = 3.5
Dynamic: no

vinyl_read_threads

Since version 1.8.2 The maximum number of read threads that vinyl can use for some concurrent operations, such as I/O and compression.

Type: integer
Default = 1
Dynamic: no

vinyl_write_threads

Since version 1.8.2. The maximum number of write threads that vinyl can use for some concurrent operations, such as I/O and compression.

Type: integer
Default = 2
Dynamic: no

Checkpoint daemon

- checkpoint_count
- checkpoint_interval
- checkpoint_wal_threshold

The checkpoint daemon is a fiber which is constantly running. At intervals, it may make new snapshot (.snap) files and then may delete old snapshot files.

The checkpoint_interval and checkpoint_count configuration settings determine how long the intervals are, and how many snapshots should exist before deletions occur.

Tarantool garbage collector

The checkpoint daemon may activate the Tarantool garbage collector which deletes old files. This garbage collector is distinct from the Lua garbage collector which is for Lua objects, and distinct from a Tarantool garbage collector which specializes in handling shard buckets.

If the checkpoint daemon deletes an old snapshot file, then the Tarantool garbage collector will also delete any write-ahead log (.xlog) files which are older than the snapshot file and which contain information that is present in the snapshot file. It will also delete obsolete vinyl .run files.

The checkpoint daemon and the Tarantool garbage collector will not delete a file if:

- a backup is ongoing and the file has not been backed up (see "Hot backup"), or
- replication is ongoing and the file has not been relayed to a replica (see "Replication architecture"),
- a replica is connecting, or
- a replica has fallen behind. The progress of each replica is tracked; if a replica's position is far from being up to date, then the server stops to give it a chance to catch up. If an administrator concludes that a replica is permanently down, then the correct procedure is to restart the server, or (preferably) remove the replica from the cluster.

checkpoint_interval

Since version 1.7.4. The interval between actions by the checkpoint daemon, in seconds. If checkpoint_interval is set to a value greater than zero, and there is activity which causes change to a database, then the checkpoint daemon will call box.snapshot every checkpoint_interval seconds, creating a new snapshot file each time. If checkpoint_interval is set to zero, then the checkpoint daemon is disabled.

For example:

```
box.cfg{checkpoint_interval=60}
```

will cause the checkpoint daemon to create a new database snapshot once per minute, if there is activity.

Type: integer
Default: 3600 (one hour)
Dynamic: yes

checkpoint_count

Since version 1.7.4. The maximum number of snapshots that may exist on the memtx_dir directory before the checkpoint daemon will delete old snapshots. If checkpoint_count equals zero, then the checkpoint daemon does not delete old snapshots. For example:

```
box.cfg{
    checkpoint_interval = 3600,
    checkpoint_count  = 10
}
```

will cause the checkpoint daemon to create a new snapshot each hour until it has created ten snapshots. After that, it will delete the oldest snapshot (and any associated write-ahead-log files) after creating a new one.

Remember that, as noted earlier, snapshots will not be deleted if replication is ongoing and the file has not been relayed to a replica. Therefore checkpoint_count has no effect unless all replicas are alive.

Type: integer
Default: 2
Dynamic: yes

checkpoint_wal_threshold

Since version 2.1.2. The threshold for the total size in bytes of all WAL files created since the last checkpoint. Once the configured threshold is exceeded, the WAL thread notifies the checkpoint daemon that it must make a new checkpoint and delete old WAL files.

This parameter enables administrators to handle a problem that could occur with calculating how much disk space to allocate for a partition containing WAL files.

For example, suppose checkpoint_interval = 2 and checkpoint_count = 5 and the average amount that Tarantool writes between each checkpoint interval = 1 GB. Then one could calculate that the necessary amount is (2*5*1) 10GB. But this calculation would be wrong if, instead of writing 1 GB during one checkpoint interval, Tarantool encounters an unusual spike and tries to write 11 GB, causing an operating-system ENOSPC ("no space") error. By setting checkpoint_wal_threshold to a lower value, say 9 GB, an administrator could prevent the error.

Type: integer
Default: 10^18 (a large number so in effect there is no limit by default)
Dynamic: yes

Binary logging and snapshots

- force_recovery,
- wal_max_size,
- snap_io_rate_limit,
- wal_mode,
- wal_dir_rescan_delay

force_recovery

Since version 1.7.4. If force_recovery equals true, Tarantool tries to continue if there is an error while reading a snapshot file (at server instance start) or a write-ahead log file (at server instance start or when applying an update at a replica): skips invalid records, reads as much data as possible and lets the process finish with a warning. Users can prevent the error from recurring by writing to the database and executing box.snapshot().

Otherwise, Tarantool aborts recovery if there is an error while reading.

Type: boolean
Default: false

Dynamic: no

wal_max_size

Since version 1.7.4. The maximum number of bytes in a single write-ahead log file. When a request would cause an .xlog file to become larger than wal_max_size, Tarantool creates another WAL file.

Type: integer
Default: 268435456 (256 * 1024 * 1024) bytes
Dynamic: no

snap_io_rate_limit

Since version 1.4.9. Reduce the throttling effect of box.snapshot on INSERT/UPDATE/DELETE performance by setting a limit on how many megabytes per second it can write to disk. The same can be achieved by splitting wal_dir and memtx_dir locations and moving snapshots to a separate disk. The limit also affects what box.stat.vinyl().regulator may show for the write rate of dumps to .run and .index files.

Type: float
Default: null
Dynamic: yes

wal_mode

Since version 1.6.2. Specify fiber-WAL-disk synchronization mode as:

- none: write-ahead log is not maintained;
- write: fibers wait for their data to be written to the write-ahead log (no fsync(2));
- fsync: fibers wait for their data, fsync(2) follows each write(2);

Type: string
Default: “write”
Dynamic: no

wal_dir_rescan_delay

Since version 1.6.2. Number of seconds between periodic scans of the write-ahead-log file directory, when checking for changes to write-ahead-log files for the sake of replication or hot standby.

Type: float
Default: 2
Dynamic: no

Hot standby

hot_standby

Since version 1.7.4. Whether to start the server in hot standby mode.

Hot standby is a feature which provides a simple form of failover without replication.

The expectation is that there will be two instances of the server using the same configuration. The first one to start will be the "primary" instance. The second one to start will be the "standby" instance.

To initiate the standby instance, start a second instance of the Tarantool server on the same computer with the same box.cfg configuration settings – including the same directories and same non-null URIs – and with the additional configuration setting hot_standby = true. Expect to see a notification ending with the words I> Entering hot standby mode. This is fine. It means that the standby instance is ready to take over if the primary instance goes down.

The standby instance will initialize and will try to take a lock on wal_dir, but will fail because the primary instance has made a lock on wal_dir. So the standby instance goes into a loop, reading the write ahead log which the primary instance is writing (so the two instances are always in sync), and trying to take the lock. If the primary instance goes down for any reason, the lock will be released. In this case, the standby instance will succeed in taking the lock, will connect on the listen address and will become the primary instance. Expect to see a notification ending with the words I> ready to accept requests.

Thus there is no noticeable downtime if the primary instance goes down.

Hot standby feature has no effect:

- if wal_dir_rescan_delay = a large number (on Mac OS and FreeBSD); on these platforms, it is designed so that the loop repeats every wal_dir_rescan_delay seconds.
- if wal_mode = 'none'; it is designed to work with wal_mode = `'write'` or wal_mode = `'fsync'`.
- for spaces created with engine = 'vinyl'; it is designed to work for spaces created with engine = `'memtx'`.

Type: boolean
Default: false
Dynamic: no

Replication

- replication
- replication_anon
- replication_connect_timeout
- replication_connect_quorum
- replication_skip_conflict
- replication_sync_lag
- replication_sync_timeout
- replication_timeout
- replicaset_uuid

- instance_uuid

replication

Since version 1.7.4. If replication is not an empty string, the instance is considered to be a Tarantool replica. The replica will try to connect to the master specified in replication with a URI (Universal Resource Identifier), for example:

konstantin:secret_password@tarantool.org:3301

If there is more than one replication source in a replica set, specify an array of URIs, for example (replace 'uri' and 'uri2' in this example with valid URIs):

box.cfg{ replication = { 'uri1', 'uri2' } }

If one of the URIs is "self" – that is, if one of the URIs is for the instance where box.cfg{} is being executed on – then it is ignored. Thus it is possible to use the same replication specification on multiple server instances, as shown in these examples.

The default user name is 'guest'.

A read-only replica does not accept data-change requests on the listen port.

The replication parameter is dynamic, that is, to enter master mode, simply set replication to an empty string and issue:

box.cfg{ replication = new-value }

Type: string
Default: null
Dynamic: yes

replication_anon

Since version 2.3.1. A Tarantool replica can be anonymous. This type of replica is read-only (but you still can write to temporary and replica-local spaces), and it isn't present in the _cluster table.

Since an anonymous replica isn't registered in the _cluster table, there is no limitation for anonymous replicas count in a replica set: you can have as many of them as you want.

In order to make a replica anonymous, pass the option replication_anon=true to box.cfg and set read_only to true.

Let's go through anonymous replica bootstrap. Suppose we have got a master configured with

```
box.cfg{listen=3301}
```

and created a local space called "loc":

```
box.schema.space.create('loc', {is_local=true})
box.space.loc:create_index("pk")
```

Now, to configure an anonymous replica, we need to issue box.cfg, as usual.

```
box.cfg{replication_anon=true, read_only=true, replication=3301}
```

As mentioned above, replication_anon may be set to true only together with read_only. The instance will fetch the master's snapshot and start following its changes. It will receive no id, so its id value will remain zero.

```
tarantool> box.info.id
---
- 0
...
tarantool> box.info.replication
---
- 1:
    id: 1
    uuid: 3c84f8d9-e34d-4651-969c-3d0ed214c60f
    lsn: 4
    upstream:
    status: follow
    idle: 0.6912029999985
    peer:
    lag: 0.00014615058898926
...
```

Now we can use the replica. For example, we can do inserts into the local space:

```
tarantool> for i = 1,10 do
    > box.space.loc:insert{i}
    > end
---
...
```

Note that while the instance is anonymous, it will increase the 0-th component of its vclock:

```
tarantool> box.info.vclock
---
- {0: 10, 1: 4}
...
```

Let's now promote the anonymous replica to a regular one:

```
tarantool> box.cfg{replication_anon=false}
2019-12-13 20:34:37.423 [71329] main I> assigned id 2 to replica 6a9c2ed2-b9e1-4c57-a0e8-51a46def7661
2019-12-13 20:34:37.424 [71329] main/102/interactive I> set 'replication_anon' configuration option to false
---
...

tarantool> 2019-12-13 20:34:37.424 [71329] main/117/applier/ I> subscribed
2019-12-13 20:34:37.424 [71329] main/117/applier/ I> remote vclock {1: 5} local vclock {0: 10, 1: 5}
2019-12-13 20:34:37.425 [71329] main/118/applierw/ C> leaving orphan mode
```

The replica has just received an id equal to 2. We can make it read-write now.

```
box.cfg{read_only=false}
2019-12-13 20:35:46.392 [71329] main/102/interactive I> set 'read_only' configuration option to false
---
...

tarantool> box.schema.space.create('test')
---
- engine: memtx
before_replace: 'function: 0x01109f9dc8'
on_replace: 'function: 0x01109f9d90'
ck_constraint: []
```

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```
field_count: 0
temporary: false
index: []
is_local: false
enabled: false
name: test
id: 513
- created
...

tarantool> box.info.vclock
---
- {0: 10, 1: 5, 2: 2}
...
```

Now the replica tracks its changes in the 2nd vclock component, as expected. It can also become a replication master from now on.

Notes:

- You cannot replicate from an anonymous instance.
- To promote an anonymous instance to a regular one, first start it as anonymous, and only then issue box.cfg{replication_anon=false}
- In order for the deanonymization to succeed, the instance must replicate from some read-write instance, otherwise it cannot be added to the _cluster table.

replication_connect_timeout

Since version 1.9.0. The number of seconds that a replica will wait when trying to connect to a master in a cluster. See orphan status for details.

This parameter is different from replication_timeout, which a master uses to disconnect a replica when the master receives no acknowledgments of heartbeat messages.

Type: float
Default: 30
Dynamic: yes

replication_connect_quorum

Since version 1.9.0. By default a replica will try to connect to all the masters, or it will not start. (The default is recommended so that all replicas will receive the same replica set UUID.)

However, by specifying replication_connect_quorum = N, where N is a number greater than or equal to zero, users can state that the replica only needs to connect to N masters.

This parameter has effect during bootstrap and during configuration update. Setting replication_connect_quorum = 0 makes Tarantool require no immediate reconnect only in case of recovery. See orphan status for details.

Example:

```
box.cfg{replication_connect_quorum=2}
```

Type: integer

Default: null

Dynamic: yes

replication_skip_conflict

Since version 1.10.1. By default, if a replica adds a unique key that another replica has added, replication stops with error = ER_TUPLE_FOUND.

However, by specifying replication_skip_conflict = true, users can state that such errors may be ignored. So instead of saving the broken transaction to the xlog, it will be written there as NOP (No operation).

Example:

```
box.cfg{replication_skip_conflict=true}
```

Type: boolean

Default: false

Dynamic: yes

Note: replication_skip_conflict = true is recommended to be used only for manual replication recovery.

---

replication_sync_lag

Since version 1.9.0. The maximum lag allowed for a replica. When a replica syncs (gets updates from a master), it may not catch up completely. The number of seconds that the replica is behind the master is called the "lag". Syncing is considered to be complete when the replica's lag is less than or equal to replication_sync_lag.

If a user sets replication_sync_lag to nil or to 365 * 100 * 86400 (TIMEOUT_INFINITY), then lag does not matter – the replica is always considered to be "synced". Also, the lag is ignored (assumed to be infinite) in case the master is running Tarantool older than 1.7.7, which does not send heartbeat messages.

This parameter is ignored during bootstrap. See orphan status for details.

Type: float

Default: 10

Dynamic: yes

replication_sync_timeout

Since version 1.10.2. The number of seconds that a replica will wait when trying to sync with a master in a cluster, or a quorum of masters, after connecting or during configuration update. This could fail indefinitely if replication_sync_lag is smaller than network latency, or if the replica cannot keep pace with master updates. If replication_sync_timeout expires, the replica enters orphan status.

Type: float

Default: 300

Dynamic: yes

replication_timeout

Since version 1.8.2. If the master has no updates to send to the replicas, it sends heartbeat messages every replication_timeout seconds, and each replica sends an ACK packet back.

Both master and replicas are programmed to drop the connection if they get no response in four replication_timeout periods. If the connection is dropped, a replica tries to reconnect to the master.

See more in Monitoring a replica set.

Type: integer
Default: 1
Dynamic: yes

replicaset_uuid

Since version 1.9.0. As described in section "Replication architecture", each replica set is identified by a universally unique identifier called replica set UUID, and each instance is identified by an instance UUID.

Ordinarily it is sufficient to let the system generate and format the UUID strings which will be permanently stored.

However, some administrators may prefer to store Tarantool configuration information in a central repository, for example Apache ZooKeeper. Such administrators can assign their own UUID values for either – or both – instances (instance_uuid) and replica set (replicaset_uuid), when starting up for the first time.

General rules:

- The values must be true unique identifiers, not shared by other instances or replica sets within the common infrastructure.
- The values must be used consistently, not changed after initial setup (the initial values are stored in snapshot files and are checked whenever the system is restarted).
- The values must comply with RFC 4122. The nil UUID is not allowed.

The UUID format includes sixteen octets represented as 32 hexadecimal (base 16) digits, displayed in five groups separated by hyphens, in the form 8-4-4-4-12 for a total of 36 characters (32 alphanumeric characters and four hyphens).

Example:

```
box.cfg{replicaset_uuid='7b853d13-508b-4b8e-82e6-806f088ea6e9'}
```

Type: string
Default: null
Dynamic: no

instance_uuid

Since version 1.9.0. For replication administration purposes, it is possible to set the universally unique identifiers of the instance (instance_uuid) and the replica set (replicaset_uuid), instead of having the system generate the values.

See the description of replicaset_uuid parameter for details.

Example:

```
box.cfg{instance_uuid='037fec43-18a9-4e12-a684-a42b716fcd02'}
```

Type: string
Default: null
Dynamic: no

Networking

- io_collect_interval,
- net_msg_max
- readahead,

io_collect_interval
Since version 1.4.9. The instance will sleep for io_collect_interval seconds between iterations of the event loop. Can be used to reduce CPU load in deployments in which the number of client connections is large, but requests are not so frequent (for example, each connection issues just a handful of requests per second).

Type: float
Default: null
Dynamic: yes

net_msg_max
Since version 1.10.1. To handle messages, Tarantool allocates fibers. To prevent fiber overhead from affecting the whole system, Tarantool restricts how many messages the fibers handle, so that some pending requests are blocked.

On powerful systems, increase net_msg_max and the scheduler will immediately start processing pending requests.

On weaker systems, decrease net_msg_max and the overhead may decrease although this may take some time because the scheduler must wait until already-running requests finish.

When net_msg_max is reached, Tarantool suspends processing of incoming packages until it has processed earlier messages. This is not a direct restriction of the number of fibers that handle network messages, rather it is a system-wide restriction of channel bandwidth. This in turn causes restriction of the number of incoming network messages that the transaction processor thread handles, and therefore indirectly affects the fibers that handle network messages. (The number of fibers is smaller than the number of messages because messages can be released as soon as they are delivered, while incoming requests might not be processed until some time after delivery.)

On typical systems, the default value (768) is correct.

Type: integer

Default: 768

Dynamic: yes

readahead

Since version 1.6.2. The size of the read-ahead buffer associated with a client connection. The larger the buffer, the more memory an active connection consumes and the more requests can be read from the operating system buffer in a single system call. The rule of thumb is to make sure the buffer can contain at least a few dozen requests. Therefore, if a typical tuple in a request is large, e.g. a few kilobytes or even megabytes, the read-ahead buffer size should be increased. If batched request processing is not used, it's prudent to leave this setting at its default.

Type: integer

Default: 16320

Dynamic: yes

Logging

- log_level
- log
- log_nonblock
- too_long_threshold
- log_format

log_level

Since version 1.6.2. What level of detail the log will have. There are seven levels:

- 1 – SYSERROR
- 2 – ERROR
- 3 – CRITICAL
- 4 – WARNING
- 5 – INFO
- 6 – VERBOSE
- 7 – DEBUG

By setting log_level, one can enable logging of all classes below or equal to the given level. Tarantool prints its logs to the standard error stream by default, but this can be changed with the log configuration parameter.

Type: integer

Default: 5

Dynamic: yes

Warning: prior to Tarantool 1.7.5 there were only six levels and DEBUG was level 6. Starting with Tarantool 1.7.5 VERBOSE is level 6 and DEBUG is level 7. VERBOSE is a new level for monitoring repetitive events which would cause too much log writing if INFO were used instead.

log

Since version 1.7.4. By default, Tarantool sends the log to the standard error stream (stderr). If log is specified, Tarantool sends the log to a file, or to a pipe, or to the system logger.

Example setting for sending the log to a file:

```
box.cfg{log = 'tarantool.log'}
-- or
box.cfg{log = 'file:tarantool.log'}
```

This will open the file tarantool.log for output on the server's default directory. If the log string has no prefix or has the prefix "file:", then the string is interpreted as a file path.

Example setting for sending the log to a pipe:

```
box.cfg{log = '| cronolog tarantool.log'}
-- or
box.cfg{log = 'pipe: cronolog tarantool.log'}'
```

This will start the program cronolog when the server starts, and will send all log messages to the standard input (stdin) of cronolog. If the log string begins with '|' or has the prefix "pipe:", then the string is interpreted as a Unix pipeline.

Example setting for sending the log to syslog:

```
box.cfg{log = 'syslog:identity=tarantool'}
-- or
box.cfg{log = 'syslog:facility=user'}
-- or
box.cfg{log = 'syslog:identity=tarantool,facility=user'}
-- or
box.cfg{log = 'syslog:server=unix:/dev/log'}
```

If the log string begins with "syslog:", then it is interpreted as a message for the syslogd program which normally is running in the background of any Unix-like platform. The setting can be 'syslog:', 'syslog:facility=. . . ', 'syslog:identity=. . . ', 'syslog:server=. . . ', or a combination.

The syslog:identity setting is an arbitrary string which will be placed at the beginning of all messages. The default value is: tarantool.

The syslog:facility setting is currently ignored but will be used in the future. The value must be one of the syslog keywords, which tell syslogd where the message should go. The possible values are: auth, authpriv, cron, daemon, ftp, kern, lpr, mail, news, security, syslog, user, uucp, local0, local1, local2, local3, local4, local5, local6, local7. The default value is: user.

The syslog:server setting is the locator for the syslog server. It can be a Unix socket path beginning with "unix:", or an ipv4 port number. The default socket value is: dev/log (on Linux) or /var/run/syslog (on Mac OS). The default port value is: 514, the UDP port.

When logging to a file, Tarantool reopens the log on SIGHUP. When log is a program, its pid is saved in the log.logger_pid variable. You need to send it a signal to rotate logs.

Type: string
Default: null
Dynamic: no

log_nonblock

Since version 1.7.4. If log_nonblock equals true, Tarantool does not block during logging when the system is not ready for writing, and drops the message instead. If log_level is high, and many messages go to the log, setting log_nonblock to true may improve logging performance at the cost of some log messages getting lost.

This parameter has effect only if the output is going to "syslog:" or "pipe:". Setting log_nonblock to true is illegal if the output is going to a file.

The default log_nonblock value is nil, which means that blocking behavior corresponds to the type of logger. This is a behavior change: in earlier versions of the Tarantool server, the default value was true.

Type: boolean

Default: nil

Dynamic: no

too_long_threshold

Since version 1.6.2. If processing a request takes longer than the given value (in seconds), warn about it in the log. Has effect only if log_level is more than or equal to 4 (WARNING).

Type: float

Default: 0.5

Dynamic: yes

log_format

Since version 1.7.6. Log entries have two possible formats:

- 'plain' (the default), or
- 'json' (with more detail and with JSON labels).

Here is what a log entry looks like after box.cfg{log_format='plain'}:

```
2017-10-16 11:36:01.508 [18081] main/101/interactive I> set 'log_format' configuration option to "plain"
```

Here is what a log entry looks like after box.cfg{log_format='json'}:

```
{"time": "2017-10-16T11:36:17.996-0600",
"level": "INFO",
"message": "set 'log_format' configuration option to \"json\"",
"pid": 18081,|
"cord_name": "main",
"fiber_id": 101,
"fiber_name": "interactive",
"file": "builtin\/box\/load_cfg.lua",
"line": 317}
```

The log_format='plain' entry has time, process id, cord name, fiber_id, fiber_name, log level, and message.

The log_format='json' entry has the same things along with their labels, and in addition has the file name and line number of the Tarantool source.

Setting log_format to 'json' is illegal if the output is going to "syslog:".

Type: string
Default: 'plain'
Dynamic: yes

Logging example

This will illustrate how "rotation" works, that is, what happens when the server instance is writing to a log and signals are used when archiving it.

Start with two terminal shells, Terminal #1 and Terminal #2.

On Terminal #1: start an interactive Tarantool session, then say the logging will go to Log_file, then put a message "Log Line #1" in the log file:

```
box.cfg{log='Log_file'}
log = require('log')
log.info('Log Line #1')
```

On Terminal #2: use mv so the log file is now named Log_file.bak. The result of this is: the next log message will go to Log_file.bak.

```
mv Log_file Log_file.bak
```

On Terminal #1: put a message "Log Line #2" in the log file.

```
log.info('Log Line #2')
```

On Terminal #2: use ps to find the process ID of the Tarantool instance.

```
ps -A | grep tarantool
```

On Terminal #2: use kill -HUP to send a SIGHUP signal to the Tarantool instance. The result of this is: Tarantool will open Log_file again, and the next log message will go to Log_file. (The same effect could be accomplished by executing log.rotate() on the instance.)

kill -HUP process_id

On Terminal #1: put a message "Log Line #3" in the log file.

```
log.info('Log Line #3')
```

On Terminal #2: use less to examine files. Log_file.bak will have these lines, except that the date and time will depend on when the example is done:

```
2015-11-30 15:13:06.373 [27469] main/101/interactive I> Log Line #1`
2015-11-30 15:14:25.973 [27469] main/101/interactive I> Log Line #2`
```

and Log_file will have

```
log file has been reopened
2015-11-30 15:15:32.629 [27469] main/101/interactive I> Log Line #3
```

Feedback

- feedback_enabled
- feedback_host
- feedback_interval

By default a Tarantool daemon sends a small packet once per hour, to https://feedback.tarantool.io. The packet contains three values from box.info: box.info.version, box.info.uuid, and box.info.cluster_uuid. By changing the feedback configuration parameters, users can adjust or turn off this feature.

feedback_enabled

Since version 1.10.1 Whether to send feedback.

If this is set to true, feedback will be sent as described above. If this is set to false, no feedback will be sent.

Type: boolean
Default: true
Dynamic: yes

feedback_host

Since version 1.10.1. The address to which the packet is sent. Usually the recipient is Tarantool, but it can be any URL.

Type: string
Default: 'https://feedback.tarantool.io'
Dynamic: yes

feedback_interval

Since version 1.10.1. The number of seconds between sendings, usually 3600 (1 hour).

Type: float
Default: 3600
Dynamic: yes

Deprecated parameters

These parameters are deprecated since Tarantool version 1.7.4:

- coredump
- logger
- logger_nonblock
- panic_on_snap_error,
- panic_on_wal_error
- replication_source

- slab_alloc_arena
- slab_alloc_factor
- slab_alloc_maximal
- slab_alloc_minimal
- snap_dir
- snapshot_count
- snapshot_period
- rows_per_wal

coredump
: Deprecated, do not use.

  Type: boolean
  Default: false
  Dynamic: no

logger
: Deprecated in favor of log. The parameter was only renamed, while the type, values and semantics remained intact.

logger_nonblock
: Deprecated in favor of log_nonblock. The parameter was only renamed, while the type, values and semantics remained intact.

panic_on_snap_error
: Deprecated in favor of force_recovery.

  If there is an error while reading a snapshot file (at server instance start), abort.

  Type: boolean
  Default: true
  Dynamic: no

panic_on_wal_error
: Deprecated in favor of force_recovery.

  Type: boolean
  Default: true
  Dynamic: yes

replication_source
: Deprecated in favor of replication. The parameter was only renamed, while the type, values and semantics remained intact.

slab_alloc_arena
Deprecated in favor of memtx_memory.

How much memory Tarantool allocates to actually store tuples, in gigabytes. When the limit is reached, INSERT or UPDATE requests begin failing with error ER_MEMORY_ISSUE. While the server does not go beyond the defined limit to allocate tuples, there is additional memory used to store indexes and connection information. Depending on actual configuration and workload, Tarantool can consume up to 20% more than the limit set here.

Type: float
Default: 1.0
Dynamic: no

slab_alloc_factor
Deprecated, do not use.

The multiplier for computing the sizes of memory chunks that tuples are stored in. A lower value may result in less wasted memory depending on the total amount of memory available and the distribution of item sizes.

Type: float
Default: 1.1
Dynamic: no

slab_alloc_maximal
Deprecated in favor of memtx_max_tuple_size. The parameter was only renamed, while the type, values and semantics remained intact.

slab_alloc_minimal
Deprecated in favor of memtx_min_tuple_size. The parameter was only renamed, while the type, values and semantics remained intact.

snap_dir
Deprecated in favor of memtx_dir. The parameter was only renamed, while the type, values and semantics remained intact.

snapshot_period
Deprecated in favor of checkpoint_interval. The parameter was only renamed, while the type, values and semantics remained intact.

snapshot_count
Deprecated in favor of checkpoint_count. The parameter was only renamed, while the type, values and semantics remained intact.

rows_per_wal
Deprecated in favour of wal_max_size. The parameter does not allow to properly limit size of WAL logs.

5.5 C API reference

5.5.1 Module box

box_function_ctx_t

Opaque structure passed to a C stored procedure

int box_return_tuple(box_function_ctx_t *ctx, box_tuple_t *tuple)

Return a tuple from a C stored procedure.

The returned tuple is automatically reference-counted by Tarantool. An example program that uses box_return_tuple() is write.c.

Parameters

- ctx (box_funtion_ctx_t*) – an opaque structure passed to the C stored procedure by Tarantool
- tuple (box_tuple_t*) – a tuple to return

Returns -1 on error (perhaps, out of memory; check box_error_last())

Returns 0 otherwise

uint32_t box_space_id_by_name(const char *name, uint32_t len)

Find space id by name.

This function performs a SELECT request on the _vspace system space.

Parameters

- char* name (const) – space name
- len (uint32_t) – length of name

Returns BOX_ID_NIL on error or if not found (check box_error_last())

Returns space_id otherwise

See also: box_index_id_by_name

uint32_t box_index_id_by_name(uint32_t space_id, const char *name, uint32_t len)

Find index id by name.

This function performs a SELECT request on the _vindex system space.

Parameters

- space_id (uint32_t) – space identifier
- char* name (const) – index name
- len (uint32_t) – length of name

Returns BOX_ID_NIL on error or if not found (check box_error_last())

Returns space_id otherwise

See also: box_space_id_by_name

int box_insert(uint32_t space_id, const char *tuple, const char *tuple_end, box_tuple_t **result)

Execute an INSERT/REPLACE request.

Parameters

- space_id (uint32_t) – space identifier

- char* tuple (const) – encoded tuple in MsgPack Array format ([field1, field2, …])
- char* tuple_end (const) – end of a tuple
- result (box_tuple_t**) – output argument. Resulting tuple. Can be set to NULL to discard result

Returns -1 on error (check box_error_last())

Returns 0 otherwise

See also space_object.insert()

int box_replace(uint32_t space_id, const char *tuple, const char *tuple_end, box_tuple_t **result)
Execute a REPLACE request.

Parameters

- space_id (uint32_t) – space identifier
- char* tuple (const) – encoded tuple in MsgPack Array format ([field1, field2, …])
- char* tuple_end (const) – end of a tuple
- result (box_tuple_t**) – output argument. Resulting tuple. Can be set to NULL to discard result

Returns -1 on error (check box_error_last())

Returns 0 otherwise

See also space_object.replace()

int box_delete(uint32_t space_id, uint32_t index_id, const char *key, const char *key_end, box_tuple_t **result)
Execute a DELETE request.

Parameters

- space_id (uint32_t) – space identifier
- index_id (uint32_t) – index identifier
- char* key (const) – encoded key in MsgPack Array format ([field1, field2, …])
- char* key_end (const) – end of a key
- result (box_tuple_t**) – output argument. An old tuple. Can be set to NULL to discard result

Returns -1 on error (check box_error_last())

Returns 0 otherwise

See also space_object.delete()

int box_update(uint32_t space_id, uint32_t index_id, const char *key, const char *key_end, const char *ops, const char *ops_end, int index_base, box_tuple_t **result)
Execute an UPDATE request.

Parameters

- space_id (uint32_t) – space identifier
- index_id (uint32_t) – index identifier
- char* key (const) – encoded key in MsgPack Array format ([field1, field2, …])
- char* key_end (const) – end of a key

- char* ops (const) – encoded operations in MsgPack Array format, e.g. [['=', field_id, value], ['!', 2, 'xxx']]
- char* ops_end (const) – end of an ops section
- index_base (int) – 0 if field_ids are zero-based as in C, 1 if field ids are 1-based as in Lua
- result (box_tuple_t**) – output argument. An old tuple. Can be set to NULL to discard result

Returns -1 on error (check box_error_last())

Returns 0 otherwise

See also space_object.update()

int box_upsert(uint32_t space_id, uint32_t index_id, const char *tuple, const char *tuple_end, const char *ops, const char *ops_end, int index_base, box_tuple_t **result)

Execute an UPSERT request.

Parameters

- space_id (uint32_t) – space identifier
- index_id (uint32_t) – index identifier
- char* tuple (const) – encoded tuple in MsgPack Array format ([field1, field2, . . .])
- char* tuple_end (const) – end of a tuple
- char* ops (const) – encoded operations in MsgPack Array format, e.g. [['=', field_id, value], ['!', 2, 'xxx']]
- char* ops_end (const) – end of a ops
- index_base (int) – 0 if field_ids are zero-based as in C, 1 if field ids are 1-based as in Lua
- result (box_tuple_t**) – output argument. An old tuple. Can be set to NULL to discard result

Returns -1 on error (check :box_error_last())

Returns 0 otherwise

See also space_object.upsert()

int box_truncate(uint32_t space_id)

Truncate a space.

Parameters

- space_id (uint32_t) – space identifier

5.5.2 Module clock

double clock_realtime(void)
double clock_monotonic(void)
double clock_process(void)
double clock_thread(void)

uint64_t clock_realtime64(void)
uint64_t clock_monotonic64(void)
uint64_t clock_process64(void)

uint64_t clock_thread64(void)

5.5.3 Module coio

enum COIO_EVENT

enumerator COIO_READ
READ event

enumerator COIO_WRITE
WRITE event

int coio_wait(int fd, int event, double timeout)
Wait until READ or WRITE event on socket (fd). Yields.

Parameters

- fd (int) – non-blocking socket file description
- event (int) – requested events to wait. Combination of COIO_READ | COIO_WRITE bit flags.
- timeout (double) – timeout in seconds.

Returns 0 - timeout

Returns >0 - returned events. Combination of TNT_IO_READ | TNT_IO_WRITE bit flags.

ssize_t coio_call(ssize_t (*func)(va_list), ...)
Create new eio task with specified function and arguments. Yield and wait until the task is complete. This function may use the worker_pool_threads configuration parameter.

To avoid double error checking, this function does not throw exceptions. In most cases it is also necessary to check the return value of the called function and perform necessary actions. If func sets errno, the errno is preserved across the call.

Returns -1 and errno = ENOMEM if failed to create a task

Returns the function's return (errno is preserved).

Example:

```
static ssize_t openfile_cb(va_list ap)
{
        const char* filename = va_arg(ap);
        int flags = va_arg(ap);
        return open(filename, flags);
}

if (coio_call(openfile_cb, "/tmp/file", 0) == -1)
    // handle errors.
...
```

int coio_getaddrinfo(const char *host, const char *port, const struct addrinfo *hints, struct addrinfo **res, double timeout)
Fiber-friendly version of getaddrinfo(3).

int coio_close(int fd)
Close the fd and wake any fiber blocked in coio_wait() call on this fd.

Parameters

- fd (int) – non-blocking socket file description

Returns the result of close(fd), see close(2)

5.5.4 Module error

enum box_error_code

enumerator ER_UNKNOWN

enumerator ER_ILLEGAL_PARAMS

enumerator ER_MEMORY_ISSUE

enumerator ER_TUPLE_FOUND

enumerator ER_TUPLE_NOT_FOUND

enumerator ER_UNSUPPORTED

enumerator ER_NONMASTER

enumerator ER_READONLY

enumerator ER_INJECTION

enumerator ER_CREATE_SPACE

enumerator ER_SPACE_EXISTS

enumerator ER_DROP_SPACE

enumerator ER_ALTER_SPACE

enumerator ER_INDEX_TYPE

enumerator ER_MODIFY_INDEX

enumerator ER_LAST_DROP

enumerator ER_TUPLE_FORMAT_LIMIT

enumerator ER_DROP_PRIMARY_KEY

enumerator ER_KEY_PART_TYPE

enumerator ER_EXACT_MATCH

enumerator ER_INVALID_MSGPACK

enumerator ER_PROC_RET

enumerator ER_TUPLE_NOT_ARRAY

enumerator ER_FIELD_TYPE

enumerator ER_FIELD_TYPE_MISMATCH

enumerator ER_SPLICE

enumerator ER_UPDATE_ARG_TYPE

enumerator ER_TUPLE_IS_TOO_LONG

enumerator ER_UNKNOWN_UPDATE_OP

enumerator ER_UPDATE_FIELD

enumerator ER_FIBER_STACK

enumerator ER_KEY_PART_COUNT

enumerator ER_PROC_LUA

enumerator ER_NO_SUCH_PROC

enumerator ER_NO_SUCH_TRIGGER

enumerator ER_NO_SUCH_INDEX

enumerator ER_NO_SUCH_SPACE

enumerator ER_NO_SUCH_FIELD

enumerator ER_EXACT_FIELD_COUNT

enumerator ER_INDEX_FIELD_COUNT

enumerator ER_WAL_IO

enumerator ER_MORE_THAN_ONE_TUPLE

enumerator ER_ACCESS_DENIED

enumerator ER_CREATE_USER

enumerator ER_DROP_USER

enumerator ER_NO_SUCH_USER

enumerator ER_USER_EXISTS

enumerator ER_PASSWORD_MISMATCH

enumerator ER_UNKNOWN_REQUEST_TYPE

enumerator ER_UNKNOWN_SCHEMA_OBJECT

enumerator ER_CREATE_FUNCTION

enumerator ER_NO_SUCH_FUNCTION

enumerator ER_FUNCTION_EXISTS

enumerator ER_FUNCTION_ACCESS_DENIED

enumerator ER_FUNCTION_MAX

enumerator ER_SPACE_ACCESS_DENIED

enumerator ER_USER_MAX

enumerator ER_NO_SUCH_ENGINE

enumerator ER_RELOAD_CFG

enumerator ER_CFG

enumerator ER_UNUSED60

enumerator ER_UNUSED61

enumerator ER_UNKNOWN_REPLICA

enumerator ER_REPLICASET_UUID_MISMATCH

enumerator ER_INVALID_UUID

enumerator ER_REPLICASET_UUID_IS_RO

enumerator ER_INSTANCE_UUID_MISMATCH

enumerator ER_REPLICA_ID_IS_RESERVED

enumerator ER_INVALID_ORDER

enumerator ER_MISSING_REQUEST_FIELD

enumerator ER_IDENTIFIER

enumerator ER_DROP_FUNCTION

enumerator ER_ITERATOR_TYPE

enumerator ER_REPLICA_MAX

enumerator ER_INVALID_XLOG

enumerator ER_INVALID_XLOG_NAME

enumerator ER_INVALID_XLOG_ORDER

enumerator ER_NO_CONNECTION

enumerator ER_TIMEOUT

enumerator ER_ACTIVE_TRANSACTION

enumerator ER_NO_ACTIVE_TRANSACTION

enumerator ER_CROSS_ENGINE_TRANSACTION

enumerator ER_NO_SUCH_ROLE

enumerator ER_ROLE_EXISTS

enumerator ER_CREATE_ROLE

enumerator ER_INDEX_EXISTS

enumerator ER_TUPLE_REF_OVERFLOW

enumerator ER_ROLE_LOOP

enumerator ER_GRANT

enumerator ER_PRIV_GRANTED

enumerator ER_ROLE_GRANTED

enumerator ER_PRIV_NOT_GRANTED

enumerator ER_ROLE_NOT_GRANTED

enumerator ER_MISSING_SNAPSHOT

enumerator ER_CANT_UPDATE_PRIMARY_KEY

enumerator ER_UPDATE_INTEGER_OVERFLOW

enumerator ER_GUEST_USER_PASSWORD

enumerator ER_TRANSACTION_CONFLICT

enumerator ER_UNSUPPORTED_ROLE_PRIV

enumerator ER_LOAD_FUNCTION

enumerator ER_FUNCTION_LANGUAGE

enumerator ER_RTREE_RECT

enumerator ER_PROC_C

enumerator ER_UNKNOWN_RTREE_INDEX_DISTANCE_TYPE

enumerator ER_PROTOCOL

enumerator ER_UPSERT_UNIQUE_SECONDARY_KEY

enumerator ER_WRONG_INDEX_RECORD

enumerator ER_WRONG_INDEX_PARTS

enumerator ER_WRONG_INDEX_OPTIONS

enumerator ER_WRONG_SCHEMA_VERSION

enumerator ER_MEMTX_MAX_TUPLE_SIZE

enumerator ER_WRONG_SPACE_OPTIONS

enumerator ER_UNSUPPORTED_INDEX_FEATURE

enumerator ER_VIEW_IS_RO

enumerator ER_UNUSED114

enumerator ER_SYSTEM

enumerator ER_LOADING

enumerator ER_CONNECTION_TO_SELF

enumerator ER_KEY_PART_IS_TOO_LONG

enumerator ER_COMPRESSION

enumerator ER_CHECKPOINT_IN_PROGRESS

enumerator ER_SUB_STMT_MAX

enumerator ER_COMMIT_IN_SUB_STMT

enumerator ER_ROLLBACK_IN_SUB_STMT

enumerator ER_DECOMPRESSION

enumerator ER_INVALID_XLOG_TYPE

enumerator ER_ALREADY_RUNNING

enumerator ER_INDEX_FIELD_COUNT_LIMIT

enumerator ER_LOCAL_INSTANCE_ID_IS_READ_ONLY

enumerator ER_BACKUP_IN_PROGRESS

enumerator ER_READ_VIEW_ABORTED

enumerator ER_INVALID_INDEX_FILE

enumerator ER_INVALID_RUN_FILE

enumerator ER_INVALID_VYLOG_FILE

enumerator ER_CHECKPOINT_ROLLBACK

enumerator ER_VY_QUOTA_TIMEOUT

enumerator ER_PARTIAL_KEY

enumerator ER_TRUNCATE_SYSTEM_SPACE

enumerator box_error_code_MAX

box_error_t
Error - contains information about error.

const char * box_error_type(const box_error_t *error)
Return the error type, e.g. "ClientError", "SocketError", etc.

Parameters

- error (box_error_t*) – error

Returns not-null string

uint32_t box_error_code(const box_error_t *error)
Return IPROTO error code

Parameters

- error (box_error_t*) – error

Returns enum box_error_code

const char * box_error_message(const box_error_t *error)
Return the error message

Parameters

- error (box_error_t*) – error

Returns not-null string

box_error_t * box_error_last(void)
Get the information about the last API call error.

The Tarantool error handling works most like libc's errno. All API calls return -1 or NULL in the event of error. An internal pointer to box_error_t type is set by API functions to indicate what went wrong. This value is only significant if API call failed (returned -1 or NULL).

Successful function can also touch the last error in some cases. You don't have to clear the last error before calling API functions. The returned object is valid only until next call to any API function.

You must set the last error using box_error_set() in your stored C procedures if you want to return a custom error message. You can re-throw the last API error to IPROTO client by keeping the current value and returning -1 to Tarantool from your stored procedure.

Returns last error

void box_error_clear(void)
Clear the last error.

int box_error_set(const char *file, unsigned line, uint32_t code, const char *format, ...)
Set the last error.

Parameters

- char* file (const) –
- line (unsigned) –
- code (uint32_t) – IPROTO error code
- char* format (const) –
- ... – format arguments

See also: IPROTO error code

box_error_raise(code, format, ...)
A backward-compatible API define.

5.5.5 Module fiber

struct fiber
Fiber - contains information about a fiber.

typedef int (*fiber_func)(va_list)
Function to run inside a fiber.

struct fiber *fiber_new(const char *name, fiber_func f)
Create a new fiber.

Takes a fiber from the fiber cache, if it's not empty. Can fail only if there is not enough memory for the fiber structure or fiber stack.

The created fiber automatically returns itself to the fiber cache when its "main" function completes.

Parameters

- char* name (const) – string with fiber name
- f (fiber_func) – func for run inside fiber

See also: fiber_start()

struct fiber *fiber_new_ex(const char *name, const struct fiber_attr *fiber_attr, fiber_func f)
Create a new fiber with defined attributes.

Can fail only if there is not enough memory for the fiber structure or fiber stack.

The created fiber automatically returns itself to the fiber cache if has a default stack size when its "main" function completes.

Parameters

- char* name (const) – string with fiber name
- struct fiber_attr* fiber_attr (const) – fiber attributes container
- f (fiber_func) – function to run inside the fiber

See also: fiber_start()

void fiber_start(struct fiber *callee, ...)
Start execution of created fiber.

Parameters

- fiber* callee (struct) – fiber to start
- ... – arguments to start the fiber with

void fiber_yield(void)
Return control to another fiber and wait until it'll be woken.

See also: fiber_wakeup()

void fiber_wakeup(struct fiber *f)
Interrupt a synchronous wait of a fiber

Parameters

- fiber* f (struct) – fiber to be woken up

void fiber_cancel(struct fiber *f)
Cancel the subject fiber (set FIBER_IS_CANCELLED flag)

If target fiber's flag FIBER_IS_CANCELLABLE set, then it would be woken up (maybe prematurely). Then current fiber yields until the target fiber is dead (or is woken up by fiber_wakeup()).

Parameters

- fiber* f (struct) – fiber to be cancelled

bool fiber_set_cancellable(bool yesno)
Make it possible or not possible to wakeup the current fiber immediately when it's cancelled.

Parameters

- fiber* f (struct) – fiber
- yesno (bool) – status to set

Returns previous state

void fiber_set_joinable(struct fiber *fiber, bool yesno)
Set fiber to be joinable (false by default).

Parameters

- fiber* f (struct) – fiber
- yesno (bool) – status to set

void fiber_join(struct fiber *f)
Wait until the fiber is dead and then move its execution status to the caller. The fiber must not be detached.

Parameters

- fiber* f (struct) – fiber to be woken up

Before: FIBER_IS_JOINABLE flag is set.

See also: fiber_set_joinable()

void fiber_sleep(double s)
Put the current fiber to sleep for at least 's' seconds.

Parameters

- s (double) – time to sleep

Note: this is a cancellation point.

See also: fiber_is_cancelled()

bool fiber_is_cancelled(void)
Check current fiber for cancellation (it must be checked manually).

double fiber_time(void)
Report loop begin time as double (cheap).

uint64_t fiber_time64(void)
Report loop begin time as 64-bit int.

void fiber_reschedule(void)
Reschedule fiber to end of event loop cycle.

struct slab_cache

struct slab_cache *cord_slab_cache(void)
: Return slab_cache suitable to use with tarantool/small library

struct fiber *fiber_self(void)
: Return the current fiber.

struct fiber_attr

void fiber_attr_new(void)
: Create a new fiber attributes container and initialize it with default parameters.

  Can be used for creating many fibers: corresponding fibers will not take ownership.

void fiber_attr_delete(struct fiber_attr *fiber_attr)
: Delete the fiber_attr and free all allocated resources. This is safe when fibers created with this attribute still exist.

  Parameters

  - fiber_attr* fiber_attribute (struct) – fiber attributes container

int fiber_attr_setstacksize(struct fiber_attr *fiber_attr, size_t stack_size)
: Set the fiber's stack size in the fiber attributes container.

  Parameters

  - fiber_attr* fiber_attr (struct) – fiber attributes container
  - stack_size (size_t) – stack size for new fibers (in bytes)

  Returns 0 on success

  Returns -1 on failure (if stack_size is smaller than the minimum allowable fiber stack size)

size_t fiber_attr_getstacksize(struct fiber_attr *fiber_attr)
: Get the fiber's stack size from the fiber attributes container.

  Parameters

  - fiber_attr* fiber_attr (struct) – fiber attributes container, or NULL for default

  Returns stack size (in bytes)

struct fiber_cond
: A conditional variable: a synchronization primitive that allow fibers in Tarantool's cooperative multitasking environment to yield until some predicate is satisfied.

  Fiber conditions have two basic operations – "wait" and "signal", – where "wait" suspends the execution of a fiber (i.e. yields) until "signal" is called.

  Unlike pthread_cond, fiber_cond doesn't require mutex/latch wrapping.

struct fiber_cond *fiber_cond_new(void)
: Create a new conditional variable.

void fiber_cond_delete(struct fiber_cond *cond)
: Delete the conditional variable.

  Note: behavior is undefined if there are fibers waiting for the conditional variable.

  Parameters

  - fiber_cond* cond (struct) – conditional variable to delete

void fiber_cond_signal(struct fiber_cond *cond);
: Wake up one (any) of the fibers waiting for the conditional variable.

Does nothing if no one is waiting.

Parameters

- fiber_cond* cond (struct) – conditional variable

void fiber_cond_broadcast(struct fiber_cond *cond);
Wake up all fibers waiting for the conditional variable.

Does nothing if no one is waiting.

Parameters

- fiber_cond* cond (struct) – conditional variable

int fiber_cond_wait_timeout(struct fiber_cond *cond, double timeout)
Suspend the execution of the current fiber (i.e. yield) until fiber_cond_signal() is called.

Like pthread_cond, fiber_cond can issue spurious wake ups caused by explicit fiber_wakeup() or fiber_cancel() calls. It is highly recommended to wrap calls to this function into a loop and check the actual predicate and fiber_is_cancelled() on every iteration.

Parameters

- fiber_cond* cond (struct) – conditional variable
- double timeout (struct) – timeout in seconds

Returns 0 on fiber_cond_signal() call or a spurious wake up

Returns -1 on timeout, and the error code is set to 'TimedOut'

int fiber_cond_wait(struct fiber_cond *cond)
Shortcut for fiber_cond_wait_timeout().

5.5.6 Module index

box_iterator_t
A space iterator

enum iterator_type
Controls how to iterate over tuples in an index. Different index types support different iterator types. For example, one can start iteration from a particular value (request key) and then retrieve all tuples where keys are greater or equal (= GE) to this key.

If iterator type is not supported by the selected index type, iterator constructor must fail with ER_UNSUPPORTED. To be selectable for primary key, an index must support at least ITER_EQ and ITER_GE types.

NULL value of request key corresponds to the first or last key in the index, depending on iteration direction. (first key for GE and GT types, and last key for LE and LT). Therefore, to iterate over all tuples in an index, one can use ITER_GE or ITER_LE iteration types with start key equal to NULL. For ITER_EQ, the key must not be NULL.

enumerator ITER_EQ
key == x ASC order

enumerator ITER_REQ
key == x DESC order

enumerator ITER_ALL
all tuples

enumerator ITER_LT
    key < x

enumerator ITER_LE
    key <= x

enumerator ITER_GE
    key >= x

enumerator ITER_GT
    key > x

enumerator ITER_BITS_ALL_SET
    all bits from x are set in key

enumerator ITER_BITS_ANY_SET
    at least one x's bit is set

enumerator ITER_BITS_ALL_NOT_SET
    all bits are not set

enumerator ITER_OVERLAPS
    key overlaps x

enumerator ITER_NEIGHBOR
    tuples in distance ascending order from specified point

box_iterator_t *box_index_iterator(uint32_t space_id, uint32_t index_id, int type, const char *key, const char *key_end)

Allocate and initialize iterator for space_id, index_id.

The returned iterator must be destroyed by box_iterator_free.

Parameters

- space_id (uint32_t) – space identifier
- index_id (uint32_t) – index identifier
- type (int) – iterator_type
- char* key (const) – encode key in MsgPack Array format ([part1, part2, . . .])
- char* key_end (const) – the end of encoded key

Returns NULL on error (check box_error_last)

Returns iterator otherwise

See also box_iterator_next, box_iterator_free

int box_iterator_next(box_iterator_t *iterator, box_tuple_t **result)

Retrieve the next item from the iterator.

Parameters

- iterator (box_iterator_t*) – an iterator returned by box_index_iterator
- result (box_tuple_t**) – output argument. result a tuple or NULL if there is no more data.

Returns -1 on error (check box_error_last)

Returns 0 on success. The end of data is not an error.

void box_iterator_free(box_iterator_t *iterator)

Destroy and deallocate iterator.

Parameters

- iterator (box_iterator_t*) – an iterator returned by box_index_iterator

int iterator_direction(enum iterator_type type)
Determine a direction of the given iterator type: -1 for REQ, LT, LE, and +1 for all others.

ssize_t box_index_len(uint32_t space_id, uint32_t index_id)
Return the number of element in the index.

Parameters

- space_id (uint32_t) – space identifier
- index_id (uint32_t) – index identifier

Returns -1 on error (check box_error_last)

Returns >= 0 otherwise

ssize_t box_index_bsize(uint32_t space_id, uint32_t index_id)
Return the number of bytes used in memory by the index.

Parameters

- space_id (uint32_t) – space identifier
- index_id (uint32_t) – index identifier

Returns -1 on error (check box_error_last)

Returns >= 0 otherwise

int box_index_random(uint32_t space_id, uint32_t index_id, uint32_t rnd, box_tuple_t **result)
Return a random tuple from the index (useful for statistical analysis).

Parameters

- space_id (uint32_t) – space identifier
- index_id (uint32_t) – index identifier
- rnd (uint32_t) – random seed
- result (box_tuple_t**) – output argument. result a tuple or NULL if there is no tuples in space

See also: index_object.random

int box_index_get(uint32_t space_id, uint32_t index_id, const char *key, const char *key_end, box_tuple_t **result)
Get a tuple from index by the key.

Please note that this function works much more faster than index_object.select or box_index_iterator + box_iterator_next.

Parameters

- space_id (uint32_t) – space identifier
- index_id (uint32_t) – index identifier
- char* key (const) – encode key in MsgPack Array format ([part1, part2, . . .])
- char* key_end (const) – the end of encoded key
- result (box_tuple_t**) – output argument. result a tuple or NULL if there is no tuples in space

Returns -1 on error (check box_error_last)

Returns 0 on success

See also: index_object.get()

int box_index_min(uint32_t space_id, uint32_t index_id, const char *key, const char *key_end, box_tuple_t **result)

Return a first (minimal) tuple matched the provided key.

Parameters

- space_id (uint32_t) – space identifier
- index_id (uint32_t) – index identifier
- char* key (const) – encode key in MsgPack Array format ([part1, part2, . . .])
- char* key_end (const) – the end of encoded key
- result (box_tuple_t**) – output argument. result a tuple or NULL if there is no tuples in space

Returns -1 on error (check box_error_last())

Returns 0 on success

See also: index_object.min()

int box_index_max(uint32_t space_id, uint32_t index_id, const char *key, const char *key_end, box_tuple_t **result)

Return a last (maximal) tuple matched the provided key.

Parameters

- space_id (uint32_t) – space identifier
- index_id (uint32_t) – index identifier
- char* key (const) – encode key in MsgPack Array format ([part1, part2, . . .])
- char* key_end (const) – the end of encoded key
- result (box_tuple_t**) – output argument. result a tuple or NULL if there is no tuples in space

Returns -1 on error (check box_error_last())

Returns 0 on success

See also: index_object.max()

ssize_t box_index_count(uint32_t space_id, uint32_t index_id, int type, const char *key, const char *key_end)

Count the number of tuple matched the provided key.

Parameters

- space_id (uint32_t) – space identifier
- index_id (uint32_t) – index identifier
- type (int) – iterator_type
- char* key (const) – encode key in MsgPack Array format ([part1, part2, . . .])
- char* key_end (const) – the end of encoded key

Returns -1 on error (check box_error_last())

Returns 0 on success

See also: index_object.count()

const box_key_def_t *box_index_key_def(uint32_t space_id, uint32_t index_id)
Return key definition for an index

Returned object is valid until the next yield.

Parameters

- space_id (uint32_t) – space identifier
- index_id (uint32_t) – index identifier

Returns key definition on success

Returns NULL on error

See also: box_tuple_compare(), box_tuple_format_new()

5.5.7 Module latch

box_latch_t
A lock for cooperative multitasking environment

box_latch_t *box_latch_new(void)
Allocate and initialize the new latch.

Returns allocated latch object

Return type box_latch_t *

void box_latch_delete(box_latch_t *latch)
Destroy and free the latch.

Parameters

- latch (box_latch_t*) – latch to destroy

void box_latch_lock(box_latch_t *latch)
Lock a latch. Waits indefinitely until the current fiber can gain access to the latch.

param box_latch_t* latch latch to lock

int box_latch_trylock(box_latch_t *latch)
Try to lock a latch. Return immediately if the latch is locked.

Parameters

- latch (box_latch_t*) – latch to lock

Returns status of operation. 0 - success, 1 - latch is locked

Return type int

void box_latch_unlock(box_latch_t *latch)
Unlock a latch. The fiber calling this function must own the latch.

Parameters

- latch (box_latch_t*) – latch to unlock

5.5.8 Module lua/utils

void *luaL_pushcdata(struct lua_State *L, uint32_t ctypeid)

Push cdata of given ctypeid onto the stack.

CTypeID must be used from FFI at least once. Allocated memory returned uninitialized. Only numbers and pointers are supported.

Parameters

- L (lua_State*) – Lua State
- ctypeid (uint32_t) – FFI's CTypeID of this cdata

Returns memory associated with this cdata

See also: luaL_checkcdata()

void *luaL_checkcdata(struct lua_State *L, int idx, uint32_t *ctypeid)

Check whether the function argument idx is a cdata.

Parameters

- L (lua_State*) – Lua State
- idx (int) – stack index
- ctypeid (uint32_t*) – output argument. FFI's CTypeID of returned cdata

Returns memory associated with this cdata

See also: luaL_pushcdata()

void luaL_setcdatagc(struct lua_State *L, int idx)

Set finalizer function on a cdata object.

Equivalent to call ffi.gc(obj, function). Finalizer function must be on the top of the stack.

Parameters

- L (lua_State*) – Lua State
- idx (int) – stack index

uint32_t luaL_ctypeid(struct lua_State *L, const char *ctypename)

Return CTypeID (FFI) of given CDATA type.

Parameters

- L (lua_State*) – Lua State
- char* ctypename (const) – C type name as string (e.g. "struct request" or "uint32_t")

Returns CTypeID

See also: luaL_pushcdata(), luaL_checkcdata()

int luaL_cdef(struct lua_State *L, const char *ctypename)

Declare symbols for FFI.

Parameters

- L (lua_State*) – Lua State
- char* ctypename (const) – C definitions (e.g. "struct stat")

Returns 0 on success

Returns LUA_ERRRUN, LUA_ERRMEM or LUA_ERRERR otherwise.

See also: ffi.cdef(def)

void luaL_pushuint64(struct lua_State *L, uint64_t val)
Push uint64_t onto the stack.

Parameters

- L (lua_State*) – Lua State
- val (uint64_t) – value to push

void luaL_pushint64(struct lua_State *L, int64_t val)
Push int64_t onto the stack.

Parameters

- L (lua_State*) – Lua State
- val (int64_t) – value to push

uint64_t luaL_checkuint64(struct lua_State *L, int idx)
Check whether the argument idx is a uint64 or a convertable string and returns this number.

Throws error if the argument can't be converted

uint64_t luaL_checkint64(struct lua_State *L, int idx)
Check whether the argument idx is a int64 or a convertable string and returns this number.

Throws error if the argument can't be converted

uint64_t luaL_touint64(struct lua_State *L, int idx)
Check whether the argument idx is a uint64 or a convertable string and returns this number.

Returns the converted number or 0 of argument can't be converted

int64_t luaL_toint64(struct lua_State *L, int idx)
Check whether the argument idx is a int64 or a convertable string and returns this number.

Returns the converted number or 0 of argument can't be converted

void luaT_pushtuple(struct lua_State *L, box_tuple_t *tuple)
Push a tuple onto the stack.

Parameters

- L (lua_State*) – Lua State

Throws error on OOM

See also: luaT_istuple

box_tuple_t *luaT_istuple(struct lua_State *L, int idx)
Check whether idx is a tuple.

Parameters

- L (lua_State*) – Lua State
- idx (int) – the stack index

Returns non-NULL if idx is a tuple

Returns NULL if idx is not a tuple

int luaT_error(lua_State *L)
Re-throw the last Tarantool error as a Lua object.

See also: lua_error(), box_error_last().

int luaT_cpcall(lua_State *L, lua_CFunction func, void *ud)
: Similar to lua_cpcall(), but with the proper support of Tarantool errors.

lua_State *luaT_state(void)
: Get the global Lua state used by Tarantool.

5.5.9 Module say (logging)

enum say_level

enumerator S_FATAL
: do not use this value directly

enumerator S_SYSERROR

enumerator S_ERROR

enumerator S_CRIT

enumerator S_WARN

enumerator S_INFO

enumerator S_VERBOSE

enumerator S_DEBUG

say(level, format, ...)
: Format and print a message to Tarantool log file.

Parameters

- level (int) – log level
- char* format (const) – printf()-like format string
- ... – format arguments

See also printf(3), say_level

say_error(format, ...)
say_crit(format, ...)
say_warn(format, ...)
say_info(format, ...)
say_verbose(format, ...)
say_debug(format, ...)
say_syserror(format, ...)
: Format and print a message to Tarantool log file.

Parameters

- char* format (const) – printf()-like format string
- ... – format arguments

See also printf(3), say_level

Example:

```
say_info("Some useful information: %s", status);
```

5.5.10 Module schema

enum SCHEMA

enumerator BOX_SYSTEM_ID_MIN
: Start of the reserved range of system spaces.

enumerator BOX_SCHEMA_ID
: Space id of _schema.

enumerator BOX_SPACE_ID
: Space id of _space.

enumerator BOX_VSPACE_ID
: Space id of _vspace view.

enumerator BOX_INDEX_ID
: Space id of _index.

enumerator BOX_VINDEX_ID
: Space id of _vindex view.

enumerator BOX_FUNC_ID
: Space id of _func.

enumerator BOX_VFUNC_ID
: Space id of _vfunc view.

enumerator BOX_USER_ID
: Space id of _user.

enumerator BOX_VUSER_ID
: Space id of _vuser view.

enumerator BOX_PRIV_ID
: Space id of _priv.

enumerator BOX_VPRIV_ID
: Space id of _vpriv view.

enumerator BOX_CLUSTER_ID
: Space id of _cluster.

enumerator BOX_TRIGGER_ID
: Space id of _trigger.

enumerator BOX_TRUNCATE_ID
: Space id of _truncate.

enumerator BOX_SYSTEM_ID_MAX
: End of reserved range of system spaces.

enumerator BOX_ID_NIL
: NULL value, returned on error.

5.5.11 Module trivia/config

API_EXPORT
: Extern modifier for all public functions.

PACKAGE_VERSION_MAJOR
: Package major version - 2 for 2.0.5.

PACKAGE_VERSION_MINOR
: Package minor version - 0 for 2.0.5.

PACKAGE_VERSION_PATCH
: Package patch version - 5 for 2.0.5.

PACKAGE_VERSION
: A string with major-minor-patch-commit-id identifier of the release, e.g. 2.0.5-75-gdd8e14ffb.

SYSCONF_DIR
: System configuration dir (e.g /etc)

INSTALL_PREFIX
: Install prefix (e.g. /usr)

BUILD_TYPE
: Build type, e.g. Debug or Release

BUILD_INFO
: CMake build type signature, e.g. Linux-x86_64-Debug

BUILD_OPTIONS
: Command line used to run CMake.

COMPILER_INFO
: Pathes to C and CXX compilers.

TARANTOOL_C_FLAGS
: C compile flags used to build Tarantool.

TARANTOOL_CXX_FLAGS
: CXX compile flags used to build Tarantool.

MODULE_LIBDIR
: A path to install *.lua module files.

MODULE_LUADIR
: A path to install *.so/*.dylib module files.

MODULE_INCLUDEDIR
: A path to Lua includes (the same directory where this file is contained)

MODULE_LUAPATH
: A constant added to package.path in Lua to find *.lua module files.

MODULE_LIBPATH
: A constant added to package.cpath in Lua to find *.so module files.

5.5.12 Module tuple

box_tuple_format_t

box_tuple_format_t *box_tuple_format_default(void)
: Tuple format.

  Each Tuple has an associated format (class). Default format is used to create tuples which are not attached to any particular space.

box_tuple_t
: Tuple

box_tuple_t *box_tuple_new(box_tuple_format_t *format, const char *tuple, const char *tuple_end)

Allocate and initialize a new tuple from raw MsgPack Array data.

Parameters

- format (box_tuple_format_t*) – tuple format. Use box_tuple_format_default() to create space-independent tuple.
- char* tuple (const) – tuple data in MsgPack Array format ([field1, field2, . . .])
- char* tuple_end (const) – the end of data

Returns NULL on out of memory

Returns tuple otherwise

See also: box.tuple.new()

> Warning: When working with tuples, it is the developer's responsibility to ensure that enough space is allocated, taking especial caution when writing to them with msgpuck functions such as mp_encode_array().

int box_tuple_ref(box_tuple_t *tuple)

Increase the reference counter of tuple.

Tuples are reference counted. All functions that return tuples guarantee that the last returned tuple is reference counted internally until the next call to API function that yields or returns another tuple.

You should increase the reference counter before taking tuples for long processing in your code. The Lua garbage collector will not destroy a tuple that has references, even if another fiber removes them from a space. After processing, decrement the reference counter using box_tuple_unref(), otherwise the tuple will leak.

Parameters

- tuple (box_tuple_t*) – a tuple

Returns -1 on error

Returns 0 otherwise

See also: box_tuple_unref()

void box_tuple_unref(box_tuple_t *tuple)

Decrease the reference counter of tuple.

Parameters

- tuple (box_tuple_t*) – a tuple

Returns -1 on error

Returns 0 otherwise

See also: box_tuple_ref()

uint32_t box_tuple_field_count(const box_tuple_t *tuple)

Return the number of fields in a tuple (the size of MsgPack Array).

Parameters

- tuple (box_tuple_t*) – a tuple

size_t box_tuple_bsize(const box_tuple_t *tuple)

Return the number of bytes used to store internal tuple data (MsgPack Array).

Parameters

- tuple (box_tuple_t*) – a tuple

ssize_t box_tuple_to_buf(const box_tuple_t *tuple, char *buf, size_t size)

Dump raw MsgPack data to the memory buffer buf of size size.

Store tuple fields in the memory buffer.

Upon successful return, the function returns the number of bytes written. If buffer size is not enough then the return value is the number of bytes which would have been written if enough space had been available.

Returns -1 on error

Returns number of bytes written on success.

box_tuple_format_t *box_tuple_format(const box_tuple_t *tuple)

Return the associated format.

Parameters

- tuple (box_tuple_t*) – a tuple

Returns tuple format

const char *box_tuple_field(const box_tuple_t *tuple, uint32_t field_id)

Return the raw tuple field in MsgPack format. The result is a pointer to raw MessagePack data which can be decoded with mp_decode functions, for an example see the tutorial program read.c.

The buffer is valid until the next call to a box_tuple_* function.

Parameters

- tuple (box_tuple_t*) – a tuple
- field_id (uint32_t) – zero-based index in MsgPack array.

Returns NULL if i >= box_tuple_field_count()

Returns msgpack otherwise

enum field_type

enumerator FIELD_TYPE_ANY

enumerator FIELD_TYPE_UNSIGNED

enumerator FIELD_TYPE_STRING

enumerator FIELD_TYPE_NUMBER

enumerator FIELD_TYPE_DOUBLE

enumerator FIELD_TYPE_INTEGER

enumerator FIELD_TYPE_BOOLEAN

enumerator FIELD_TYPE_VARBINARY

enumerator FIELD_TYPE_SCALAR

enumerator FIELD_TYPE_DECIMAL

enumerator FIELD_TYPE_ARRAY

enumerator FIELD_TYPE_MAX

Possible data types for tuple fields.

One cannot use STRS/ENUM macros for types because there is a mismatch between enum name (STRING) and type name literal ("STR"). STR is already used as a type in Objective C.

typedef struct key_def box_key_def_t
Key definition

box_key_def_t *box_key_def_new(uint32_t *fields, uint32_t *types, uint32_t part_count)
Create a key definition with the key fields with passed types on passed positions.

May be used for tuple format creation and/or tuple comparison.

Parameters

- fields (uint32_t*) – array with key field identifiers
- types (uint32_t) – array with key field types
- part_count (uint32_t) – the number of key fields

Returns key definition on success

Returns NULL on error

void box_key_def_delete(box_key_def_t *key_def)
Delete a key definition

Parameters

- key_def (box_key_def_t*) – key definition to delete

box_tuple_format_t *box_tuple_format_new(struct key_def *keys, uint16_t key_count)
Return new in-memory tuple format based on passed key definitions

Parameters

- keys (key_def) – array of keys defined for the format
- key_count (uint16_t) – count of keys

Returns new tuple format on success

Returns NULL on error

void box_tuple_format_ref(box_tuple_format_t *format)
Increment tuple format reference count

Parameters

- tuple_format (box_tuple_format_t) – tuple format to ref

void box_tuple_format_unref(box_tuple_format_t *format)
Decrement tuple format reference count

Parameters

- tuple_format (box_tuple_format_t) – tuple format to unref

int box_tuple_compare(const box_tuple_t *tuple_a, const box_tuple_t *tuple_b, const box_key_def_t *key_def)
Compare tuples using key definition

Parameters

- box_tuple_t* tuple_a (const) – the first tuple

- box_tuple_t* tuple_b (const) – the second tuple
- box_key_def_t* key_def (const) – key definition

Returns 0 if key_fields(tuple_a) == key_fields(tuple_b)

Returns <0 if key_fields(tuple_a) < key_fields(tuple_b)

Returns >0 if key_fields(tuple_a) > key_fields(tuple_b)

See also: enum field_type

int box_tuple_compare_with_key(const box_tuple_t *tuple, const char *key, const box_key_def_t *key_def);
Compare a tuple with a key using key definition

Parameters

- box_tuple_t* tuple (const) – tuple
- char* key (const) – key with MessagePack array header
- box_key_def_t* key_def (const) – key definition

Returns 0 if key_fields(tuple) == parts(key)

Returns <0 if key_fields(tuple) < parts(key)

Returns >0 if key_fields(tuple) > parts(key)

See also: enum field_type

box_tuple_iterator_t
Tuple iterator

box_tuple_iterator_t *box_tuple_iterator(box_tuple_t *tuple)
Allocate and initialize a new tuple iterator. The tuple iterator allows iterating over fields at the root level of a MsgPack array.

Example:

```
box_tuple_iterator_t* it = box_tuple_iterator(tuple);
if (it == NULL) {
    // error handling using box_error_last()
}
const char* field;
while (field = box_tuple_next(it)) {
    // process raw MsgPack data
}

// rewind the iterator to the first position
box_tuple_rewind(it)
assert(box_tuple_position(it) == 0);

// rewind three fields
field = box_tuple_seek(it, 3);
assert(box_tuple_position(it) == 4);

box_iterator_free(it);
```

void box_tuple_iterator_free(box_tuple_iterator_t *it)
Destroy and free tuple iterator

uint32_t box_tuple_position(box_tuple_iterator_t *it)
Return zero-based next position in iterator. That is, this function returnы the field id of the field that

will be returned by the next call to box_tuple_next(). Returned value is zero after initialization or rewind and box_tuple_field_count() after the end of iteration.

Parameters

- it (box_tuple_iterator_t*) – a tuple iterator

Returns position

void box_tuple_rewind(box_tuple_iterator_t *it)

Rewind iterator to the initial position.

Parameters

- it (box_tuple_iterator_t*) – a tuple iterator

After: box_tuple_position(it) == 0

const char *box_tuple_seek(box_tuple_iterator_t *it, uint32_t field_no)

Seek the tuple iterator.

The result is a pointer to raw MessagePack data which can be decoded with mp_decode functions, for an example see the tutorial program read.c. The returned buffer is valid until the next call to box_tuple_* API. The requested field_no is returned by the next call to box_tuple_next(it).

Parameters

- it (box_tuple_iterator_t*) – a tuple iterator
- field_no (uint32_t) – field number - zero-based position in MsgPack array

After:

- box_tuple_position(it) == field_not if returned value is not NULL.
- box_tuple_position(it) == box_tuple_field_count(tuple) if returned value is NULL.

const char *box_tuple_next(box_tuple_iterator_t *it)

Return the next tuple field from tuple iterator.

The result is a pointer to raw MessagePack data which can be decoded with mp_decode functions, for an example see the tutorial program read.c. The returned buffer is valid until next call to box_tuple_* API.

Parameters

- it (box_tuple_iterator_t*) – a tuple iterator

Returns NULL if there are no more fields

Returns MsgPack otherwise

Before: box_tuple_position() is zero-based ID of returned field.

After: box_tuple_position(it) == box_tuple_field_count(tuple) if returned value is NULL.

box_tuple_t *box_tuple_update(const box_tuple_t *tuple, const char *expr, const char *expr_end)

box_tuple_t *box_tuple_upsert(const box_tuple_t *tuple, const char *expr, const char *expr_end)

5.5.13 Module txn

bool box_txn(void)

Return true if there is an active transaction.

int box_txn_begin(void)

Begin a transaction in the current fiber.

A transaction is attached to caller fiber, therefore one fiber can have only one active transaction. See also box.begin().

Returns 0 on success

Returns -1 on error. Perhaps a transaction has already been started.

int box_txn_commit(void)

Commit the current transaction. See also box.commit().

Returns 0 on success

Returns -1 on error. Perhaps a disk write failure

void box_txn_rollback(void)

Roll back the current transaction. See also box.rollback().

box_txn_savepoint_t * savepoint(void)

Return a descriptor of a savepoint.

void box_txn_rollback_to_savepoint(box_txn_savepoint_t *savepoint)

Roll back the current transaction as far as the specified savepoint.

void *box_txn_alloc(size_t size)

Allocate memory on txn memory pool.

The memory is automatically deallocated when the transaction is committed or rolled back.

Returns NULL on out of memory

5.6 Internals

5.6.1 Binary protocol

The binary protocol is called a "request/response" protocol because it is for sending requests to a Tarantool server and receiving responses. There is complete access to Tarantool functionality, including:

- request multiplexing, for example ability to issue multiple requests asynchronously via the same connection
- response format that supports zero-copy writes

The protocol can be called "binary" because the most-frequently-used database accesses are done with binary codes instead of Lua request text. Tarantool experts use it to write their own connectors, to understand network messages, to support new features that their favorite connector doesn't support yet, or to avoid repetitive parsing by the server.

Index

Section	Description
Symbols and terms	Notation of binary protocol
Illustration	Illustration of use
Header and body	Header of a request
Requests: IPROTO_SELECT IPROTO_INSERT IPROTO_REPLACE IPROTO_UPDATE IPROTO_DELETE IPROTO_CALL_16 IPROTO_AUTH IPROTO_EVAL IPROTO_UPSERT IPROTO_CALL IPROTO_EXECUTE IPROTO_NOP IPROTO_PREPARE IPROTO_PING IPROTO_JOIN IPROTO_SUBSCRIBE IPROTO_VOTE_DEPRECATED IPROTO_VOTE IPROTO_FETCH_SNAPSHOT IPROTO_REGISTER	Body of a request
Responses if no error and no SQL	Responses for no SQL
Responses for errors	Responses for errors
Responses for SQL	Responses for SQL
Authentication	Authentication after connection
Replication	Replication request
Type DECIMAL	MessagePack extension type
XLOG/SNAP	Format of .xlog and .snap files

Binary protocol – symbols and terms

For diagrams in this section, the box borders have special meanings:

```
0    X
+----+
|    | - X + 1 bytes
+----+
 TYPE - type of MessagePack value (if it is a MessagePack object)

+=====+
|    | - Variable size MessagePack object
+=====+
 TYPE - type of MessagePack value

+~~~~+
|    | - Variable size MessagePack Array/Map
+~~~~+
 TYPE - type of MessagePack value
```

And words that start with MP_ mean: a MessagePack type or a range of MessagePack types, including the signal and possibly including a value, with slight modification:

- MP_NIL nil
- MP_UINT unsigned integer
- MP_INT either integer or unsigned integer
- MP_STR string
- MP_BIN binary string
- MP_ARRAY array
- MP_MAP map
- MP_BOOL boolean
- MP_FLOAT float
- MP_DOUBLE double
- MP_EXT extension (including the DECIMAL type)
- MP_OBJECT any MessagePack object

Short descriptions are in MessagePack's "spec" page.

And words that start with IPROTO_ mean: a Tarantool constant which is either defined or mentioned in the iproto_constants.h file. These constants are used as keys within MP_MAP maps.

Binary protocol – illustration

To follow the examples in this section, get a single Linux computer and start three command-line shells ("terminals").

– On terminal #1, Start monitoring port 3302 with tcpdump: sudo tcpdump -i lo 'port 3302' -X

On terminal #2, start a server with: box.cfg{listen=3302} box.schema.user.grant('guest','read,write, execute,create,drop','universe')

On terminal #3, start another server, which will act as a client, with: box.cfg{} net_box = require('net.box') conn = net_box.connect('localhost:3302') conn.space._space:select(280)

Now look at what tcpdump shows for the job connecting to 3302. – the "request". After the words "length 32" is a packet that ends with with these 32 bytes: (we have added indented comments):

```
ce 00 00 00 1b   MP_UINT = decimal 27 = number of bytes after this
82               MP_MAP, size 2 (we'll call this "Main-Map")
01                 IPROTO_SYNC (Main-Map Item#1)
04                 MP_INT = 4 = number that gets incremented with each request
00                 IPROTO_REQUEST_TYPE (Main-Map Item#2)
01                 IPROTO_SELECT
86                 MP_MAP, size 6 (we'll call this "Select-Map")
10                   IPROTO_SPACE_ID (Select-Map Item#1)
cd 01 18               MP_UINT = decimal 280 = id of _space
11                   IPROTO_INDEX_ID (Select-Map Item#2)
00                   MP_INT = 0 = id of index within _space
14                   IPROTO_ITERATOR (Select-Map Item#3)
00                   MP_INT = 0 = Tarantool iterator_type.h constant ITER_EQ
13                   IPROTO_OFFSET (Select-Map Item#4)
00                   MP_INT = 0 = amount to offset
12                   IPROTO_LIMIT (Select-Map Item#5)
ce ff ff ff ff     MP_UINT = 4294967295 = biggest possible limit
20                   IPROTO_KEY (Select-Map Item#6)
91                   MP_ARRAY, size 1 (we'll call this "Key-Array")
cd 01 18                 MP_UINT = 280 (Select-Map Item#6, Key-Array Item#1)
                      -- 280 is the key value that we are searching for
```

Now read the source code file net_box.c and skip to the line netbox_encode_select(lua_State *L). From the comments and from simple function calls like mpstream_encode_uint(&stream, IPROTO_SPACE_ID); you will be able to see how net_box put together the packet contents that you have just observed with tcpdump.

There are libraries for reading and writing MessagePack objects. C programmers sometimes include msgpuck.h.

Now you know how Tarantool itself makes requests with the binary protocol. When in doubt about a detail, consult net_box.c – it has routines for each request. Some connectors have similar code.

Binary protocol – header and body

Except during connection (which involves a greeting from the server and optional authentication that we will discuss later in this section), the protocol is pure request/response (the client requests and the server responds). It is legal to put more than one request in a packet.

Almost all requests and responses contain both a header and a body.

```
Normal Request/Response header and body:

0        5
+--------+ +============+ +===================================+
| HEADER | |            | |                                   |
| + BODY | |   HEADER   | |               BODY                |
|  SIZE  | |            | |                                   |
+--------+ +============+ +===================================+
  MP_INT       MP_MAP                     MP_MAP
```

HEADER + BODY SIZE is the size of the header plus the size of the body. It may be useful to compare it with the number of bytes remaining in the packet.

HEADER may contain, in any order:

```
HEADER:

+=====================================+======================+================
|                              |                  |                          |
|   0x00: IPROTO_REQUEST_TYPE        |   0x01: IPROTO_SYNC |   0x05: IPROTO_SCHEMA_VERSION
↪|
|        or Response-Code-Indicator | MP_INT: MP_INT       | MP_INT: MP_INT                 |
| MP_INT: MP_INT                    |                  |                          |
|                              |                  |                          |
+=====================================+======================+================
                      MP_MAP
```

IPROTO_SYNC = 0x01. An unsigned integer that should be incremented so that it is unique in every request. This integer is also returned from box.session.sync(). The IPROTO_SYNC value of a response should be the same as the IPROTO_SYNC value of a request.

IPROTO_SCHEMA_VERSION = 0x05. An unsigned number, sometimes called SCHEMA_ID, that goes up when there is a major change. In a request header IPROTO_SCHEMA_VERSION is optional, so the version will not be checked if it is absent. In a response header IPROTO_SCHEMA_VERSION is always present, and it is up to the client to check if it has changed.

IPROTO_REQUEST_TYPE or Response-Code-Indicator = 0x00. An unsigned number that indicates what will be in the BODY. In requests IPROTO_REQUEST_TYPE will be followed by IPROTO_SELECT etc. In responses Response-Code-Indicator will be followed by IPROTO_OK etc.

The BODY has the details of the request or response. In a request, it can also be absent or be an empty map. Both these states will be interpreted equally. Responses will contain the BODY anyway even if it is a IPROTO_PING request.

Have a look at file xrow.c function xrow_header_encode, to see how Tarantool encodes the header. Have a look at file net_box.c, function netbox_decode_data, to see how Tarantool decodes the header. For example, in a successful response to box.space:select(), the Response-Code-Indicator value will be 0 = IPROTO_OK and the array will have all the tuples of the result.

Binary protocol – requests

After the HEADER, for a request, there will be a body that begins with these request-type IPROTO codes.

IPROTO_SELECT = 0x01.

See space_object:select(). The body is a 6-item map:

```
+=========================+==========================+======================
|                    |                    |                    |
|   0x10: IPROTO_SPACE_ID |   0x11: IPROTO_INDEX_ID |   0x12: IPROTO_LIMIT     |
| MP_INT: MP_INT          | MP_INT: MP_INT          | MP_INT: MP_INT          |
|                    |                    |                    |
+=========================+==========================+======================
|                    |                    |                    |
|   0x13: IPROTO_OFFSET   |   0x14: IPROTO_ITERATOR |   0x20: IPROTO_KEY      |
| MP_INT: MP_INT          | MP_INT: MP_INT          | MP_INT: MP_ARRAY        |
|                    |                    |                    |
```

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```
+========================+=========================+=======================
         MP_MAP
```

IPROTO_SPACE_ID (0x10) + MP_INT, IPROTO_INDEX_ID (0x11) + MP_INT, IPROTO_ITERATOR (0x14) + MP_INT, IPROTO_OFFSET (0x13) + MP_INT, IPROTO_LIMIT (0x12) + MP_INT, IPROTO_KEY (0x20) + MP_ARRAY (array of key values). See the illustration of IPROTO_SELECT in the earlier section, Binary protocol – illustration.

IPROTO_INSERT == 0x02.

See space_object:insert(). The body is a 2-item map:

```
+========================+======================+
|                        |                      |
|   0x10: IPROTO_SPACE_ID |   0x21: IPROTO_TUPLE |
| MP_INT: MP_INT         | MP_INT: MP_ARRAY     |
|                        |                      |
+========================+======================+
            MP_MAP
```

IPROTO_SPACE_ID (0x10) + MP_INT, IPROTO_TUPLE + MP_ARRAY (array of field values).

IPROTO_REPLACE = 0x03, See space_object:replace(). The body is a 2-item map, the same as for IPROTO_INSERT:

```
+========================+======================+
|                        |                      |
|   0x10: IPROTO_SPACE_ID |   0x21: IPROTO_TUPLE |
| MP_INT: MP_INT         | MP_INT: MP_ARRAY     |
|                        |                      |
+========================+======================+
           MP_MAP
```

IPROTO_SPACE_ID (0x10) + MP_INT, IPROTO_TUPLE (0x21) + MP_ARRAY (array of field values).

IPROTO_UPDATE = 0x04.

See space_object:update(). The body is usually a 4-item map,

```
+========================+===============================+
|                        |                               |
|   0x10: IPROTO_SPACE_ID |   0x11: IPROTO_INDEX_ID       |
| MP_INT: MP_INT         | MP_INT: MP_INT                |
|                        |                               |
+========================+===============================+
|                        |              +~~~~~~~~~~~+ |
|                        |              | usually   | |
|                        |              | OPERATOR, | |
|                        | (IPROTO_TUPLE) | FIELD_NO, | |
|   0x20: IPROTO_KEY     |    0x21:      | VALUE     | |
| MP_INT: MP_ARRAY       |  MP_INT:      +~~~~~~~~~~~+ |
|                        |               MP_ARRAY    |
+========================+===============================+
            MP_MAP
```

IPROTO_SPACE_ID (0x10) + MP_INT, IPROTO_INDEX_ID (0x11) + MP_INT with index number starting with 0, IPROTO_KEY (0x20) + MP_ARRAY (array of index keys), IPROTO_TUPLE (0x21) + MP_ARRAY (array of update operations). If the operation specifies no values, it is a 2-item array:

OPERATOR MP_STR = "#", FIELD_NO MP_INT = field number starting with 1. If the operation specifies one value, it is a 3-item array:

```
0           2
+-------------+==========+============+
|             |          |            |
| OPERATOR    | FIELD_NO | VALUE      |
| MP_STR      | MP_INT   | MP_OBJECT  |
|             |          |            |
+-------------+==========+============+
          MP_ARRAY
```

OPERATOR MP_STR = "+" or "-" or "&" or "^" or "|" or "!" or "="), FIELD_NO MP_INT = field number starting with 1, VALUE MP_OBJECT, that is, any type, MP_INT, MP_STR, etc.. Otherwise the operation is a 5-item array:

```
0           2
+-----------+==========+==========+========+==========+
|           |          |          |        |          |
| ':'       | FIELD_NO | POSITION | OFFSET | VALUE    |
| MP_STR    | MP_INT   | MP_INT   | MP_INT | MP_STR   |
|           |          |          |        |          |
+-----------+==========+==========+========+==========+
                    MP_ARRAY
```

OPERATOR MP_STR = ":", FIELD_NO MP_INT = field number starting with 1, POSITION MP_INT, OFFSET MP_INT, VALUE MP_STR.

For example, suppose a user changes field #2 in tuple #2 in space #256 to 'BBBB'. The body will look like this: (notice that in this case there is an extra map item IPROTO_INDEX_BASE, to emphasize that field numbers start with 1, which is optional and can be omitted):

```
04                IPROTO_UPDATE
85                IPROTO_MAP, size 5
10                  IPROTO_SPACE_ID, Map Item#1
cd 02 00              MP_UINT 256
11                  IPROTO_INDEX_ID, Map Item#2
00                  MP_INT 0 = primary-key index number
15                  IPROTO_INDEX_BASE, Map Item#3
01                  MP_INT = 1 i.e. field numbers start at 1
21                  IPROTO_TUPLE, Map Item#4
91                  MP_ARRAY, size 1, for array of operations
93                    MP_ARRAY, size 3
a1 3d                     MP_STR = OPERATOR = '='
02                        MP_INT = FIELD_NO = 2
a5 42 42 42 42 42          MP_STR = VALUE = 'BBBB'
20                  IPROTO_KEY, Map Item#5
91                  MP_ARRAY, size 1, for array of key values
02                    MP_UINT = primary-key value = 2
```

IPROTO_DELETE = 0x05.

See space_object:delete(). The body is a 3-item map:

```
+=======================+==========================+=====================+
|                       |                          |                     |
|   0x10: IPROTO_SPACE_ID |   0x11: IPROTO_INDEX_ID |   0x20: IPROTO_KEY |
| MP_INT: MP_INT        | MP_INT: MP_INT           | MP_INT: MP_ARRAY    |
```

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```
|                      |                      |                  |
+======================+======================+====================+
                      MP_MAP
```

IPROTO_SPACE_ID (0x10) + MP_INT, IPROTO_INDEX_ID (0x11) + MP_INT, IPROTO_KEY (0x20) + MP_ARRAY (array of key values).

IPROTO_CALL_16 = 0x06.

See conn:call(). The suffix _16 is a hint that this is for the call() until Tarantool 1.6. It is deprecated. Use IPROTO_CALL instead. The body is a 2-item map:

```
+=============================+=======================+
|                             |                       |
|   0x22: IPROTO_FUNCTION_NAME |   0x21: IPROTO_TUPLE  |
| MP_INT: MP_STRING           | MP_INT: MP_ARRAY      |
|                             |                       |
+=============================+=======================+
                 MP_MAP
```

IPROTO_FUNCTION_NAME (0x22) + function name (MP_STRING), IPROTO_TUPLE (0x22) + array of arguments (MP_ARRAY). The return value is an array of tuples.

IPROTO_AUTH = 0x07.

See authentication. See the later section Binary protocol – authentication.

IPROTO_EVAL = 0x08.

See conn:eval(). Since the argument is a Lua expression, this is Tarantool's way to handle non-binary with the binary protocol. Any request that does not have its own code, for example box.space.space-name:drop(), will be handled either with IPROTO_CALL or IPROTO_EVAL. Some client-like utilities, such as tarantoolctl, make extensive use of eval. The body is a 2-item map:

```
+=======================+======================+
|                       |                      |
|   0x27: IPROTO_EXPR   |   0x21: IPROTO_TUPLE |
| MP_INT: MP_STRING     | MP_INT: MP_ARRAY     |
|                       |                      |
+=======================+======================+
              MP_MAP
```

IPROTO_EXPR (0x27) + expression (MP_STRING), IPROTO_TUPLE (0x21) + array of arguments to match placeholders.

IPROTO_UPSERT = 0x09.

See space_object:upsert().

```
+==============================+==============================+
|                              |                              |
|   0x10: IPROTO_SPACE_ID      |   0x15: IPROTO_INDEX_BASE    |
| MP_INT: MP_INT               | MP_INT: MP_INT               |
|                              |                              |
+==============================+==============================+
|             +~~~~~~~~~~+ |                              |
|             | usually  | |   0x21: IPROTO_TUPLE         |
|             | OPERATOR, | | MP_INT: MP_ARRAY           |
| (IPROTO_OPS) | FIELD_NO, | |                            |
```

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```
|    0x28:        | VALUE     | |                              |
|  MP_INT:        +~~~~~~~~~~~+ |                              |
|                 MP_ARRAY    |                              |
+=================================+=================================+
          MP_MAP
```

IPROTO_SPACE_ID (0x10) + MP_INT, IPROTO_INDEX_BASE (0x15) + MP_INT with index number starting with 1, IPROTO_OPS (0x28) + MP_ARRAY (array of upsert operations), IPROTO_TUPLE (0x21) + MP_ARRAY (array of primary-key-field values).

The IPROTO_OPS is the same as the IPROTO_OPS of IPROTO_UPDATE.

IPROTO_CALL = 0x0a.

See conn:call(). The body is a 2-item map:

```
+=================================+======================+
|                          |                     |
|   0x22: IPROTO_FUNCTION_NAME |   0x21: IPROTO_TUPLE |
| MP_INT: MP_STRING            | MP_INT: MP_ARRAY     |
|                          |                     |
+=================================+======================+
                    MP_MAP
```

IPROTO_FUNCTION_NAME (0x22) + function name (MP_STRING), IPROTO_TUPLE (0x22) + array of arguments (MP_ARRAY). The response will be a list of values, similar to the IPROTO_EVAL response.

IPROTO_EXECUTE = 0x0b.

See box.execute(), this is only for SQL. The body is a 3-item map:

```
+=========================+==========================+==========================
|                     |                     |                     |
|   0x43: IPROTO_STMT_ID  |   0x11: IPROTO_SQL_BIND |   0x20: IPROTO_OPTIONS |
| MP_INT: MP_INT          | MP_INT: MP_INT          | MP_INT: MP_ARRAY       |
|   or                |                     |                     |
|   0x40: IPROTO_SQL_TEXT |                     |                     |
| MP_INT: MP_STR          |                     |                     |
|                     |                     |                     |
+=========================+==========================+==========================
                      MP_MAP
```

IPROTO_STMT_ID (0x43) + statement-id (MP_INT) if executing a prepared statement or IPROTO_SQL_TEXT (0x40) + statement-text (MP_STR) if executing an SQL string, IPROTO_SQL_BIND (0x41) + array of parameter values to match ? placeholders or :name placeholders, IPROTO_OPTIONS (0x2b) + array of options (usually empty).

For example, suppose we prepare a statement with two ? placeholders, and execute with two parameters, thus: n = conn:prepare([[VALUES (?, ?);]]) conn:execute(n.stmt_id, {1,'a'}) Then the body will look like this:

```
0b              IPROTO_EXECUTE
83              MP_MAP, size 3
43                IPROTO_STMT_ID Map Item#1
ce d7 aa 74 1b      MP_UINT value of n.stmt_id
41                IPROTO_SQL_BIND Map Item#2
92                MP_ARRAY, size 2
```

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```
01              MP_INT = 1 = value for first parameter
a1 61           MP_STR = 'a' = value for second parameter
2b            IPROTO_OPTIONS Map Item#3
90            MP_ARRAY, size 0 (there are no options)
```

To call a prepared statement with named parameters from a connector pass the parameters within an array of maps. A client should wrap each element into a map, where the key holds a name of the parameter (with a colon) and the value holds an actual value. So, to bind foo and bar to 42 and 43, a client should send IPROTO_SQL_TEXT: <...>, IPROTO_SQL_BIND: [{"foo": 42}, {"bar": 43}].

If a statement has both named and non-named parameters, wrap only named ones into a map. The rest of parameters are positional and substituted in order.

IPROTO_NOP = 0x0c.

There is no Lua request exactly equivalent to IPROTO_NOP. It causes the LSN to be incremented. It could be sometimes used for updates where the old and new values are the same, but the LSN must be increased because a data-change must be recorded. The body is: nothing.

IPROTO_PREPARE = 0x0d.

See box.prepare, this is only for SQL. The body is a 1-item map:

```
+=========================+
|                         |
|   0x10: IPROTO_STMT_ID  |
| MP_INT: MP_INT          |
|   or                    |
|   0x10: IPROTO_SQL_TEXT |
| MP_INT: MP_STR          |
|                         |
+=========================+
    MP_MAP
```

IPROTO_STMT_ID (0x43) + statement-id (MP_INT) if executing a prepared statement or IPROTO_SQL_TEXT (0x40) + statement-text (string) if executing an SQL string. Thus the IPROTO_PREPARE map item is the same as the first item of the IPROTO_EXECUTE map.

IPROTO_PING = 0x40.

See conn:ping(). The BODY will be an empty map because IPROTO_PING in the HEADER contains all the information that the server instance needs.

IPROTO_JOIN = 0x41, for replication IPROTO_SUBSCRIBE = 0x42, for replication SUBSCRIBE IPROTO_VOTE_DEPRECATED = 0x43, for old style vote, superseded by IPROTO_VOTE IPROTO_VOTE = 0x44, for master election IPROTO_FETCH_SNAPSHOT = 0x45, for starting anonymous replication IPROTO_REGISTER =0x46, for leaving anonymous replication.

Tarantool constants 0x41 to 0x46 (decimal 65 to 70) are for replication. Connectors and clients do not need to send replication packets. See Binary protocol – replication.

Binary protocol – responses if no error and no SQL

After the HEADER, for a response, there will be a body. It will contain IPROTO_OK (0x00) (there was no error), or an error code other than IPROTO_OK (there was an error). Responses to SQL statements are slightly different and will be described in the later section, Binary protocol – responses for SQL.

For IPROTO_OK, the header Response-Code-Indicator will be 0 and the body will be:

```
++======================+
||                      |
||   0x30: IPROTO_DATA  |
|| MP_INT: MP_OBJECT    |
||                      |
++======================+
    MP_MAP
```

For IPROTO_PING the body will be an empty map. For most data-access requests (IPROTO_SELECT IPROTO_INSERT IPROTO_DELETE etc.) it will be an array of tuples that contain an array of fields. For IPROTO_EVAL and IPROTO_CALL it will usually be an array but, since Lua requests can result in a wide variety of structures, bodies can have a wide variety of structures.

For example, after box.space.space-name:insert{6} a successful response will look like this:

```
ce 00 00 00 20                MP_UINT = HEADER + BODY SIZE
83                          MP_MAP, size 3
00                            Response-Code-Indicator
ce 00 00 00 00                  MP_UINT = IPROTO_OK
01                            IPROTO_SYNC
cf 00 00 00 00 00 00 00 53        MP_UINT = sync value
05                            IPROTO_SCHEMA_VERSION
ce 00 00 00 68                  MP_UINT = schema version
81                          MP_MAP, size 1
30                            IPROTO_DATA
dd 00 00 00 01                  MP_ARRAY, size 1 (row count)
91                            MP_ARRAY, size 1 (field count)
06                            MP_INT = 6 = the value that was inserted
```

IPROTO_DATA is what we get with net_box and Module buffer so if we were using net_box we could decode with msgpack.decode_unchecked(), or we could convert to a string with ffi.string(pointer,length). The pickle.unpack() function might also be helpful.

Binary protocol – responses for errors

For a response other than IPROTO_OK, the header Response-Code-Indicator will be 0x8XXX and the body will be:

```
++=======================+
||                       |
||   0x31: IPROTO_ERROR  |
|| MP_INT: MP_STRING     |
||                       |
++=======================+
      MP_MAP
```

where 0x8XXX is the indicator for an error and XXX is a value in src/box/errcode.h. src/box/errcode.h also has some convenience macros which define hexadecimal constants for return codes.

For example, if we try to create a duplicate space with conn:eval([[box.schema.space.create('_space');]]) the server response will look like this:

```
ce 00 00 00 3b                  MP_UINT = HEADER + BODY SIZE
83                            MP_MAP, size 3 (i.e. 3 items in header)
  00                            Response-Code-Indicator
  ce 00 00 80 0a                  MP_UINT = hexadecimal 800a
```

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```
 01                             IPROTO_SYNC
 cf 00 00 00 00 00 00 00 26       MP_UINT = sync value
 05                             IPROTO_SCHEMA_VERSION
 ce 00 00 00 78                   MP_UINT = schema version value
 81                             MP_MAP, size 1
   31                             IPROTO_ERROR
   db 00 00 00 1d 53 70 61 63 etc. MP_STR = "Space '_space' already exists"
```

Looking in errcode.h we find that error code 0x0a (decimal 10) is ER_SPACE_EXISTS, and the string associated with ER_SPACE_EXISTS is “Space ‘%s’ already exists”.

Binary protocol – responses for SQL

After the HEADER, for a response to an SQL statement, there will be a body that is slightly different from the body for Binary protocol – responses if no error and no SQL.

If the SQL request is not SELECT or VALUES or PRAGMA, then the response body contains only IPROTO_SQL_INFO (0x42). Usually IPROTO_SQL_INFO is a map with only one item – SQL_INFO_ROW_COUNT (0x00) – which is the number of changed rows.

```
+=======================================================+
|                                                       |
|   0x42: IPROTO_SQL_INFO                               |
| MP_MAP: usually 1 item  +~~~~~~~~~~~~~~~~~~~~~~~~~~~~~+ |
|                         |                             | |
|                         |   0x00: SQL_INFO_ROW_COUNT  | |
|                         | MP_UINT: changed row count  | |
|                         |                             | |
|                         +~~~~~~~~~~~~~~~~~~~~~~~~~~~~~+ |
|                                                       |
+=======================================================+
```

For example, if the request is INSERT INTO table-name VALUES (1), (2), (3), then the response body contains an IPROTO_SQL_INFO map with SQL_INFO_ROW_COUNT = 3. SQL_INFO_ROW_COUNT can be 0 for statements that do not change rows, but can be 1 for statements that create new objects.

The IPROTO_SQL_INFO map may contain a second item – SQL_INFO_AUTO_INCREMENT_IDS (0x01) – which is the new primary-key value (or values) for an INSERT in a table defined with PRIMARY KEY AUTOINCREMENT. In this case the MP_MAP will have two keys, and one of the two keys will be 0x01: SQL_INFO_AUTO_INCREMENT_IDS, which is an array of unsigned integers.

For example, if we use the same net.box connection that we used for Binary protocol – illustration and we say conn:execute([[CREATE TABLE t1 (dd INT PRIMARY KEY AUTOINCREMENT, дд STRING COLLATE "unicode");]]) conn:execute([[INSERT INTO t1 VALUES (NULL, 'a'), (NULL, 'b');]]) and we watch what tcpdump displays, we will see two noticeable things: (1) the CREATE statement caused a schema change so the response has a new IPROTO_SCHEMA_VERSION value and the body includes the new contents of some system tables (caused by requests from net.box which users will not see); (2) the final bytes of the response to the INSERT will be:

```
81   MP_MAP, size 1
42     IPROTO_SQL_INFO
82     MP_MAP, size 2
00       Tarantool constant (not in iproto_constants.h) = SQL_INFO_ROW_COUNT
02       1 = row count
01       Tarantool constant (not in iproto_constants.h) = SQL_INFO_AUTOINCREMENT_ID
```

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```
92        MP_ARRAY, size 2
01          first autoincrement number
02          second autoincrement number
```

If the SQL statement is SELECT or VALUES or PRAGMA, the response contains:

- IPROTO_METADATA + array of column maps, with each column map containing at least IPROTO_FIELD_NAME (0x00) + MP_STR, and IPROTO_FIELD_TYPE (0x01) + MP_STR. Additionally, if sql_full_metadata in the _session_settings system space is TRUE, then the array will have these additional column maps which correspond to components described in the box.execute() section: IPROTO_FIELD_COLL (0x02) + MP_STR, IPROTO_FIELD_IS_NULLABLE (0x03) + MP_BOOL, IPROTO_FIELD_IS_AUTOINCREMENT (0x04) + MP_BOOL, IPROTO_FIELD_SPAN (0x05) + MP_STR or MP_NIL.
- IPROTO_DATA + array of tuples = the result set “rows”

```
EXECUTE SELECT RESPONSE BODY:
                      MAP
+=============================================+=============================+
|                                  |                          |
|     0x32: IPROTO_METADATA                    |                          |
| MP_ARRAY: array of maps:                 |                          |
|          +~~~~~~~~~~~~~~~~~~~~~~-------~~+ |                          |
|          | +~~~~~~~~~~~~~-------~~~~~~~~+ | |     0x30: IPROTO_DATA     |
|          | |   0x00: IPROTO_FIELD_NAME | | | MP_ARRAY: array of tuples |
|          | | MP_STR: field name        | | |                          |
|          | |   0x01: IPROTO_FIELD_TYPE | | |                          |
|          | | MP_STR: field type        | | |                          |
|          | | + more if full metadata   | | |                          |
|          | +~~~~~~~~~~~~~~~~~~~~~~~~~~~+ | |                          |
|          |        MP_MAP                 | |                          |
|          +~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~+ |                          |
|                MP_ARRAY                  |                          |
|                                  |                          |
+=============================================+=============================+
```

For example, if we use the same net_box connection that we used for Binary protocol – illustration and we ask for full metadata by saying conn.space._session_settings:update('sql_full_metadata', {{'=', 'value', true}}) and we select the two rows from the table that we just created conn:execute([[SELECT dd, дд AS д FROM t1;]]) then tcpdump will show this response, after the header:

```
82                         MP_MAP, size 2 (i.e. metadata and rows)
32                           IPROTO_METADATA
92                           MP_ARRAY, size 2 (i.e. 2 columns)
85                             MP_MAP, size 5 (i.e. 5 items for column#1)
00 a2 44 44                      IPROTO_FIELD_NAME + 'DD'
01 a7 69 6e 74 65 67 65 72       IPROTO_FIELD_TYPE + 'integer'
03 c2                            IPROTO_FIELD_IS_NULLABLE + false
04 c3                            IPROTO_FIELD_IS_AUTOINCREMENT + true
05 c0                            PROTO_FIELD_SPAN + nil
85                             MP_MAP, size 5 (i.e. 5 items for column#2)
00 a2 d0 94                      IPROTO_FIELD_NAME + 'Д' upper case
01 a6 73 74 72 69 6e 67          IPROTO_FIELD_TYPE + 'string'
02 a7 75 6e 69 63 6f 64 65       IPROTO_FIELD_COLL + 'unicode'
03 c3                            IPROTO_FIELD_IS_NULLABLE + true
05 a4 d0 b4 d0 b4                IPROTO_FIELD_SPAN + 'дд' lower case
```

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```
30                          IPROTO_DATA
92                          MP_ARRAY, size 2
92                            MP_ARRAY, size 2
01                              MP_INT = 1 i.e. contents of row#1 column#1
a1 61                           MP_STR = 'a' i.e. contents of row#1 column#2
92                            MP_ARRAY, size 2
02                              MP_INT = 2 i.e. contents of row#2 column#1
a1 62                           MP_STR = 'b' i.e. contents of row#2 column#2
```

If instead we said conn:prepare([[SELECT dd, дд AS д FROM t1;]]) then tcpdump would should show almost the same response, but there would be no IPROTO_DATA and there would be two additional items: 34 00 = IPROTO_BIND_COUNT + MP_UINT = 0 (there are no parameters to bind), 33 90 = IPROTO_BIND_METADATA + MP_ARRAY, size 0 (there are no parameters to bind).

```
84                        MP_MAP, size 4
43                          IPROTO_STMT_ID
ce c2 3c 2c 1e                MP_UINT = statement id
34                          IPROTO_BIND_COUNT
00                          MP_INT = 0 = number of parameters to bind
33                          IPROTO_BIND_METADATA
90                          MP_ARRAY, size 0 = there are no parameters to bind
32                          IPROTO_METADATA
92                          MP_ARRAY, size 2 (i.e. 2 columns)
85                            MP_MAP, size 5 (i.e. 5 items for column#1)
00 a2 44 44                     IPROTO_FIELD_NAME + 'DD'
01 a7 69 6e 74 65 67 65 72      IPROTO_FIELD_TYPE + 'integer'
03 c2                           IPROTO_FIELD_IS_NULLABLE + false
04 c3                           IPROTO_FIELD_IS_AUTOINCREMENT + true
05 c0                           PROTO_FIELD_SPAN + nil
85                            MP_MAP, size 5 (i.e. 5 items for column#2)
00 a2 d0 94                     IPROTO_FIELD_NAME + 'Д' upper case
01 a6 73 74 72 69 6e 67         IPROTO_FIELD_TYPE + 'string'
02 a7 75 6e 69 63 6f 64 65      IPROTO_FIELD_COLL + 'unicode'
03 c3                           IPROTO_FIELD_IS_NULLABLE + true
05 a4 d0 b4 d0 b4               IPROTO_FIELD_SPAN + 'дд' lower case
```

Now read the source code file net_box.c where the function "decode_metadata_optional" is an example of how Tarantool itself decodes extra items.

Binary protocol – authentication

When a client connects to the server instance, the instance responds with a 128-byte text greeting message, like this:

```
Greeting packet sent by server after connect:

0                                     63
+--------------------------------------+
|                                      |
| Tarantool Greeting (server version)  |
|               64 bytes               |
+---------------------+----------------+
|                     |                |
| BASE64 encoded SALT |      NULL      |
```

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```
|      44 bytes       |                |
+---------------------+----------------+
64                   107              127
```

The greeting contains two 64-byte lines of ASCII text. Each line ends with a newline character (\n). The first line contains the instance version and protocol type. The second line contains up to 44 bytes of base64-encoded random string, to use in the authentication packet, and ends with up to 23 spaces.

Part of the greeting is a base-64-encoded session salt - a random string which can be used for authentication. The length of a decoded salt (44 bytes) exceeds the amount necessary to sign the authentication message (the first 20 bytes). An excess is reserved for future authentication schemas.

Authentication is optional – if it is skipped, then the session user is `'guest'` (the `'guest'` user does not need a password).

If authentication is not skipped, then at any time an authentication packet can be prepared using the greeting, as follows.

```
PREPARE SCRAMBLE:

    LEN(ENCODED_SALT) = 44;
    LEN(SCRAMBLE)     = 20;

prepare 'chap-sha1' scramble:

    salt = base64_decode(encoded_salt);
    step_1 = sha1(password);
    step_2 = sha1(step_1);
    step_3 = sha1(salt, step_2);
    scramble = xor(step_1, step_3);
    return scramble;

AUTHORIZATION BODY: CODE = IPROTO_AUTH (0x07)

+==================+====================================+
|                  |        +-------------+-----------+ |
|  (KEY)           | (TUPLE)|  len == 9   | len == 20 | |
|   0x23:IPROTO_USER_NAME |   0x21:| "chap-sha1" |  SCRAMBLE | |
| MP_INT:MP_STRING | MP_INT:|  MP_STRING  |  MP_BIN   | |
|                  |        +-------------+-----------+ |
|                  |                   MP_ARRAY         |
+==================+====================================+
                MP_MAP
```

<key> holds the user name. <tuple> must be an array of 2 fields: authentication mechanism ("chap-sha1" is the only supported mechanism right now) and password, encrypted according to the specified mechanism.

The server instance responds to an authentication packet with a standard response with 0 tuples.

To see how Tarantool handles this, look at net_box.c function netbox_encode_auth.

Binary protocol – replication

```
-- replication keys
<server_id>    ::= 0x02
<lsn>          ::= 0x03
```

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```
<timestamp>     ::= 0x04
<server_uuid>   ::= 0x24
<cluster_uuid>  ::= 0x25
<vclock>        ::= 0x26
```

```
-- replication codes
<join>          ::= 0x41
<subscribe>     ::= 0x42
```

```
JOIN:

In the beginning you must send an initial IPROTO_JOIN request (0x41)
               HEADER                          BODY
+================+===========================++===========================+
|                |                           ||   IPROTO_INSTANCE_UUID |
|   0x00: 0x41   |   0x01: IPROTO_SYNC   ||   0x24: UUID             |
| MP_INT: MP_INT | MP_INT: MP_INT          || MP_INT: MP_STRING       |
|                |                           ||                         |
+================+===========================++===========================+
               MP_MAP                          MP_MAP

Then the instance which you want to connect to will send its last SNAP file,
by simply creating a number of INSERTs (with additional LSN and ServerID)
(do not reply to this). Then that instance will send a vclock's MP_MAP and
close a socket.

+================+===========================++================================+
|                |                           ||        +~~~~~~~~~~~~~~~~~+ |
|                |                           ||        |                 | |
|   0x00: 0x00   |   0x01: IPROTO_SYNC   ||   0x26:| SRV_ID: SRV_LSN | |
| MP_INT: MP_INT | MP_INT: MP_INT          || MP_INT:| MP_INT: MP_INT  | |
|                |                           ||        +~~~~~~~~~~~~~~~~~+ |
|                |                           ||               MP_MAP       |
+================+===========================++================================+
               MP_MAP                          MP_MAP

SUBSCRIBE:

Then you must send an IPROTO_SUBSCRIBE request (0x42)

                              HEADER
+===========================+===========================+
|                         |                         |
|     0x00: 0x42          |    0x01: IPROTO_SYNC   |
|   MP_INT: MP_INT        |  MP_INT: MP_INT        |
|                         |                         |
+===========================+===========================+
|    IPROTO_INSTANCE_UUID |    IPROTO_CLUSTER_UUID |
|   0x24: UUID            |   0x25: UUID           |
| MP_INT: MP_STRING       | MP_INT: MP_STRING      |
|                         |                         |
+===========================+===========================+
                 MP_MAP

      BODY
+=======================+
```

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```
|                        |
|   0x26: IPROTO_VCLOCK |
| MP_INT: MP_INT         |
|                        |
+========================+
      MP_MAP

Then you must process every request that could come through other masters.
Every request between masters will have Additional LSN and SERVER_ID.
```

Frequently a master sends a heartbeat message to a replica. For example, if there is a replica with id = 2, and a timestamp with a moment in 2020, a master might send this:

```
83                       MP_MAP, size 3
00                         Main-Map Item #1 IPROTO_REQUEST_TYPE
00                           MP_UINT = 0
02                         Main-Map Item #2 IPROTO_REPLICA_ID
02                           MP_UINT = 2 = id
04                         Main-Map Item #3 IPROTO_TIMESTAMP
cb                           MP_DOUBLE (MessagePack "Float 64")
41 d7 ba 06 7b 3a 03 21      8-byte timestamp
```

and the replica might send back this:

```
81                        MP_MAP, size 1
00                          Main-Map Item #1 Response-code-indicator
00                          MP_UINT = 0 = IPROTO_OK
81                          Main-Map Item #2, MP_MAP, size 1
26                            Sub-Map Item #1 IPROTO_VCLOCK
81                            Sub-Map Item #2, MP_MAP, size 1
01                              MP_UINT = 1 = id (part 1 of vclock)
06                              MP_UINT = 6 = lsn (part 2 of vclock)
```

The DECIMAL type

MessagePack EXT type MP_EXT together with the extension type MP_DECIMAL is used as a record header.

MP_DECIMAL is 1.

MessagePack spec defines two kinds of types:

- fixext 1/2/4/8/16 types have fixed length so the length is not encoded explicitly;
- ext 8/16/32 types require the data length to be encoded.

MP_EXP + optional length imply using one of these types.

The decimal MessagePack representation looks like this:

```
+--------+-------------------+------------+===============+
| MP_EXT | length (optional) | MP_DECIMAL | PackedDecimal |
+--------+-------------------+------------+===============+
```

Here length is the length of PackedDecimal field, and it is of type MP_UINT, when encoded explicitly (i.e. when the type is ext 8/16/32).

PackedDecimal has the following structure:

```
 <--- length bytes -->
+-------+=============+
| scale |     BCD     |
+-------+=============+
```

Here scale is either MP_INT or MP_UINT. scale = -exponent (exponent negated!)

BCD is a sequence of bytes representing decimal digits of the encoded number (each byte represents two decimal digits each encoded using 4 bits), so byte >> 4 is the first digit and byte & 0x0f is the second digit. The leftmost digit in the array is the most significant. The rightmost digit in the array is the least significant.

The first byte of the BCD array contains the first digit of the number, represented as follows:

```
|  4 bits          |  4 bits          |
   = 0x                = the 1st digit
```

The last byte of the BCD array contains the last digit of the number and the nibble, represented as follows:

```
|  4 bits          |  4 bits          |
   = the last digit    = nibble
```

The nibble represents the number's sign:

- 0x0a, 0x0c, 0x0e, 0x0f stand for plus,
- 0x0b and 0x0d stand for minus.

Examples

The decimal -12.34 will be encoded as 0xd6,0x01,0x02,0x01,0x23,0x4d:

```
|MP_EXT (fixext 4) | MP_DECIMAL | scale |  1   |  2,3 |  4 (minus) |
|       0xd6       |    0x01    | 0x02  | 0x01 | 0x23 | 0x4d       |
```

The decimal 0.000000000000000000000000000000000010 will be encoded as 0xc7,0x03,0x01,0x24,0x01,0x0c:

```
| MP_EXT (ext 8) | length | MP_DECIMAL | scale |  1   | 0 (plus) |
|      0xc7      |  0x03  |    0x01    | 0x24  | 0x01 | 0x0c     |
```

XLOG / SNAP

.xlog and .snap files have nearly the same format. The header looks like:

```
<type>\n                  SNAP\n or XLOG\n
<version>\n               currently 0.13\n
Server: <server_uuid>\n   where UUID is a 36-byte string
VClock: <vclock_map>\n    e.g. {1: 0}\n
\n
```

After the file header come the data tuples. Tuples begin with a row marker 0xd5ba0bab and the last tuple may be followed by an EOF marker 0xd510aded. Thus, between the file header and the EOF marker, there may be data tuples that have this form:

```
0            3 4                                 17
+-------------+========+============+===========+=========+
|             |        |            |           |         |
```

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```
| 0xd5ba0bab  | LENGTH | CRC32 PREV | CRC32 CUR | PADDING |
|             |        |            |           |         |
+-------------+========+============+===========+=========+
  MP_FIXEXT2    MP_INT     MP_INT       MP_INT      ---

+============+ +===================================+
|            | |                                   |
|   HEADER   | |               BODY                |
|            | |                                   |
+============+ +===================================+
   MP_MAP                     MP_MAP
```

See the example in the File formats section.

5.6.2 File formats

Data persistence and the WAL file format

To maintain data persistence, Tarantool writes each data change request (insert, update, delete, replace, upsert) into a write-ahead log (WAL) file in the wal_dir directory. A new WAL file is created for every rows_per_wal records, or for every wal_max_size bytes. Each data change request gets assigned a continuously growing 64-bit log sequence number. The name of the WAL file is based on the log sequence number of the first record in the file, plus an extension .xlog.

Apart from a log sequence number and the data change request (formatted as in Tarantool's binary protocol), each WAL record contains a header, some metadata, and then the data formatted according to msgpack rules. For example, this is what the WAL file looks like after the first INSERT request ("s:insert({1})") for the sandbox database created in our "Getting started" exercises. On the left are the hexadecimal bytes that you would see with:

```
$ hexdump 00000000000000000000.xlog
```

and on the right are comments.

```
Hex dump of WAL file       Comment
--------------------       -------
58 4c 4f 47 0a             "XLOG\n"
30 2e 31 33 0a             "0.13\n" = version
53 65 72 76 65 72 3a 20    "Server: "
38 62 66 32 32 33 65 30 2d [Server UUID]\n
36 39 31 34 2d 34 62 35 35
2d 39 34 64 32 2d 64 32 62
36 64 30 39 62 30 31 39 36
0a
56 43 6c 6f 63 6b 3a 20    "Vclock: "
7b 7d                      "{}" = vclock value, initially blank
...                        (not shown = tuples for system spaces)
d5 ba 0b ab                Magic row marker always = 0xab0bbad5
19                         Length, not including length of header, = 25 bytes
00                           Record header: previous crc32
ce 8c 3e d6 70               Record header: current crc32
a7 cc 73 7f 00 00 66 39      Record header: padding
84                         msgpack code meaning "Map of 4 elements" follows
00 02                        element#1: tag=request type, value=0x02=IPROTO_INSERT
```

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```
02 01                      element#2: tag=server id, value=0x01
03 04                      element#3: tag=lsn, value=0x04
04 cb 41 d4 e2 2f 62 fd d5 d4 element#4: tag=timestamp, value=an 8-byte "Float64"
82                      msgpack code meaning "map of 2 elements" follows
10 cd 02 00                  element#1: tag=space id, value=512, big byte first
21 91 01                    element#2: tag=tuple, value=1-element fixed array={1}
```

Tarantool processes requests atomically: a change is either accepted and recorded in the WAL, or discarded completely. Let's clarify how this happens, using the REPLACE request as an example:

1. The server instance attempts to locate the original tuple by primary key. If found, a reference to the tuple is retained for later use.
2. The new tuple is validated. If for example it does not contain an indexed field, or it has an indexed field whose type does not match the type according to the index definition, the change is aborted.
3. The new tuple replaces the old tuple in all existing indexes.
4. A message is sent to the WAL writer running in a separate thread, requesting that the change be recorded in the WAL. The instance switches to work on the next request until the write is acknowledged.
5. On success, a confirmation is sent to the client. On failure, a rollback procedure is begun. During the rollback procedure, the transaction processor rolls back all changes to the database which occurred after the first failed change, from latest to oldest, up to the first failed change. All rolled back requests are aborted with ER_WAL_IO error. No new change is applied while rollback is in progress. When the rollback procedure is finished, the server restarts the processing pipeline.

One advantage of the described algorithm is that complete request pipelining is achieved, even for requests on the same value of the primary key. As a result, database performance doesn't degrade even if all requests refer to the same key in the same space.

The transaction processor thread communicates with the WAL writer thread using asynchronous (yet reliable) messaging; the transaction processor thread, not being blocked on WAL tasks, continues to handle requests quickly even at high volumes of disk I/O. A response to a request is sent as soon as it is ready, even if there were earlier incomplete requests on the same connection. In particular, SELECT performance, even for SELECTs running on a connection packed with UPDATEs and DELETEs, remains unaffected by disk load.

The WAL writer employs a number of durability modes, as defined in configuration variable wal_mode. It is possible to turn the write-ahead log completely off, by setting wal_mode to none. Even without the write-ahead log it's still possible to take a persistent copy of the entire data set with the box.snapshot() request.

An .xlog file always contains changes based on the primary key. Even if the client requested an update or delete using a secondary key, the record in the .xlog file will contain the primary key.

The snapshot file format

The format of a snapshot .snap file is nearly the same as the format of a WAL .xlog file. However, the snapshot header differs: it contains the instance's global unique identifier and the snapshot file's position in history, relative to earlier snapshot files. Also, the content differs: an .xlog file may contain records for any data-change requests (inserts, updates, upserts, and deletes), a .snap file may only contain records of inserts to memtx spaces.

Primarily, the .snap file's records are ordered by space id. Therefore the records of system spaces – such as _schema, _space, _index, _func, _priv and _cluster – will be at the start of the .snap file, before the records of any spaces that were created by users.

Secondarily, the .snap file's records are ordered by primary key within space id.

5.6.3 The recovery process

The recovery process begins when box.cfg{} happens for the first time after the Tarantool server instance starts.

The recovery process must recover the databases as of the moment when the instance was last shut down. For this it may use the latest snapshot file and any WAL files that were written after the snapshot. One complicating factor is that Tarantool has two engines – the memtx data must be reconstructed entirely from the snapshot and the WAL files, while the vinyl data will be on disk but might require updating around the time of a checkpoint. (When a snapshot happens, Tarantool tells the vinyl engine to make a checkpoint, and the snapshot operation is rolled back if anything goes wrong, so vinyl's checkpoint is at least as fresh as the snapshot file.)

Step 1 Read the configuration parameters in the box.cfg{} request. Parameters which affect recovery may include work_dir, wal_dir, memtx_dir, vinyl_dir and force_recovery.

Step 2 Find the latest snapshot file. Use its data to reconstruct the in-memory databases. Instruct the vinyl engine to recover to the latest checkpoint.

There are actually two variations of the reconstruction procedure for memtx databases, depending on whether the recovery process is "default".

If the recovery process is default (force_recovery is false), memtx can read data in the snapshot with all indexes disabled. First, all tuples are read into memory. Then, primary keys are built in bulk, taking advantage of the fact that the data is already sorted by primary key within each space.

If the recovery process is non-default (force_recovery is true), Tarantool performs additional checking. Indexes are enabled at the start, and tuples are added one by one. This means that any unique-key constraint violations will be caught, and any duplicates will be skipped. Normally there will be no constraint violations or duplicates, so these checks are only made if an error has occurred.

Step 3 Find the WAL file that was made at the time of, or after, the snapshot file. Read its log entries until the log-entry LSN is greater than the LSN of the snapshot, or greater than the LSN of the vinyl checkpoint. This is the recovery process's "start position"; it matches the current state of the engines.

Step 4 Redo the log entries, from the start position to the end of the WAL. The engine skips a redo instruction if it is older than the engine's checkpoint.

Step 5 For the memtx engine, re-create all secondary indexes.

5.6.4 Server startup with replication

In addition to the recovery process described above, the server must take additional steps and precautions if replication is enabled.

Once again the startup procedure is initiated by the box.cfg{} request. One of the box.cfg parameters may be replication that specifies replication source(-s). We will refer to this replica, which is starting up due to box.cfg, as the "local" replica to distinguish it from the other replicas in a replica set, which we will refer to as "distant" replicas.

#1. If there is no snapshot .snap file and the 'replication' parameter is empty and cfg.read_only=false: then the local replica assumes it is an unreplicated "standalone" instance, or is the first replica of a new replica set. It will generate new UUIDs for itself and for the replica set. The replica UUID is stored in the _cluster space (unless the replica is anonymous); the replica set UUID is stored in the _schema space. Since a snapshot contains all the data in all the spaces, that means the local replica's snapshot will contain the replica UUID and the replica set UUID. Therefore, when the local replica restarts on later occasions, it will be able to recover these UUIDs when it reads the .snap file.

#1a. If there is no snapshot .snap file and the 'replication' parameter is empty and cfg.read_only=true: When an instance is starting with box.cfg({... read_only = true}), it cannot be the first replica of a new replica set because the first replica must be a master. Therefore an error message will occur: ER_BOOTSTRAP_READONLY. To avoid this, change the setting for this (local) instance to read_only = false, or ensure that another (distant) instance starts first and has the local instance's UUID in its _cluster space. In the latter case, if ER_BOOTSTRAP_READONLY still occurs, set the local instance's box.replication_connect_timeout to a larger value.

#2. If there is no snapshot .snap file and the 'replication' parameter is not empty and the ‘‘_cluster‘‘ space contains no other replica UUIDs: then the local replica assumes it is not a standalone instance, but is not yet part of a replica set. It must now join the replica set. It will send its replica UUID to the first distant replica which is listed in replication and which will act as a master. This is called the “join request”. When a distant replica receives a join request, it will send back:

(1) the distant replica's replica set UUID,

(2) the contents of the distant replica's .snap file. When the local replica receives this information, it puts the replica set UUID in its _schema space, puts the distant replica's UUID and connection information in its _cluster space, and makes a snapshot containing all the data sent by the distant replica. Then, if the local replica has data in its WAL .xlog files, it sends that data to the distant replica. The distant replica will receive this and update its own copy of the data, and add the local replica's UUID to its _cluster space.

#3. If there is no snapshot .snap file and the 'replication' parameter is not empty and the ‘‘_cluster‘‘ space contains other replica UUIDs: then the local replica assumes it is not a standalone instance, and is already part of a replica set. It will send its replica UUID and replica set UUID to all the distant replicas which are listed in replication. This is called the “on-connect handshake”. When a distant replica receives an on-connect handshake:

(1) the distant replica compares its own copy of the replica set UUID to the one in the on-connect handshake. If there is no match, then the handshake fails and the local replica will display an error.

(2) the distant replica looks for a record of the connecting instance in its _cluster space. If there is none, then the handshake fails. Otherwise the handshake is successful. The distant replica will read any new information from its own .snap and .xlog files, and send the new requests to the local replica.

In the end . . . the local replica knows what replica set it belongs to, the distant replica knows that the local replica is a member of the replica set, and both replicas have the same database contents.

#4. If there is a snapshot file and replication source is not empty: first the local replica goes through the recovery process described in the previous section, using its own .snap and .xlog files. Then it sends a “subscribe” request to all the other replicas of the replica set. The subscribe request contains the server vector clock. The vector clock has a collection of pairs 'server id, lsn' for every replica in the _cluster system space. Each distant replica, upon receiving a subscribe request, will read its .xlog files' requests and send them to the local replica if (lsn of .xlog file request) is greater than (lsn of the vector clock in the subscribe request). After all the other replicas of the replica set have responded to the local replica's subscribe request, the replica startup is complete.

The following temporary limitations apply for versions 1.7 and 2.1:

- The URIs in the replication parameter should all be in the same order on all replicas. This is not mandatory but is an aid to consistency.
- The maximum number of entries in the _cluster space is 32. Tuples for out-of-date replicas are not automatically re-used, so if this 32-replica limit is reached, users may have to reorganize the _cluster space manually.

5.7 Interactive console

The “interactive console” is Tarantool’s basic “command-line interface” for entering requests and seeing results. It is what users see when they start the server without an instance file, or start tarantoolctl with enter. It is often called the Lua console to distinguish it from the administrative console, but in fact it can handle both Lua and SQL input. The majority of examples in this manual show what users see with the interactive console, including the prompt (which can be “tarantool> “), the instruction (which can be a Lua request or an SQL statement), and the response (which can be a display in either YAML format or Lua format).

```
-- Typical interactive console example with Lua input and YAML output
tarantool> box.info().replication
---
- 1:
    id: 1
    uuid: a5d22f66-2d28-4a35-b78f-5bf73baf6c8a
    lsn: 0
...
```

The input language can be changed to SQL with \set language sql or changed to Lua (the default) with \set language lua.

The delimiter can be changed to any character with set delimiter <character>. The default is nothing, which means input does not need to end with a delimiter. But a common recommendation is to say set delimiter ; especially if input is SQL.

The output format can be changed to Lua with \set output lua or changed to YAML (the default) with \set output yaml.

Ordinarily. output from the console has YAML format. That means that there is a line for document-start "---", and each item begins on a separate line starting with "- ", and each sub-item in a nested structure is indented, and there is a line for document-end "...".

Optionally, output from the console can have Lua format. That means that there are no lines for document-start or document-end, and items are not on separate lines (they are only separated by commas), and each sub-item in a nested structure is placed inside “{}” braces. So, when input is a Lua object description, output will equal input.

YAML is good for readability. Lua is good for re-using results as requests. A third format, MsgPack, is good for database storage. Currently the default output format is YAML but it may be Lua in a future version, and it may be Lua if the last set_default_output call was console.set_default_output('lua').

Type	Lua input	Lua output	YAML output	MsgPack storage
scalar	1	1	--- - 1 ...	\x01
scalar sequence	1,2,3	1,2,3	--- - 1 - 2 - 3 ...	\x01 \x02 \x03
2-element table	{1,2}	{1,2}	--- - - 1 - - 2 ...	0x92 0x01 0x02
map	{key=1}	{key=1}	--- - key: 1 ...	\x81 \xa3 \x6b \x65 \x79 \x01

5.8 Utility tarantoolctl

tarantoolctl is a utility for administering Tarantool instances, checkpoint files and modules. It is shipped and installed as part of Tarantool distribution.

See also tarantoolctl usage examples in Server administration section.

5.8.1 Command format

tarantoolctl COMMAND NAME [URI] [FILE] [OPTIONS..]

where:

- COMMAND is one of the following: start, stop, status, restart, logrotate, check, enter, eval, connect, cat, play, rocks.
- NAME is the name of an instance file or a module.
- FILE is the path to some file (.lua, .xlog or .snap).
- URI is the URI of some Tarantool instance.
- OPTIONS are options taken by some tarantoolctl commands.

5.8.2 Commands for managing Tarantool instances

tarantoolctl start NAME Start a Tarantool instance.

Additionally, this command sets the TARANTOOLCTL environment variable to 'true', to mark that the instance was started by tarantoolctl.

Note: tarantoolctl works for instances without box.cfg{} called or with delayed box.cfg{} call.

For example, this can be used to manage instances which receive configuration from an external server. For such instances, tarantoolctl start goes to background when box.cfg{} is called, so it will wait until options for box.cfg are received. However this is not the case for daemon management systems like systemd, as they handle backgrounding on their side.

tarantoolctl stop NAME Stop a Tarantool instance.

tarantoolctl status NAME Show an instance's status (started/stopped). If pid file exists and an alive control socket exists, the return code is 0. Otherwise, the return code is not 0.

Reports typical problems to stderr (e.g. pid file exists and control socket doesn't).

tarantoolctl restart NAME Stop and start a Tarantool instance.

Additionally, this command sets the TARANTOOL_RESTARTED environment variable to 'true', to mark that the instance was restarted by tarantoolctl.

tarantoolctl logrotate NAME Rotate logs of a started Tarantool instance. Works only if logging-into-file is enabled in the instance file. Pipe/syslog make no effect.

tarantoolctl check NAME Check an instance file for syntax errors.

tarantoolctl enter NAME [--language=language] Enter an instance's interactive Lua or SQL console.

Supported option:

- --language=language to set interactive console language. Can be either Lua or SQL.

tarantoolctl eval NAME FILE Evaluate a local Lua file on a running Tarantool instance.

tarantoolctl connect URI Connect to a Tarantool instance on an admin-console port. Supports both TCP/Unix sockets.

5.8.3 Commands for managing checkpoint files

tarantoolctl cat FILE.. [--space=space_no ..] [--show-system] [--from=from_lsn] [--to=to_lsn] [--replica=replica_id ..]
Print into stdout the contents of .snap/.xlog files.

tarantoolctl play URI FILE.. [--space=space_no ..] [--show-system] [--from=from_lsn] [--to=to_lsn] [--replica=replica_id ..
Play the contents of .snap/.xlog files to another Tarantool instance.

Supported options:

- --space=space_no to filter the output by space number. May be passed more than once.
- --show-system to show the contents of system spaces.
- --from=from_lsn to show operations starting from the given lsn.
- --to=to_lsn to show operations ending with the given lsn.
- --replica=replica_id to filter the output by replica id. May be passed more than once.

5.8.4 Commands for managing Tarantool modules

tarantoolctl rocks install NAME Install a module in the current directory.

tarantoolctl rocks remove NAME Remove a module.

tarantoolctl rocks show NAME Show information about an installed module.

tarantoolctl rocks search NAME Search the repository for modules.

tarantoolctl rocks list List all installed modules.

tarantoolctl rocks pack {<rockspec> | <name> [<version>]} Create a rock by packing sources or binaries.

As an argument, you can specify:

- a .rockspec file to create a source rock containing the module's sources, or
- the name of an installed module (and its version if there are more than one) to create a binary rock containing the compiled module.

tarantoolctl rocks unpack {<rock_file> | <rockspec> | <name> [version]} Unpack the contents of a rock into a new directory under the current one.

As an argument, you can specify:

- source or binary rock files,
- .rockspec files, or
- names of rocks or .rockspec files in remote repositories (and the rock version if there are more than one).

Supported options:

- --server=server_name check this server first, then the usual list.
- --only-server=server_name check this server only, ignore the usual list.

5.9 Tips on Lua syntax

The Lua syntax for data-manipulation functions can vary. Here are examples of the variations with select() requests. The same rules exist for the other data-manipulation functions.

Every one of the examples does the same thing: select a tuple set from a space named 'tester' where the primary-key field value equals 1. For these examples, we assume that the numeric id of 'tester' is 512, which happens to be the case in our sandbox example only.

5.9.1 Object reference variations

First, there are three object reference variations:

```
-- #1 module . submodule . name
tarantool> box.space.tester:select{1}
-- #2 replace name with a literal in square brackets
tarantool> box.space['tester']:select{1}
-- #3 use a variable for the entire object reference
tarantool> s = box.space.tester
tarantool> s:select{1}
```

Examples in this manual usually have the "box.space.tester:" form (#1). However, this is a matter of user preference and all the variations exist in the wild.

Also, descriptions in this manual use the syntax "space_object:" for references to objects which are spaces, and "index_object:" for references to objects which are indexes (for example box.space.tester.index.primary:).

5.9.2 Parameter variations

Then, there are seven parameter variations:

```
-- #1
tarantool> box.space.tester:select{1}
-- #2
tarantool> box.space.tester:select({1})
-- #3
tarantool> box.space.tester:select(1)
-- #4
tarantool> box.space.tester.select(box.space.tester,1)
-- #5
tarantool> box.space.tester:select({1},{iterator='EQ'})
-- #6
tarantool> variable = 1
tarantool> box.space.tester:select{variable}
-- #7
tarantool> variable = {1}
tarantool> box.space.tester:select(variable)
```

Lua allows to omit parentheses () when invoking a function if its only argument is a Lua table, and we use it sometimes in our examples. This is why select{1} is equivalent to select({1}). Literal values such as 1 (a scalar value) or {1} (a Lua table value) may be replaced by variable names, as in examples #6 and #7.

Although there are special cases where braces can be omitted, they are preferable because they signal "Lua table". Examples and descriptions in this manual have the {1} form. However, this too is a matter of user preference and all the variations exist in the wild.

5.9.3 Rules for object names

Database objects have loose rules for names: the maximum length is 65000 bytes (not characters), and almost any legal Unicode character is allowed, including spaces, ideograms and punctuation.

In those cases, to prevent confusion with Lua operators and separators, object references should have the literal-in-square-brackets form (#2), or the variable form (#3). For example:

```
tarantool> box.space['1*A']:select{1}
tarantool> s = box.space['1*A !@$%^&*()_+12345678901234567890']
tarantool> s:select{1}
```

Disallowed:

- characters which are unassigned code points,
- line and paragraph separators,
- control characters,
- the replacement character (U+FFFD).

Not recommended: characters which cannot be displayed.

Names are "case sensitive", so 'A' and 'a' are not the same.

CHAPTER 6

Tutorials

These tutorials are for those who would like to dig deeper into Tarantool usage.

If you are new to Tarantool, please see our Getting Started guides first.

6.1 Lua tutorials

Here are three tutorials on using Lua stored procedures with Tarantool:

- Insert one million tuples with a Lua stored procedure,
- Sum a JSON field for all tuples,
- Indexed pattern search.

6.1.1 Insert one million tuples with a Lua stored procedure

This is an exercise assignment: "Insert one million tuples. Each tuple should have a constantly-increasing numeric primary-key field and a random alphabetic 10-character string field."

The purpose of the exercise is to show what Lua functions look like inside Tarantool. It will be necessary to employ the Lua math library, the Lua string library, the Tarantool box library, the Tarantool box.tuple library, loops, and concatenations. It should be easy to follow even for a person who has not used either Lua or Tarantool before. The only requirement is a knowledge of how other programming languages work and a memory of the first two chapters of this manual. But for better understanding, follow the comments and the links, which point to the Lua manual or to elsewhere in this Tarantool manual. To further enhance learning, type the statements in with the tarantool client while reading along.

Configure

We are going to use the Tarantool sandbox that was created for our "Getting started" exercises. So there is a single space, and a numeric primary key, and a running Tarantool server instance which also serves as a client.

Delimiter

In earlier versions of Tarantool, multi-line functions had to be enclosed within "delimiters". They are no longer necessary, and so they will not be used in this tutorial. However, they are still supported. Users who wish to use delimiters, or users of older versions of Tarantool, should check the syntax description for declaring a delimiter before proceeding.

Create a function that returns a string

We will start by making a function that returns a fixed string, "Hello world".

```
function string_function()
  return "hello world"
end
```

The word "function" is a Lua keyword – we're about to go into Lua. The function name is string_function. The function has one executable statement, return "hello world". The string "hello world" is enclosed in double quotes here, although Lua doesn't care – one could use single quotes instead. The word "end" means "this is the end of the Lua function declaration." To confirm that the function works, we can say

```
string_function()
```

Sending function-name() means "invoke the Lua function." The effect is that the string which the function returns will end up on the screen.

For more about Lua strings see Lua manual chapter 2.4 "Strings" . For more about functions see Lua manual chapter 5 "Functions".

The screen now looks like this:

```
tarantool> function string_function()
         >   return "hello world"
         > end
---
...
tarantool> string_function()
---
- hello world
...
tarantool>
```

Create a function that calls another function and sets a variable

Now that string_function exists, we can invoke it from another function.

```
function main_function()
  local string_value
  string_value = string_function()
  return string_value
end
```

We begin by declaring a variable "string_value". The word "local" means that string_value appears only in main_function. If we didn't use "local" then string_value would be visible everywhere - even by other users using other clients connected to this server instance! Sometimes that's a very desirable feature for inter-client communication, but not this time.

Then we assign a value to string_value, namely, the result of string_function(). Soon we will invoke main_function() to check that it got the value.

For more about Lua variables see Lua manual chapter 4.2 "Local Variables and Blocks" .

The screen now looks like this:

```
tarantool> function main_function()
         >   local string_value
         >   string_value = string_function()
         >   return string_value
         > end
---
...
tarantool> main_function()
---
- hello world
...
tarantool>
```

Modify the function so it returns a one-letter random string

Now that it's a bit clearer how to make a variable, we can change string_function() so that, instead of returning a fixed literal "Hello world", it returns a random letter between 'A' and 'Z'.

```
function string_function()
  local random_number
  local random_string
  random_number = math.random(65, 90)
  random_string = string.char(random_number)
  return random_string
end
```

It is not necessary to destroy the old string_function() contents, they're simply overwritten. The first assignment invokes a random-number function in Lua's math library; the parameters mean "the number must be an integer between 65 and 90." The second assignment invokes an integer-to-character function in Lua's string library; the parameter is the code point of the character. Luckily the ASCII value of 'A' is 65 and the ASCII value of 'Z' is 90 so the result will always be a letter between A and Z.

For more about Lua math-library functions see Lua users "Math Library Tutorial". For more about Lua string-library functions see Lua users "String Library Tutorial" .

Once again the string_function() can be invoked from main_function() which can be invoked with main_function().

The screen now looks like this:

```
tarantool> function string_function()
         >   local random_number
         >   local random_string
         >   random_number = math.random(65, 90)
         >   random_string = string.char(random_number)
         >   return random_string
         > end
---
...
tarantool> main_function()
```

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```
---
- C
...
tarantool>
```

... Well, actually it won't always look like this because math.random() produces random numbers. But for the illustration purposes it won't matter what the random string values are.

Modify the function so it returns a ten-letter random string

Now that it's clear how to produce one-letter random strings, we can reach our goal of producing a ten-letter string by concatenating ten one-letter strings, in a loop.

```
function string_function()
  local random_number
  local random_string
  random_string = ""
  for x = 1,10,1 do
    random_number = math.random(65, 90)
    random_string = random_string .. string.char(random_number)
  end
  return random_string
end
```

The words "for x = 1,10,1" mean "start with x equals 1, loop until x equals 10, increment x by 1 for each iteration." The symbol ".." means "concatenate", that is, add the string on the right of the ".." sign to the string on the left of the ".." sign. Since we start by saying that random_string is "" (a blank string), the end result is that random_string has 10 random letters. Once again the string_function() can be invoked from main_function() which can be invoked with main_function().

For more about Lua loops see Lua manual chapter 4.3.4 "Numeric for".

The screen now looks like this:

```
tarantool> function string_function()
         >   local random_number
         >   local random_string
         >   random_string = ""
         >   for x = 1,10,1 do
         >     random_number = math.random(65, 90)
         >     random_string = random_string .. string.char(random_number)
         >   end
         >   return random_string
         > end
---
...
tarantool> main_function()
---
- 'ZUDJBHKEFM'
...
tarantool>
```

Make a tuple out of a number and a string

Now that it's clear how to make a 10-letter random string, it's possible to make a tuple that contains a number and a 10-letter random string, by invoking a function in Tarantool's library of Lua functions.

```
function main_function()
  local string_value, t
  string_value = string_function()
  t = box.tuple.new({1, string_value})
  return t
end
```

Once this is done, t will be the value of a new tuple which has two fields. The first field is numeric: 1. The second field is a random string. Once again the string_function() can be invoked from main_function() which can be invoked with main_function().

For more about Tarantool tuples see Tarantool manual section Submodule box.tuple.

The screen now looks like this:

```
tarantool> function main_function()
         > local string_value, t
         > string_value = string_function()
         > t = box.tuple.new({1, string_value})
         > return t
         > end
---
...
tarantool> main_function()
---
- [1, 'PNPZPCOOKA']
...
tarantool>
```

Modify main_function to insert a tuple into the database

Now that it's clear how to make a tuple that contains a number and a 10-letter random string, the only trick remaining is putting that tuple into tester. Remember that tester is the first space that was defined in the sandbox, so it's like a database table.

```
function main_function()
  local string_value, t
  string_value = string_function()
  t = box.tuple.new({1,string_value})
  box.space.tester:replace(t)
end
```

The new line here is box.space.tester:replace(t). The name contains 'tester' because the insertion is going to be to tester. The second parameter is the tuple value. To be perfectly correct we could have said box.space.tester:insert(t) here, rather than box.space.tester:replace(t), but "replace" means "insert even if there is already a tuple whose primary-key value is a duplicate", and that makes it easier to re-run the exercise even if the sandbox database isn't empty. Once this is done, tester will contain a tuple with two fields. The first field will be 1. The second field will be a random 10-letter string. Once again the string_function() can be invoked from main_function() which can be invoked with main_function(). But main_function() won't tell the whole story, because it does not return t, it only puts t into the database. To confirm that something got inserted, we'll use a SELECT request.

```
main_function()
box.space.tester:select{1}
```

For more about Tarantool insert and replace calls, see Tarantool manual section Submodule box.space, space_object:insert(), and space_object:replace().

The screen now looks like this:

```
tarantool> function main_function()
         >   local string_value, t
         >   string_value = string_function()
         >   t = box.tuple.new({1,string_value})
         >   box.space.tester:replace(t)
         > end
---
...
tarantool> main_function()
---
...
tarantool> box.space.tester:select{1}
---
- - [1, 'EUJYVEECIL']
...
tarantool>
```

Modify main_function to insert a million tuples into the database

Now that it's clear how to insert one tuple into the database, it's no big deal to figure out how to scale up: instead of inserting with a literal value = 1 for the primary key, insert with a variable value = between 1 and 1 million, in a loop. Since we already saw how to loop, that's a simple thing. The only extra wrinkle that we add here is a timing function.

```
function main_function()
  local string_value, t
  for i = 1,1000000,1 do
    string_value = string_function()
    t = box.tuple.new({i,string_value})
    box.space.tester:replace(t)
  end
end
start_time = os.clock()
main_function()
end_time = os.clock()
'insert done in ' .. end_time - start_time .. ' seconds'
```

The standard Lua function os.clock() will return the number of CPU seconds since the start. Therefore, by getting start_time = number of seconds just before the inserting, and then getting end_time = number of seconds just after the inserting, we can calculate (end_time - start_time) = elapsed time in seconds. We will display that value by putting it in a request without any assignments, which causes Tarantool to send the value to the client, which prints it. (Lua's answer to the C printf() function, which is print(), will also work.)

For more on Lua os.clock() see Lua manual chapter 22.1 "Date and Time". For more on Lua print() see Lua manual chapter 5 "Functions".

Since this is the grand finale, we will redo the final versions of all the necessary requests: the request that created string_function(), the request that created main_function(), and the request that invokes main_function().

```
function string_function()
  local random_number
  local random_string
  random_string = ""
  for x = 1,10,1 do
    random_number = math.random(65, 90)
    random_string = random_string .. string.char(random_number)
  end
  return random_string
end

function main_function()
  local string_value, t
  for i = 1,1000000,1 do
    string_value = string_function()
    t = box.tuple.new({i,string_value})
    box.space.tester:replace(t)
  end
end
start_time = os.clock()
main_function()
end_time = os.clock()
'insert done in ' .. end_time - start_time .. ' seconds'
```

The screen now looks like this:

```
tarantool> function string_function()
         >   local random_number
         >   local random_string
         >   random_string = ""
         >   for x = 1,10,1 do
         >     random_number = math.random(65, 90)
         >     random_string = random_string .. string.char(random_number)
         >   end
         >   return random_string
         > end
---
...
tarantool> function main_function()
         >   local string_value, t
         >   for i = 1,1000000,1 do
         >     string_value = string_function()
         >     t = box.tuple.new({i,string_value})
         >     box.space.tester:replace(t)
         >   end
         > end
---
...
tarantool> start_time = os.clock()
---
...
tarantool> main_function()
---
...
tarantool> end_time = os.clock()
---
```

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```
...
tarantool> 'insert done in ' .. end_time - start_time .. ' seconds'
---
- insert done in 37.62 seconds
...
tarantool>
```

What has been shown is that Lua functions are quite expressive (in fact one can do more with Tarantool's Lua stored procedures than one can do with stored procedures in some SQL DBMSs), and that it's straightforward to combine Lua-library functions and Tarantool-library functions.

What has also been shown is that inserting a million tuples took 37 seconds. The host computer was a Linux laptop. By changing wal_mode to 'none' before running the test, one can reduce the elapsed time to 4 seconds.

6.1.2 Sum a JSON field for all tuples

This is an exercise assignment: "Assume that inside every tuple there is a string formatted as JSON. Inside that string there is a JSON numeric field. For each tuple, find the numeric field's value and add it to a 'sum' variable. At end, return the 'sum' variable." The purpose of the exercise is to get experience in one way to read and process tuples.

```
 1  json = require('json')
 2  function sum_json_field(field_name)
 3    local v, t, sum, field_value, is_valid_json, lua_table
 4    sum = 0
 5    for v, t in box.space.tester:pairs() do
 6      is_valid_json, lua_table = pcall(json.decode, t[2])
 7      if is_valid_json then
 8        field_value = lua_table[field_name]
 9        if type(field_value) == "number" then sum = sum + field_value end
10      end
11    end
12    return sum
13  end
```

LINE 3: WHY "LOCAL". This line declares all the variables that will be used in the function. Actually it's not necessary to declare all variables at the start, and in a long function it would be better to declare variables just before using them. In fact it's not even necessary to declare variables at all, but an undeclared variable is "global". That's not desirable for any of the variables that are declared in line 1, because all of them are for use only within the function.

LINE 5: WHY "PAIRS()". Our job is to go through all the rows and there are two ways to do it: with box.space.space_object:pairs() or with variable = select(...) followed by for i, n, 1 do some-function(variable[i]) end. We preferred pairs() for this example.

LINE 5: START THE MAIN LOOP. Everything inside this "for" loop will be repeated as long as there is another index key. A tuple is fetched and can be referenced with variable t.

LINE 6: WHY "PCALL". If we simply said lua_table = json.decode(t[2])), then the function would abort with an error if it encountered something wrong with the JSON string - a missing colon, for example. By putting the function inside "pcall" (protected call), we're saying: we want to intercept that sort of error, so if there's a problem just set is_valid_json = false and we will know what to do about it later.

LINE 6: MEANING. The function is json.decode which means decode a JSON string, and the parameter is t[2] which is a reference to a JSON string. There's a bit of hard coding here, we're assuming that the second field in the tuple is where the JSON string was inserted. For example, we're assuming a tuple looks like

```
field[1]: 444
field[2]: '{"Hello": "world", "Quantity": 15}'
```

meaning that the tuple's first field, the primary key field, is a number while the tuple's second field, the JSON string, is a string. Thus the entire statement means "decode t[2] (the tuple's second field) as a JSON string; if there's an error set is_valid_json = false; if there's no error set is_valid_json = true and set lua_table = a Lua table which has the decoded string".

LINE 8. At last we are ready to get the JSON field value from the Lua table that came from the JSON string. The value in field_name, which is the parameter for the whole function, must be a name of a JSON field. For example, inside the JSON string '{"Hello": "world", "Quantity": 15}', there are two JSON fields: "Hello" and "Quantity". If the whole function is invoked with sum_json_field("Quantity"), then field_value = lua_table[field_name] is effectively the same as field_value = lua_table["Quantity"] or even field_value = lua_table.Quantity. Those are just three different ways of saying: for the Quantity field in the Lua table, get the value and put it in variable field_value.

LINE 9: WHY "IF". Suppose that the JSON string is well formed but the JSON field is not a number, or is missing. In that case, the function would be aborted when there was an attempt to add it to the sum. By first checking type(field_value) == "number", we avoid that abortion. Anyone who knows that the database is in perfect shape can skip this kind of thing.

And the function is complete. Time to test it. Starting with an empty database, defined the same way as the sandbox database in our "Getting started" exercises,

```
-- if tester is left over from some previous test, destroy it
box.space.tester:drop()
box.schema.space.create('tester')
box.space.tester:create_index('primary', {parts = {1, 'unsigned'}})
```

then add some tuples where the first field is a number and the second field is a string.

```
box.space.tester:insert{444, '{"Item": "widget", "Quantity": 15}'}
box.space.tester:insert{445, '{"Item": "widget", "Quantity": 7}'}
box.space.tester:insert{446, '{"Item": "golf club", "Quantity": "sunshine"}'}
box.space.tester:insert{447, '{"Item": "waffle iron", "Quantit": 3}'}
```

Since this is a test, there are deliberate errors. The "golf club" and the "waffle iron" do not have numeric Quantity fields, so must be ignored. Therefore the real sum of the Quantity field in the JSON strings should be: 15 + 7 = 22.

Invoke the function with sum_json_field("Quantity").

```
tarantool> sum_json_field("Quantity")
---
- 22
...
```

It works. We'll just leave, as exercises for future improvement, the possibility that the "hard coding" assumptions could be removed, that there might have to be an overflow check if some field values are huge, and that the function should contain a yield instruction if the count of tuples is huge.

6.1.3 Indexed pattern search

Here is a generic function which takes a field identifier and a search pattern, and returns all tuples that match. * The field must be the first field of a TREE index. * The function will use Lua pattern matching, which allows "magic characters" in regular expressions. * The initial characters in the pattern, as far as the first magic character, will be used as an index search key. For each tuple that is found via the index, there will be a match of the whole pattern. * To be cooperative, the function should yield after every 10 tuples, unless there is a reason to delay yielding. With this function, we can take advantage of Tarantool's indexes for speed, and take advantage of Lua's pattern matching for flexibility. It does everything that an SQL LIKE search can do, and far more.

Read the following Lua code to see how it works. The comments that begin with "SEE NOTE . . . " refer to long explanations that follow the code.

```
function indexed_pattern_search(space_name, field_no, pattern)
  -- SEE NOTE #1 "FIND AN APPROPRIATE INDEX"
  if (box.space[space_name] == nil) then
    print("Error: Failed to find the specified space")
    return nil
  end
  local index_no = -1
  for i=0,box.schema.INDEX_MAX,1 do
    if (box.space[space_name].index[i] == nil) then break end
    if (box.space[space_name].index[i].type == "TREE"
        and box.space[space_name].index[i].parts[1].fieldno == field_no
        and (box.space[space_name].index[i].parts[1].type == "scalar"
        or box.space[space_name].index[i].parts[1].type == "string")) then
      index_no = i
      break
    end
  end
  if (index_no == -1) then
    print("Error: Failed to find an appropriate index")
    return nil
  end
  -- SEE NOTE #2 "DERIVE INDEX SEARCH KEY FROM PATTERN"
  local index_search_key = ""
  local index_search_key_length = 0
  local last_character = ""
  local c = ""
  local c2 = ""
  for i=1,string.len(pattern),1 do
    c = string.sub(pattern, i, i)
    if (last_character ~= "%") then
      if (c == '^' or c == "$" or c == "(" or c == ")" or c == "."
                 or c == "[" or c == "]" or c == "*" or c == "+"
                 or c == "-" or c == "?") then
        break
      end
      if (c == "%") then
        c2 = string.sub(pattern, i + 1, i + 1)
        if (string.match(c2, "%p") == nil) then break end
        index_search_key = index_search_key .. c2
      else
        index_search_key = index_search_key .. c
      end
    end
    last_character = c
  end
  index_search_key_length = string.len(index_search_key)
  if (index_search_key_length < 3) then
    print("Error: index search key " .. index_search_key .. " is too short")
```

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```
    return nil
  end
  -- SEE NOTE #3 "OUTER LOOP: INITIATE"
  local result_set = {}
  local number_of_tuples_in_result_set = 0
  local previous_tuple_field = ""
  while true do
    local number_of_tuples_since_last_yield = 0
    local is_time_for_a_yield = false
    -- SEE NOTE #4 "INNER LOOP: ITERATOR"
    for _,tuple in box.space[space_name].index[index_no]:
    pairs(index_search_key,{iterator = box.index.GE}) do
      -- SEE NOTE #5 "INNER LOOP: BREAK IF INDEX KEY IS TOO GREAT"
      if (string.sub(tuple[field_no], 1, index_search_key_length)
      > index_search_key) then
        break
      end
      -- SEE NOTE #6 "INNER LOOP: BREAK AFTER EVERY 10 TUPLES -- MAYBE"
      number_of_tuples_since_last_yield = number_of_tuples_since_last_yield + 1
      if (number_of_tuples_since_last_yield >= 10
          and tuple[field_no] ~= previous_tuple_field) then
        index_search_key = tuple[field_no]
        is_time_for_a_yield = true
        break
        end
      previous_tuple_field = tuple[field_no]
      -- SEE NOTE #7 "INNER LOOP: ADD TO RESULT SET IF PATTERN MATCHES"
      if (string.match(tuple[field_no], pattern) ~= nil) then
        number_of_tuples_in_result_set = number_of_tuples_in_result_set + 1
        result_set[number_of_tuples_in_result_set] = tuple
      end
    end
    -- SEE NOTE #8 "OUTER LOOP: BREAK, OR YIELD AND CONTINUE"
    if (is_time_for_a_yield ~= true) then
      break
    end
    require('fiber').yield()
  end
  return result_set
end
```

NOTE #1 “FIND AN APPROPRIATE INDEX” The caller has passed space_name (a string) and field_no (a number). The requirements are: (a) index type must be “TREE” because for other index types (HASH, BITSET, RTREE) a search with iterator=GE will not return strings in order by string value; (b) field_no must be the first index part; (c) the field must contain strings, because for other data types (such as “unsigned”) pattern searches are not possible; If these requirements are not met by any index, then print an error message and return nil.

NOTE #2 “DERIVE INDEX SEARCH KEY FROM PATTERN” The caller has passed pattern (a string). The index search key will be the characters in the pattern as far as the first magic character. Lua’s magic characters are % ^ $ ( ) . [ ] * + - ?. For example, if the pattern is “ABC.E”, the period is a magic character and therefore the index search key will be “ABC”. But there is a complication . . . If we see “%” followed by a punctuation character, that punctuation character is “escaped” so remove the “%” when making the index search key. For example, if the pattern is “AB%$E”, the dollar sign is escaped and therefore the index search key will be “AB$E”. Finally there is a check that the index search key length must be at least three – this is an arbitrary number, and in fact zero would be okay, but short index search keys will cause long search times.

NOTE #3 – "OUTER LOOP: INITIATE" The function's job is to return a result set, just as box.space…select <box_space-select> would. We will fill it within an outer loop that contains an inner loop. The outer loop's job is to execute the inner loop, and possibly yield, until the search ends. The inner loop's job is to find tuples via the index, and put them in the result set if they match the pattern.

NOTE #4 "INNER LOOP: ITERATOR" The for loop here is using pairs(), see the explanation of what index iterators are. Within the inner loop, there will be a local variable named "tuple" which contains the latest tuple found via the index search key.

NOTE #5 "INNER LOOP: BREAK IF INDEX KEY IS TOO GREAT" The iterator is GE (Greater or Equal), and we must be more specific: if the search index key has N characters, then the leftmost N characters of the result's index field must not be greater than the search index key. For example, if the search index key is 'ABC', then 'ABCDE' is a potential match, but 'ABD' is a signal that no more matches are possible.

NOTE #6 "INNER LOOP: BREAK AFTER EVERY 10 TUPLES – MAYBE" This chunk of code is for cooperative multitasking. The number 10 is arbitrary, and usually a larger number would be okay. The simple rule would be "after checking 10 tuples, yield, and then resume the search (that is, do the inner loop again) starting after the last value that was found". However, if the index is non-unique or if there is more than one field in the index, then we might have duplicates – for example {"ABC",1}, {"ABC", 2}, {"ABC", 3}" – and it would be difficult to decide which "ABC" tuple to resume with. Therefore, if the result's index field is the same as the previous result's index field, there is no break.

NOTE #7 "INNER LOOP: ADD TO RESULT SET IF PATTERN MATCHES" Compare the result's index field to the entire pattern. For example, suppose that the caller passed pattern "ABC.E" and there is an indexed field containing "ABCDE". Therefore the initial index search key is "ABC". Therefore a tuple containing an indexed field with "ABCDE" will be found by the iterator, because "ABCDE" > "ABC". In that case string.match will return a value which is not nil. Therefore this tuple can be added to the result set.

NOTE #8 "OUTER LOOP: BREAK, OR YIELD AND CONTINUE" There are three conditions which will cause a break from the inner loop: (1) the for loop ends naturally because there are no more index keys which are greater than or equal to the index search key, (2) the index key is too great as described in NOTE #5, (3) it is time for a yield as described in NOTE #6. If condition (1) or condition (2) is true, then there is nothing more to do, the outer loop ends too. If and only if condition (3) is true, the outer loop must yield and then continue. If it does continue, then the inner loop – the iterator search – will happen again with a new value for the index search key.

EXAMPLE:

Start Tarantool, cut and paste the code for function indexed_pattern_search(), and try the following:

```
box.space.t:drop()
box.schema.space.create('t')
box.space.t:create_index('primary',{})
box.space.t:create_index('secondary',{unique=false,parts={2,'string',3,'string'}})
box.space.t:insert{1,'A','a'}
box.space.t:insert{2,'AB',''}
box.space.t:insert{3,'ABC','a'}
box.space.t:insert{4,'ABCD',''}
box.space.t:insert{5,'ABCDE','a'}
box.space.t:insert{6,'ABCDE',''}
box.space.t:insert{7,'ABCDEF','a'}
box.space.t:insert{8,'ABCDF',''}
indexed_pattern_search("t", 2, "ABC.E.")
```

The result will be:

```
tarantool> indexed_pattern_search("t", 2, "ABC.E.")
---
- - [7, 'ABCDEF', 'a']
...
```

6.2 C tutorial

Here is one C tutorial: C stored procedures.

6.2.1 C stored procedures

Tarantool can call C code with modules, or with ffi, or with C stored procedures. This tutorial only is about the third option, C stored procedures. In fact the routines are always "C functions" but the phrase "stored procedure" is commonly used for historical reasons.

In this tutorial, which can be followed by anyone with a Tarantool development package and a C compiler, there are five tasks:

(1) easy.c – prints "hello world";

(2) harder.c – decodes a passed parameter value;

(3) hardest.c – uses the C API to do a DBMS insert;

(4) read.c – uses the C API to do a DBMS select;

(5) write.c – uses the C API to do a DBMS replace.

After following the instructions, and seeing that the results are what is described here, users should feel confident about writing their own stored procedures.

Preparation

Check that these items exist on the computer:

- Tarantool 2.1 or later
- A gcc compiler, any modern version should work
- module.h and files #included in it
- msgpuck.h
- libmsgpuck.a (only for some recent msgpuck versions)

The module.h file will exist if Tarantool was installed from source. Otherwise Tarantool's "developer" package must be installed. For example on Ubuntu say:

```
$ sudo apt-get install tarantool-dev
```

or on Fedora say:

```
$ dnf -y install tarantool-devel
```

The msgpuck.h file will exist if Tarantool was installed from source. Otherwise the "msgpuck" package must be installed from https://github.com/tarantool/msgpuck.

Both module.h and msgpuck.h must be on the include path for the C compiler to see them. For example, if module.h address is /usr/local/include/tarantool/module.h, and msgpuck.h address is /usr/local/include/msgpuck/msgpuck.h, and they are not currently on the include path, say:

```
$ export CPATH=/usr/local/include/tarantool:/usr/local/include/msgpuck
```

The libmsgpuck.a static library is necessary with msgpuck versions produced after February 2017. If and only if you encounter linking problems when using the gcc statements in the examples for this tutorial, you should put libmsgpuck.a on the path (libmsgpuck.a is produced from both msgpuck and Tarantool source downloads so it should be easy to find). For example, instead of "gcc -shared -o harder.so -fPIC harder.c" for the second example below, you will need to say "gcc -shared -o harder.so -fPIC harder.c libmsgpuck.a".

Requests will be done using Tarantool as a client. Start Tarantool, and enter these requests.

```
box.cfg{listen=3306}
box.schema.space.create('capi_test')
box.space.capi_test:create_index('primary')
net_box = require('net.box')
capi_connection = net_box:new(3306)
```

In plainer language: create a space named capi_test, and make a connection to self named capi_connection.

Leave the client running. It will be necessary to enter more requests later.

easy.c

Start another shell. Change directory (cd) so that it is the same as the directory that the client is running on.

Create a file. Name it easy.c. Put these six lines in it.

```
#include "module.h"
int easy(box_function_ctx_t *ctx, const char *args, const char *args_end)
{
  printf("hello world\n");
  return 0;
}
int easy2(box_function_ctx_t *ctx, const char *args, const char *args_end)
{
  printf("hello world -- easy2\n");
  return 0;
}
```

Compile the program, producing a library file named easy.so:

```
$ gcc -shared -o easy.so -fPIC easy.c
```

Now go back to the client and execute these requests:

```
box.schema.func.create('easy', {language = 'C'})
box.schema.user.grant('guest', 'execute', 'function', 'easy')
capi_connection:call('easy')
```

If these requests appear unfamiliar, re-read the descriptions of box.schema.func.create(), box.schema.user.grant() and conn:call().

The function that matters is capi_connection:call('easy').

Its first job is to find the 'easy' function, which should be easy because by default Tarantool looks on the current directory for a file named easy.so.

Its second job is to call the 'easy' function. Since the easy() function in easy.c begins with printf("hello world\n"), the words "hello world" will appear on the screen.

Its third job is to check that the call was successful. Since the easy() function in easy.c ends with return 0, there is no error message to display and the request is over.

The result should look like this:

```
tarantool> capi_connection:call('easy')
hello world
---
- []
...
```

Now let's call the other function in easy.c – easy2(). This is almost the same as the easy() function, but there's a detail: when the file name is not the same as the function name, then we have to specify file-name.function-name.

```
box.schema.func.create('easy.easy2', {language = 'C'})
box.schema.user.grant('guest', 'execute', 'function', 'easy.easy2')
capi_connection:call('easy.easy2')
```

. . . and this time the result will be "hello world – easy2".

Conclusion: calling a C function is easy.

harder.c

Go back to the shell where the easy.c program was created.

Create a file. Name it harder.c. Put these 17 lines in it:

```
#include "module.h"
#include "msgpuck.h"
int harder(box_function_ctx_t *ctx, const char *args, const char *args_end)
{
  uint32_t arg_count = mp_decode_array(&args);
  printf("arg_count = %d\n", arg_count);
  uint32_t field_count = mp_decode_array(&args);
  printf("field_count = %d\n", field_count);
  uint32_t val;
  int i;
  for (i = 0; i < field_count; ++i)
  {
    val = mp_decode_uint(&args);
    printf("val=%d.\n", val);
  }
  return 0;
}
```

Compile the program, producing a library file named harder.so:

```
$ gcc -shared -o harder.so -fPIC harder.c
```

Now go back to the client and execute these requests:

```
box.schema.func.create('harder', {language = 'C'})
box.schema.user.grant('guest', 'execute', 'function', 'harder')
passable_table = {}
table.insert(passable_table, 1)
```

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```
table.insert(passable_table, 2)
table.insert(passable_table, 3)
capi_connection:call('harder', {passable_table})
```

This time the call is passing a Lua table (passable_table) to the harder() function. The harder() function will see it, it's in the char *args parameter.

At this point the harder() function will start using functions defined in msgpuck.h. The routines that begin with "mp" are msgpuck functions that handle data formatted according to the MsgPack specification. Passes and returns are always done with this format so one must become acquainted with msgpuck to become proficient with the C API.

For now, though, it's enough to know that mp_decode_array() returns the number of elements in an array, and mp_decode_uint returns an unsigned integer, from args. And there's a side effect: when the decoding finishes, args has changed and is now pointing to the next element.

Therefore the first displayed line will be "arg_count = 1" because there was only one item passed: passable_table. The second displayed line will be "field_count = 3" because there are three items in the table. The next three lines will be "1" and "2" and "3" because those are the values in the items in the table.

And now the screen looks like this:

```
tarantool> capi_connection:call('harder', passable_table)
arg_count = 1
field_count = 3
val=1.
val=2.
val=3.
---
- []
...
```

Conclusion: decoding parameter values passed to a C function is not easy at first, but there are routines to do the job, and they're documented, and there aren't very many of them.

hardest.c

Go back to the shell where the easy.c and the harder.c programs were created.

Create a file. Name it hardest.c. Put these 13 lines in it:

```
#include "module.h"
#include "msgpuck.h"
int hardest(box_function_ctx_t *ctx, const char *args, const char *args_end)
{
  uint32_t space_id = box_space_id_by_name("capi_test", strlen("capi_test"));
  char tuple[1024]; /* Must be big enough for mp_encode results */
  char *tuple_pointer = tuple;
  tuple_pointer = mp_encode_array(tuple_pointer, 2);
  tuple_pointer = mp_encode_uint(tuple_pointer, 10000);
  tuple_pointer = mp_encode_str(tuple_pointer, "String 2", 8);
  int n = box_insert(space_id, tuple, tuple_pointer, NULL);
  return n;
}
```

Compile the program, producing a library file named hardest.so:

```
$ gcc -shared -o hardest.so -fPIC hardest.c
```

Now go back to the client and execute these requests:

```
box.schema.func.create('hardest', {language = "C"})
box.schema.user.grant('guest', 'execute', 'function', 'hardest')
box.schema.user.grant('guest', 'read,write', 'space', 'capi_test')
capi_connection:call('hardest')
```

This time the C function is doing three things:

(1) finding the numeric identifier of the capi_test space by calling box_space_id_by_name();

(2) formatting a tuple using more msgpuck.h functions;

(3) inserting a tuple using box_insert().

Warning: char tuple[1024]; is used here as just a quick way of saying "allocate more than enough bytes". For serious programs the developer must be careful to allow enough space for all the bytes that the mp_encode routines will use up.

Now, still on the client, execute this request:

```
box.space.capi_test:select()
```

The result should look like this:

```
tarantool> box.space.capi_test:select()
---
- - [10000, 'String 2']
...
```

This proves that the hardest() function succeeded, but where did box_space_id_by_name() and box_insert() come from? Answer: the C API.

read.c

Go back to the shell where the easy.c and the harder.c and the hardest.c programs were created.

Create a file. Name it read.c. Put these 43 lines in it:

```
#include "module.h"
#include <msgpuck.h>
int read(box_function_ctx_t *ctx, const char *args, const char *args_end)
{
  char tuple_buf[1024];      /* where the raw MsgPack tuple will be stored */
  uint32_t space_id = box_space_id_by_name("capi_test", strlen("capi_test"));
  uint32_t index_id = 0;      /* The number of the space's first index */
  uint32_t key = 10000;       /* The key value that box_insert() used */
  mp_encode_array(tuple_buf, 0); /* clear */
  box_tuple_format_t *fmt = box_tuple_format_default();
  box_tuple_t *tuple = box_tuple_new(fmt, tuple_buf, tuple_buf+512);
  assert(tuple != NULL);
  char key_buf[16];           /* Pass key_buf = encoded key = 1000 */
  char *key_end = key_buf;
  key_end = mp_encode_array(key_end, 1);
  key_end = mp_encode_uint(key_end, key);
  assert(key_end < key_buf + sizeof(key_buf));
  /* Get the tuple. There's no box_select() but there's this. */
  int r = box_index_get(space_id, index_id, key_buf, key_end, &tuple);
```

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```
  assert(r == 0);
  assert(tuple != NULL);
  /* Get each field of the tuple + display what you get. */
  int field_no;             /* The first field number is 0. */
  for (field_no = 0; field_no < 2; ++field_no)
  {
    const char *field = box_tuple_field(tuple, field_no);
    assert(field != NULL);
    assert(mp_typeof(*field) == MP_STR || mp_typeof(*field) == MP_UINT);
    if (mp_typeof(*field) == MP_UINT)
    {
      uint32_t uint_value = mp_decode_uint(&field);
      printf("uint value=%u.\n", uint_value);
    }
    else /* if (mp_typeof(*field) == MP_STR) */
    {
      const char *str_value;
      uint32_t str_value_length;
      str_value = mp_decode_str(&field, &str_value_length);
      printf("string value=%.*s.\n", str_value_length, str_value);
    }
  }
  return 0;
}
```

Compile the program, producing a library file named read.so:

```
$ gcc -shared -o read.so -fPIC read.c
```

Now go back to the client and execute these requests:

```
box.schema.func.create('read', {language = "C"})
box.schema.user.grant('guest', 'execute', 'function', 'read')
box.schema.user.grant('guest', 'read,write', 'space', 'capi_test')
capi_connection:call('read')
```

This time the C function is doing four things:

(1) once again, finding the numeric identifier of the capi_test space by calling box_space_id_by_name();

(2) formatting a search key = 10000 using more msgpuck.h functions;

(3) getting a tuple using box_index_get();

(4) going through the tuple's fields with box_tuple_get() and then decoding each field depending on its type. In this case, since what we are getting is the tuple that we inserted with hardest.c, we know in advance that the type is either MP_UINT or MP_STR; however, it's very common to have a case statement here with one option for each possible type.

The result of capi_connection:call('read') should look like this:

```
tarantool> capi_connection:call('read')
uint value=10000.
string value=String 2.
---
- []
...
```

This proves that the read() function succeeded. Once again the important functions that start with box – box_index_get() and box_tuple_field() – came from the C API.

write.c

Go back to the shell where the programs easy.c, harder.c, hardest.c and read.c were created.

Create a file. Name it write.c. Put these 24 lines in it:

```
#include "module.h"
#include <msgpuck.h>
int write(box_function_ctx_t *ctx, const char *args, const char *args_end)
{
  static const char *space = "capi_test";
  char tuple_buf[1024]; /* Must be big enough for mp_encode results */
  uint32_t space_id = box_space_id_by_name(space, strlen(space));
  if (space_id == BOX_ID_NIL) {
    return box_error_set(__FILE__, __LINE__, ER_PROC_C,
    "Can't find space %s", "capi_test");
  }
  char *tuple_end = tuple_buf;
  tuple_end = mp_encode_array(tuple_end, 2);
  tuple_end = mp_encode_uint(tuple_end, 1);
  tuple_end = mp_encode_uint(tuple_end, 22);
  box_txn_begin();
  if (box_replace(space_id, tuple_buf, tuple_end, NULL) != 0)
    return -1;
  box_txn_commit();
  fiber_sleep(0.001);
  struct tuple *tuple = box_tuple_new(box_tuple_format_default(),
                                      tuple_buf, tuple_end);
  return box_return_tuple(ctx, tuple);
}
```

Compile the program, producing a library file named write.so:

```
$ gcc -shared -o write.so -fPIC write.c
```

Now go back to the client and execute these requests:

```
box.schema.func.create('write', {language = "C"})
box.schema.user.grant('guest', 'execute', 'function', 'write')
box.schema.user.grant('guest', 'read,write', 'space', 'capi_test')
capi_connection:call('write')
```

This time the C function is doing six things:

(1) once again, finding the numeric identifier of the capi_test space by calling box_space_id_by_name();

(2) making a new tuple;

(3) starting a transaction;

(4) replacing a tuple in box.space.capi_test

(5) ending a transaction;

(6) the final line is a replacement for the loop in read.c – instead of getting each field and printing it, use the box_return_tuple(...) function to return the entire tuple to the caller and let the caller display it.

The result of capi_connection:call('write') should look like this:

```
tarantool> capi_connection:call('write')
---
- [[1, 22]]
...
```

This proves that the write() function succeeded. Once again the important functions that start with box – box_txn_begin(), box_txn_commit() and box_return_tuple() – came from the C API.

Conclusion: the long description of the whole C API is there for a good reason. All of the functions in it can be called from C functions which are called from Lua. So C "stored procedures" have full access to the database.

Cleaning up

- Get rid of each of the function tuples with box.schema.func.drop.
- Get rid of the capi_test space with box.schema.capi_test:drop().
- Remove the .c and .so files that were created for this tutorial.

An example in the test suite

Download the source code of Tarantool. Look in a subdirectory test/box. Notice that there is a file named tuple_bench.test.lua and another file named tuple_bench.c. Examine the Lua file and observe that it is calling a function in the C file, using the same techniques that this tutorial has shown.

Conclusion: parts of the standard test suite use C stored procedures, and they must work, because releases don't happen if Tarantool doesn't pass the tests.

6.3 SQL tutorial

This tutorial is a demonstration of the SQL feature introduced in Tarantool 2.x series. There are two ways to go through this tutorial:

- read what we say the results are and take our word for it, or
- copy and paste each section and see everything work with Tarantool 2.3.

You will encounter all the functionality that you'd encounter in an "SQL-101" course.

6.3.1 Starting up with a first table and SELECTs

Initialize

Requests will be done using Tarantool as a client. Start Tarantool and, optionally, enter the Tarantool configuration request, for example:

```
tarantool> box.cfg{}
```

Before Tarantool 2.0 you needed to say box.cfg{...} prior to performing any database operations. Now you can start working with the database outright. Tarantool initiates the database module and applies default settings.

set

A feature of the client console program is that you can switch languages and specify the end-of-statement delimiter.

Here we say: default language is SQL and statements end with semicolons.

```
tarantool> \set language sql
tarantool> \set delimiter ;
```

CREATE, INSERT, UPDATE, SELECT

Start with simple SQL statements just to be sure they're there.

```
CREATE TABLE table1 (column1 INTEGER PRIMARY KEY, column2 VARCHAR(100));
INSERT INTO table1 VALUES (1, 'A');
UPDATE table1 SET column2 = 'B';
SELECT * FROM table1 WHERE column1 = 1;
```

The result of the SELECT statement will look like this:

```
tarantool> SELECT * FROM table1 WHERE column1 = 1;
---
- - [1, 'B']
...
```

Reality check: actually the result will include include initial fields called "metadata", the names and data types of each column. For all SELECT examples we show only the result rows without showing the metadata.

CREATE TABLE

Here is CREATE TABLE with more details:

- There are multiple columns, with different data types.
- There is a PRIMARY KEY (unique and not-null) for two of the columns.

```
CREATE TABLE table2 (column1 INTEGER,
                     column2 VARCHAR(100),
                     column3 SCALAR,
                     column4 DOUBLE,
                     PRIMARY KEY (column1, column2));
```

The result will be: "row_count: 1" (no error).

INSERT

Try to put 5 rows in the table:

- The INTEGER and DOUBLE columns get numbers.
- The VARCHAR and SCALAR columns get strings (the SCALAR strings are expressed as hexadecimals).

```
INSERT INTO table2 VALUES (1, 'AB', X'4142', 5.5);
INSERT INTO table2 VALUES (1, 'CD', X'2020', 1E4);
INSERT INTO table2 VALUES (1, 'AB', X'A5', -5.5);
INSERT INTO table2 VALUES (2, 'AB', X'2020', 12.34567);
INSERT INTO table2 VALUES (-1000, '', X'', 0.0);
```

The result will be:

- The third INSERT will fail because of a primary-key violation (1, `'AB'` is a duplication).
- The other four INSERT statements will succeed.

SELECT with ORDER BY clause

Retrieve the 4 rows in the table, in descending order by column2, then (where the column2 values are the same) in ascending order by column4.

"*" is short for "all columns".

```
SELECT * FROM table2 ORDER BY column2 DESC, column4 ASC;
```

The result will be:

```
- - [1, 'CD', '  ', 10000]
  - [1, 'AB', 'AB', 5.5]
  - [2, 'AB', '  ', 12.34567]
  - [-1000, '', '', 0]
```

SELECT with WHERE clauses

Retrieve some of what you inserted:

- The first statement uses the LIKE comparison operator which is asking for "first character must be 'A', the next characters can be anything."
- The second statement uses logical operators and parentheses, so the ANDed expressions must be true, or the ORed expression must be true. Notice the columns don't have to be indexed.

```
SELECT column1, column2, column1 * column4 FROM table2 WHERE column2
LIKE 'A%';
SELECT column1, column2, column3, column4 FROM table2
    WHERE (column1 < 2 AND column4 < 10)
    OR column3 = X'2020';
```

The results will be:

```
- - [1, 'AB', 5.5]
  - [2, 'AB', 24.69134]
```

and

```
- - [-1000, '', '', 0]
  - [1, 'AB', 'AB', 5.5]
  - [1, 'CD', '  ', 10000]
  - [2, 'AB', '  ', 12.34567]
```

SELECT with GROUP BY and aggregating

Retrieve with grouping.

The rows which have the same values for column2 are grouped and are aggregated – summed, counted, averaged – for column4.

```
SELECT column2, SUM(column4), COUNT(column4), AVG(column4)
FROM table2
GROUP BY column2;
```

The result will be:

```
- - ['', 0, 1, 0]
  - ['AB', 17.84567, 2, 8.922835]
  - ['CD', 10000, 1, 10000]
```

6.3.2 Complications and complex SELECTs

NULLs

Insert more rows, containing NULL values.

NULL is not the same as Lua nil; it commonly is used in SQL for unknown or not-applicable.

```
INSERT INTO table2 VALUES (1, NULL, X'4142', 5.5);
INSERT INTO table2 VALUES (0, '!!@', NULL, NULL);
INSERT INTO table2 VALUES (0, '!!!', X'00', NULL);
```

The result will be:

- The first INSERT will fail because NULL is not permitted for a column that was defined with a PRIMARY KEY clause.
- The other INSERT statements will succeed.

Indexes

Make a new index on column4.

There already is an index for the primary key. Indexes are useful for making queries faster. In this case, the index also acts as a constraint, because it prevents two rows from having the same values in column4. However, it is not an error that column4 has multiple occurrences of NULLs.

```
CREATE UNIQUE INDEX i ON table2 (column4);
```

The result will be: "rowcount: 1" (no error).

Create a subset table

Make a table which will have some of the columns of table2, and some of the rows of table2.

You can do this by combining INSERT with SELECT. Then select everything in the resultant subset table.

```
CREATE TABLE table3 (column1 INTEGER, column2 VARCHAR(100), PRIMARY KEY
(column2));
INSERT INTO table3 SELECT column1, column2 FROM table2 WHERE column1 <> 2;
SELECT * FROM table3;
```

The result will be:

```
- - [-1000, '']
  - [0, '!!!']
  - [0, '!!@']
  - [1, 'AB']
  - [1, 'CD']
```

SELECT with a subquery

A subquery is a query within a query.

Here we find all the rows in table2 whose (column1, column2) values are not in table3.

```
SELECT * FROM table2 WHERE (column1, column2) NOT IN (SELECT column1,
column2 FROM table3);
```

The result is, unsurprisingly, the single row which we deliberately excluded when we inserted the rows in the INSERT ... SELECT statement:

```
- - [2, 'AB', '  ', 12.34567]
```

SELECT with a join

A join is a combination of two tables. There is more than one way to do them in Tarantool: "Cartesian joins", "left outer joins", etc.

Here we're just showing the most typical case, where column values from one table match column values from another table.

```
SELECT * FROM table2, table3
    WHERE table2.column1 = table3.column1 AND table2.column2 = table3.column2
    ORDER BY table2.column4;
```

The result will be:

```
- - [0, '!!!', "\0", null, 0, '!!!']
  - [0, '!!@', null, null, 0, '!!@']
  - [-1000, '', '', 0, -1000, '']
  - [1, 'AB', 'AB', 5.5, 1, 'AB']
  - [1, 'CD', ' ', 10000, 1, 'CD']
```

6.3.3 Constraints affecting updates

CREATE TABLE, with a CHECK clause

First we make a table which includes a "constraint" that there must not be any rows containing 13 in column2. Then we try to insert such a row.

```
CREATE TABLE table4 (column1 INTEGER PRIMARY KEY, column2 INTEGER, CHECK
(column2 <> 13));
INSERT INTO table4 VALUES (12, 13);
```

Result: the insert fails, as it should, with the message “'Check constraint failed ''ck_unnamed_TABLE4_1'': column2 <> 13'”.

CREATE TABLE, with a FOREIGN KEY clause

First we make a table which includes a “constraint” that there must not be any rows containing values that do not appear in table2.

When we made table2, we specified that its “primary key” columns were (column1, column2).

```
CREATE TABLE table5 (column1 INTEGER, column2 VARCHAR(100),
    PRIMARY KEY (column1),
    FOREIGN KEY (column1, column2) REFERENCES table2 (column1, column2));
INSERT INTO table5 VALUES (2,'AB');
INSERT INTO table5 VALUES (3,'AB');
```

Result:

- The first INSERT statement succeeds because table3 contains a row with [2, 'AB', ' ', 12.34567].
- The second INSERT statement, correctly, fails with the message “Failed to execute SQL statement: FOREIGN KEY constraint failed”.

UPDATE

Due to earlier INSERT statements, these values are in table2 column4: {0, NULL, NULL, 5.5, 10000, 12.34567}. We will add 5 to every one of them except the one with 0. (Adding 5 to NULL will result in NULL, as SQL arithmetic requires.) Then we’ll use SELECT to see what happened to column4.

```
UPDATE table2 SET column4 = column4 + 5 WHERE column4 <> 0;
SELECT column4 FROM table2 ORDER BY column4;
```

The result is: {NULL, NULL, 0, 10.5, 17.34567, 10005}.

DELETE

Due to earlier INSERT statements, there are now 6 rows in table2:

```
- - [-1000, '', '', 0]
  - [0, '!!!', "\0", null]
  - [0, '!!@', null, null]
  - [1, 'AB', 'AB', 10.5]
  - [1, 'CD', '  ', 10005]
  - [2, 'AB', '  ', 17.34567]
```

We will try to delete the last and first of these rows.

```
DELETE FROM table2 WHERE column1 = 2;
DELETE FROM table2 WHERE column1 = -1000;
SELECT COUNT(column1) FROM table2;
```

The result will be:

- The first DELETE statement causes an error message because (remember?) there's a foreign-key constraint.
- The second DELETE statement succeeds.
- The SELECT statement shows that there are now only 5 rows remaining.

ALTER TABLE, with a FOREIGN KEY clause

Now we want to make another "constraint", that there must not be any rows in table1 containing values that do not appear in table5. We couldn't do this when we created table1 because at that time table5 did not exist. But we can add constraints to existing tables with the ALTER TABLE statement.

```
ALTER TABLE table1 ADD CONSTRAINT c
   FOREIGN KEY (column1) REFERENCES table5 (column1);
DELETE FROM table1;
ALTER TABLE table1 ADD CONSTRAINT c
   FOREIGN KEY (column1) REFERENCES table5 (column1);
```

Result: the ALTER TABLE statement fails the first time because there is a row in table1, and ADD CONSTRAINT requires that the table be empty. But after we delete that row, the ALTER TABLE statement succeeds the second time. Thus we have set up a chain of references, from table1 to table5 and from table5 to table2.

Triggers

The idea of a trigger is: if a change (INSERT or UPDATE or DELETE) happens, then a further action – perhaps another INSERT or UPDATE or DELETE – will happen.

There are many variants, the one we'll illustrate here is: just after doing an update in table3, do an update in table2. We will specify this as FOR EACH ROW, so (since there are 5 rows in table3) the trigger will be activated 5 times.

```
SELECT column4 FROM table2 WHERE column1 = 2;
CREATE TRIGGER tr AFTER UPDATE ON table3 FOR EACH ROW
BEGIN UPDATE table2 SET column4 = column4 + 1 WHERE column1 = 2; END;
UPDATE table3 SET column2 = column2;
SELECT column4 FROM table2 WHERE column1 = 2;
```

Result:

- The first SELECT shows that the original value of column4 in table2 where column1 = 2 was: 17.34567.
- The second SELECT returns:

  ```
  - - [22.34567]
  ```

6.3.4 Operators and functions

String operations

You can manipulate string data (usually defined with CHAR or VARCHAR data types) in many ways.

We'll illustrate here:

- the || operator for concatenation and
- the SUBSTR function for extraction.

```
SELECT column2, column2 || column2, SUBSTR(column2, 2, 1) FROM table2;
```

The result will be:

```
- - ['!!!', '!!!!!!', '!']
  - ['!!@', '!!@!!@', '!']
  - ['AB', 'ABAB', 'B']
  - ['CD', 'CDCD', 'D']
  - ['AB', 'ABAB', 'B']
```

Number operations

You can also manipulate number data (usually defined with INTEGER or DOUBLE data types) in many ways.

We'll illustrate here:

- the << operator for shift left and
- the % operator for modulo.

```
SELECT column1, column1 << 1, column1 << 2, column1 % 2 FROM table2;
```

The result will be:

```
- - [0, 0, 0, 0]
  - [0, 0, 0, 0]
  - [1, 2, 4, 1]
  - [1, 2, 4, 1]
  - [2, 4, 8, 0]
```

Ranges and limits

Tarantool can handle:

- integers anywhere in the 4-byte integer range,
- approximate-numerics anywhere in the 8-byte IEEE floating point range,
- any Unicode characters, with UTF-8 encoding and a choice of collations.

Here we will insert some such values in a new table, and see what happens when we select them, with arithmetic on a number column and ordering by a string column.

```
CREATE TABLE t6 (column1 INTEGER, column2 VARCHAR(10), column4 DOUBLE,
PRIMARY KEY (column1));
INSERT INTO t6 VALUES (-1234567890, 'АБВГД', 123456.123456);
INSERT INTO t6 VALUES (+1234567890, 'GD', 1e30);
INSERT INTO t6 VALUES (10, 'FADEW?', 0.000001);
INSERT INTO t6 VALUES (5, 'ABCDEFG', NULL);
SELECT column1 + 1, column2, column4 * 2 FROM t6 ORDER BY column2;
```

The result is:

```
- - [6, 'ABCDEFG', null]
  - [11, 'FADEW?', 2e-06]
  - [1234567891, 'GD', 2e+30]
  - [-1234567889, 'АБВГД', 246912.246912]
```

Views

A view, or “viewed table”, is virtual, that is, its rows aren’t physically in the database, their values are calculated from other tables.

Here we’ll create a view v3 based on table3, then we select from it.

```
CREATE VIEW v3 AS SELECT SUBSTR(column2,1,2), column4 FROM t6 WHERE
column4 >= 0;
SELECT * FROM v3;
```

The result is:

```
- - ['АБ', 123456.123456]
  - ['FA', 1e-06]
  - ['GD', 1e+30]
```

Common table expressions

By putting WITH + SELECT in front of a SELECT, we can make a sort of temporary view that lasts for the duration of the statement.

Here we’ll select from the sort of temporary view.

```
WITH cte AS (
            SELECT SUBSTR(column2,1,2), column4 FROM t6 WHERE column4
            >= 0)
SELECT * FROM cte;
```

Result: the same as the result we got with CREATE VIEW earlier:

```
- - ['АБ', 123456.123456]
  - ['FA', 1e-06]
  - ['GD', 1e+30]
```

VALUES

Tarantool can handle statements like SELECT 55; (select without FROM) like some other popular DBMSs. But it also handles the more standard statement VALUES (expression [, expression ...]);.

Here we’ll use both styles.

```
SELECT 55 * 55, 'The rain in Spain';
VALUES (55 * 55, 'The rain in Spain');
```

The result of either statement will be:

```
- - [3025, 'The rain in Spain']
```

Metadata

What database objects have we created? We can find out about:

- tables with SELECT * FROM "_space";
- indexes with SELECT * FROM "_index";
- triggers with SELECT * FROM "_trigger"; (These names will be familiar to old Tarantool users because we're actually selecting from NoSQL "system spaces".)

Here we will select from _space.

```
SELECT "id", "name", "owner", "engine" FROM "_space" WHERE "name"='TABLE3';
```

The result is (we know we will get a row because we created table3 earlier):

```
- - [517, 'TABLE3', 1, 'memtx']
```

6.3.5 Calling from a host language to make a big table

box.execute()

Now we will change the settings so that the console accepts statements written in Lua instead of statements written in SQL. (More ways to switch languages will exist in Tarantool clients in our next version.)

This doesn't mean we have left the SQL world though, because we can invoke SQL statements using a Lua function: box.execute(string).

Here we'll switch languages, and ask to select again what's in table3. These statements must be entered separately.

```
tarantool> \set language lua
tarantool> box.execute([[SELECT * FROM table3;]]);
```

Showing both the statements and the results:

```
tarantool> \set language lua
---
...
tarantool> box.execute([[SELECT * FROM table3;]]);
---
- - [-1000, '']
  - [0, '!!!']
  - [0, '!!@']
  - [1, 'AB']
  - [1, 'CD']
...
```

Create a million-row table

We've illustrated a lot of SQL, but does it scale? To answer that, let's make a bigger table.

For this we are going to use Lua. We will not explain the Lua, because that's in the Lua section of the Tarantool manual. Just copy-and-paste these instructions and wait for about a minute.

```
box.execute("CREATE TABLE tester (s1 INT PRIMARY KEY, s2 VARCHAR(10))");

function string_function()
  local random_number
  local random_string
  random_string = ""
  for x = 1,10,1 do
    random_number = math.random(65, 90)
    random_string = random_string .. string.char(random_number)
  end
  return random_string
end;

function main_function()
  local string_value, t, sql_statement
  for i = 1,1000000,1 do
    string_value = string_function()
    sql_statement = "INSERT INTO tester VALUES (" .. i .. ",'" .. string_value .. "')"
    box.execute(sql_statement)
  end
end;
start_time = os.clock();
main_function();
end_time = os.clock();
'insert done in ' .. end_time - start_time .. ' seconds';
```

The result is: you now have a table with a million rows, with a message saying "insert done in 88.570578 seconds".

Select from a million-row table

Now that we have something a bit larger to play with, let's see how long it takes to SELECT.

The first query we'll do will automatically go via an index, because s1 is the primary key.

The second query we'll do will not go via an index, because for s2 we didn't say CREATE INDEX xxxx ON tester (s2);.

```
box.execute([[SELECT * FROM tester WHERE s1 = 73446;]]);
box.execute([[SELECT * FROM tester WHERE s2 LIKE 'QFML%';]]);
```

The result is:

- the first statement will finish instantaneously,
- the second statement will be noticeably slower but still a fraction of a second.

Cleanup and exit

We're done. We've shown that Tarantool 2.x has a very reasonable subset of SQL, and it works.

The rest of these commands will simply destroy all the database objects that were created so that you can do the demonstration again. These statements must be entered separately.

```
tarantool> \set language sql
tarantool> DROP TABLE tester;
```

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```
tarantool> DROP TABLE table1;
tarantool> DROP VIEW v3;
tarantool> DROP TRIGGER tr;
tarantool> DROP TABLE table5;
tarantool> DROP TABLE table4;
tarantool> DROP TABLE table3;
tarantool> DROP TABLE table2;
tarantool> DROP TABLE t6;
tarantool> \set language lua
tarantool> os.exit();
```

6.4 Improving MySQL with Tarantool

Replicating MySQL is one of the Tarantool's killer functions. It allows you to keep your existing MySQL database while at the same time accelerating it and scaling it out horizontally. Even if you aren't interested in extensive expansion, simply replacing existing replicas with Tarantool can save you money, because Tarantool is more efficient per core than MySQL. To read a testimonial of a company that implemented Tarantool replication on a large scale, please see here.

Notes:

- if you run into any trouble with regards to the basics of Tarantool, you may wish to consult the Getting started guide or the Data model description.
- these instructions are for CentOS 7.5 and MySQL 5.7. They also assume that you have systemd installed and are working with an existing MySQL installation.
- a helpful log for troubleshooting during this tutorial is replicatord.log in /var/log. You can also have a look at the instance's log example.log in /var/log/tarantool.

So let's proceed.

1. First we'll install the necessary packages in CentOS:

   ```
   yum -y install git ncurses-devel cmake gcc-c++ boost boost-devel wget unzip nano bzip2 mysql-devel mysql-
   ↪lib
   ```

2. Next we'll clone the Tarantool-MySQL replication package from GitHub:

   ```
   git clone https://github.com/tarantool/mysql-tarantool-replication.git
   ```

3. Now we can build the replicator with cmake:

   ```
   cd mysql-tarantool-replication
   git submodule update --init --recursive
   cmake .
   make
   ```

4. Our replicator will run as a systemd daemon called replicatord, so let's edit its systemd service file, replicatord.service, in the mysql-tarantool-replication repo.

   ```
   nano replicatord.service
   ```

   Change the following line:

```
ExecStart=/usr/local/sbin/replicatord -c /usr/local/etc/replicatord.cfg
```

Replace the .cfg extension with .yml:

```
ExecStart=/usr/local/sbin/replicatord -c /usr/local/etc/replicatord.yml
```

5. Next let's copy some files from our replicatord repo to other necessary locations:

```
cp replicatord /usr/local/sbin/replicatord
cp replicatord.service /etc/systemd/system
```

6. Now let's enter the MySQL console and create a sample database (depending on your existing installation, you may of course be a user other than root):

```
mysql -u root -p
CREATE DATABASE menagerie;
QUIT
```

7. Next we'll get some sample data from MySQL, which we'll pull into our root directory, then install from the terminal:

```
cd
wget http://downloads.mysql.com/docs/menagerie-db.zip
unzip menagerie-db.zip
cd menagerie-db
mysql -u root -p menagerie < cr_pet_tbl.sql
mysql -u root -p menagerie < load_pet_tbl.sql
mysql menagerie -u root -p < ins_puff_rec.sql
mysql menagerie -u root -p < cr_event_tbl.sql
```

8. Let's enter the MySQL console now and massage the data for use with the Tarantool replicator (we are adding an ID, changing a field name to avoid conflict, and cutting down the number of fields; note that with real data, this is the step that will involve the most tweaking):

```
mysql -u root -p
USE menagerie;
ALTER TABLE pet ADD id INT PRIMARY KEY AUTO_INCREMENT FIRST;
ALTER TABLE pet CHANGE COLUMN 'name' 'name2' VARCHAR(255);
ALTER TABLE pet DROP sex, DROP birth, DROP death;
QUIT
```

9. Now that we have the sample data set up, we'll need to edit MySQL's configuration file for use with the replicator.

```
cd
nano /etc/my.cnf
```

Note that your my.cnf for MySQL could be in a slightly different location. Set:

```
[mysqld]
binlog_format = ROW
server_id = 1
log-bin = mysql-bin
interactive_timeout = 3600
wait_timeout = 3600
max_allowed_packet = 32M
```

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```
socket = /var/lib/mysql/mysql.sock
bind-address = 127.0.0.1

[client]
socket = /var/lib/mysql/mysql.sock
```

10. After exiting nano, we'll restart mysqld:

```
systemctl restart mysqld
```

11. Next, let's install Tarantool and set up spaces for replication. Go to the Download page and follow the instructions there to install Tarantool.

12. Now we will write a standard Tarantool program by editing the Lua example, which comes with Tarantool:

```
cd
nano /etc/tarantool/instances.available/example.lua
```

13. Replace the entire contents of the file with the following:

```
box.cfg {
    listen = 3301;
    memtx_memory = 128 * 1024 * 1024; -- 128Mb
    memtx_min_tuple_size = 16;
    memtx_max_tuple_size = 128 * 1024 * 1024; -- 128Mb
    vinyl_memory = 128 * 1024 * 1024; -- 128Mb
    vinyl_cache = 128 * 1024 * 1024; -- 128Mb
    vinyl_max_tuple_size = 128 * 1024 * 1024; -- 128Mb
    vinyl_write_threads = 2;
    wal_mode = "none";
    wal_max_size = 256 * 1024 * 1024;
    checkpoint_interval = 60 * 60; -- one hour
    checkpoint_count = 6;
    force_recovery = true;

     -- 1 – SYSERROR
     -- 2 – ERROR
     -- 3 – CRITICAL
     -- 4 – WARNING
     -- 5 – INFO
     -- 6 – VERBOSE
     -- 7 – DEBUG
     log_level = 7;
     too_long_threshold = 0.5;
 }

box.schema.user.grant('guest','read,write,execute','universe')

local function bootstrap()

    if not box.space.mysqldaemon then
        s = box.schema.space.create('mysqldaemon')
        s:create_index('primary',
        {type = 'tree', parts = {1, 'unsigned'}, if_not_exists = true})
    end
```

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```
    if not box.space.mysqldata then
        t = box.schema.space.create('mysqldata')
        t:create_index('primary',
        {type = 'tree', parts = {1, 'unsigned'}, if_not_exists = true})
    end

end

bootstrap()
```

To understand more of what's happening here, it would be best to have a look back at the earlier articles in the Tarantool 101 series or use the getting-started guide.

14. Now we need to create a symlink from instances.available to a directory named instances.enabled (similar to NGINX). So in /etc/tarantool run the following:

```
mkdir instances.enabled
ln -s /instances.available/example.lua instances.enabled
```

15. Next we can start up our Lua program with tarantoolctl, a wrapper for systemd:

```
tarantoolctl start example.lua
```

16. Now let's enter our Tarantool instance, where we can check that our target spaces were successfully created:

```
tarantoolctl enter example.lua
```

```
tarantool> box.space._space:select()
```

At the bottom you will see "mysqldaemon" and "mysqldata" spaces. Then exit with "CTRL+C".

17. Now that we have MySQL and Tarantool set up, we can proceed to configure our replicator. First let's work with replicatord.yml in the main tarantool-mysql-replication directory.

```
nano replicatord.yml
```

Change the entire file as follows, making sure to add your MySQL password and to set the appropriate user:

```
mysql:
    host: 127.0.0.1
    port: 3306
    user: root
    password:
    connect_retry: 15 # seconds

tarantool:
    host: 127.0.0.1:3301
    binlog_pos_space: 512
    binlog_pos_key: 0
    connect_retry: 15 # seconds
    sync_retry: 1000 # milliseconds

mappings:
    - database: menagerie
```

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```
    table: pet
    columns: [ id, name2, owner, species ]
    space: 513
    key_fields:  [ 0 ]
    # insert_call: function_name
    # update_call: function_name
    # delete_call: function_name
```

18. Now we need to copy replicatord.yml to the location where systemd looks for it:

```
cp replicatord.yml /usr/local/etc/replicatord.yml
```

19. Next we can start up the replicator:

```
systemctl start replicatord
```

    Now we can enter our Tarantool instance and do a select on the "mysqldata" space. We will see the replicated content from MySQL:

```
tarantoolctl enter example.lua
```

```
tarantool> box.space.mysqldata:select()
---
- - [1, 'Fluffy', 'Harold', 'cat']
  - [2, 'Claws', 'Gwen', 'cat']
  - [3, 'Buffy', 'Harold', 'dog']
  - [4, 'Fang', 'Benny', 'dog']
  - [5, 'Bowser', 'Diane', 'dog']
  - [6, 'Chirpy', 'Gwen', 'bird']
  - [7, 'Whistler', 'Gwen', 'bird']
  - [8, 'Slim', 'Benny', 'snake']
  - [9, 'Puffball', 'Diane', 'hamster']
```

20. Finally let's enter a record into MySQL and then go back to Tarantool to make sure it's replicated. So first we'll exit our Tarantool instance with CTRL-C, and then say:

```
mysql -u root -p
USE menagerie;
INSERT INTO pet(name2, owner, species) VALUES ('Spot', 'Brad', 'dog');
QUIT
```

    Once back in the terminal enter:

```
tarantoolctl enter example.lua
```

```
tarantool> box.space.mysqldata:select()
```

    You should see the replicated data in Tarantool!

6.5 libslave tutorial

libslave is a C++ library for reading data changes done by MysQL and, optionally, writing them to a Tarantool database. It works by acting as a replication slave. The MySQL server writes data-change information to a "binary log", and transfers the information to any client that says "I want to see the information starting with this file and this record, continuously". So, libslave is primarily good for making a Tarantool database replica (much faster than using a conventional MySQL slave server), and for keeping track of data changes so they can be searched.

We will not go into the many details here – the API documentation has them. We will only show an exercise: a minimal program that uses the library.

Note: Use a test machine. Do not use a production machine.

STEP 1: Make sure you have:

- a recent version of Linux (versions such as Ubuntu 14.04 will not do),
- a recent version of MySQL 5.6 or MySQL 5.7 server (MariaDB will not do),
- MySQL client development package. For example, on Ubuntu you can download it with this command:

```
$ sudo apt-get install mysql-client-core-5.7
```

STEP 2: Download libslave.

The recommended source is https://github.com/tarantool/libslave/. Downloads include the source code only.

```
$ sudo apt-get install libboost-all-dev
$ cd ~
$ git clone https://github.com/tarantool/libslave.git tarantool-libslave
$ cd tarantool-libslave
$ git submodule init
$ git submodule update
$ cmake .
$ make
```

If you see an error message mentioning the word "vector", edit field.h and add this line:

```
#include <vector>
```

STEP 3: Start the MySQL server. On the command line, add appropriate switches for doing replication. For example:

```
$ mysqld --log-bin=mysql-bin --server-id=1
```

STEP 4: For purposes of this exercise, we are assuming you have:

- a "root" user with password "root" with privileges,
- a "test" database with a table named "test",
- a binary log named "mysql-bin",
- a server with server id = 1.

The values are hard-coded in the program, though of course you can change the program – it's easy to see their settings.

STEP 5: Look at the program:

```
#include <unistd.h>
#include <iostream>
#include <sstream>
```

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```
#include "Slave.h"
#include "DefaultExtState.h"

slave::Slave* sl = NULL;

void callback(const slave::RecordSet& event) {
    slave::Position sBinlogPos = sl->getLastBinlogPos();
    switch (event.type_event) {
    case slave::RecordSet::Update: std::cout << "UPDATE" << "\n"; break;
    case slave::RecordSet::Delete: std::cout << "DELETE" << "\n"; break;
    case slave::RecordSet::Write:  std::cout << "INSERT" << "\n"; break;
    default: break;
    }
}

bool isStopping()
{
    return 0;
}

int main(int argc, char** argv)
{
    slave::MasterInfo masterinfo;
    slave::Position position("mysql-bin", 0);
    masterinfo.conn_options.mysql_host = "127.0.0.1";
    masterinfo.conn_options.mysql_port = 3306;
    masterinfo.conn_options.mysql_user = "root";
    masterinfo.conn_options.mysql_pass = "root";
    bool error = false;
    try {
        slave::DefaultExtState sDefExtState;
        slave::Slave slave(masterinfo, sDefExtState);
        sl = &slave;
        sDefExtState.setMasterPosition(position);
        slave.setCallback("test", "test", callback);
        slave.init();
        slave.createDatabaseStructure();
        try {
            slave.get_remote_binlog(isStopping);
        } catch (std::exception& ex) {
            std::cout << "Error reading: " << ex.what() << std::endl;
            error = true;
        }
    } catch (std::exception& ex) {
        std::cout << "Error initializing: " << ex.what() << std::endl;
        error = true;
    }
    return 0;
}
```

Everything unnecessary has been stripped so that you can see quickly how it works. At the start of main(), there are some settings used for connecting – host, port, user, password. Then there is an initialization call with the binary log file name = “mysql-bin”. Pay particular attention to the setCallback statement, which passes database name = “test”, table name = “test”, and callback function address = callback. The program will be looping and invoking this callback function. See how, earlier in the program, the callback function prints “UPDATE” or “DELETE” or “INSERT” depending on what is passed to it.

STEP 5: Put the program in the tarantool-libslave directory and name it example.cpp.

Step 6: Compile and build:

```
$ g++ -I/tarantool-libslave/include example.cpp -o example libslave_a.a -ldl -lpthread
```

Note: Replace tarantool-libslave/include with the full directory name.

Notice that the name of the static library is libslave_a.a, not libslave.a.

Step 7: Run:

```
$ ./example
```

The result will be nothing – the program is looping, waiting for the MySQL server to write to the replication binary log.

Step 8: Start a MySQL client program – any client program will do. Enter these statements:

```
USE test
INSERT INTO test VALUES ('A');
INSERT INTO test VALUES ('B');
DELETE FROM test;
```

Watch what happens in example.cpp output – it displays:

```
INSERT
INSERT
DELETE
DELETE
```

This is row-based replication, so you see two DELETEs, because there are two rows.

What the exercise has shown is:

- the library can be built, and
- programs that use the library can access everything that the MySQL server dumps.

For the many details and examples of usage in the field, see:

- Our downloadable libslave version:
  https://github.com/tarantool/libslave
- The version it was forked from (with a different README):
  https://github.com/vozbu/libslave/wiki/API
- How to speed up your MySQL with replication to in-memory database article
- Replicating data from MySQL to Tarantool article (in Russian)
- Asynchronous replication uncensored article (in Russian)

CHAPTER 7

Release notes

The Release Notes are summaries of significant changes introduced in Tarantool 2.2.1, 2.1.2, 2.1.1, 2.0.4, 1.10.4, 1.10.3, 1.10.2, 1.9.0, 1.8.1, 1.7.6, 1.7.5, 1.7.4, 1.7.3, 1.7.2, 1.7.1, 1.6.9, 1.6.8, and 1.6.6.

For smaller feature changes and bug fixes, see closed milestones at GitHub.

7.1 Version 2.x

Tarantool 2.x is backward compatible with Tarantool 1.10.x in binary data layout, client-server protocol and replication protocol. You can upgrade using the box.schema.upgrade() procedure.

Release 2.2.1

Release type: beta. Release date: 2019-08-02.

Announcement: https://github.com/tarantool/tarantool/releases/tag/2.2.1.

This is a beta version of the 2.2 series. The label "beta" means we have no critical issues and all planned features are there.

The goal of this release is to introduce new indexing features, extend SQL feature set, and improve integration with the core.

Functionality added or changed:

- (SQL) ALTER now allows to add a constraint:

```
CREATE TABLE t2 (id INT PRIMARY KEY);
ALTER TABLE t2 ADD CONSTRAINT ck CHECK(id > 0);
```

- (SQL) CHECK constraints are validated during DML operations performed from the Lua land:

```
s = box.schema.space.create('withdata')
pk = s:create_index('pk')
s:format({{'idx', 'number'}})
s:create_check_constraint('le10', '"idx" < 10')
```

```
tarantool> s:insert({11})
---
- error: 'Check constraint failed ''le10'': "idx" < 10'
...
```

- (SQL) New SQL types introduced: VARBINARY, UNSIGNED, and BOOLEAN.
- (SQL) CREATE TABLE statement (and all other data definition statements) are now truly transactional.
- (SQL) SQL now uses Tarantool diagnostics API to set errors, so error reporting now provides an error code in addition to error message.
- (SQL) Multiple improvements to the type system to make it more consistent.
- (SQL) Added aliases for LENGTH() from ANSI SQL: CHAR_LENGTH() and CHARACTER_LENGTH().
- (SQL) It is possible to use HAVING without GROUP BY.
- (Server) New fixed point type (DECIMAL) introduced to Tarantool:

```
decimal = require('decimal')
tarantool> a = decimal.new('123.456789')
---
...
tarantool> decimal.precision(a)
---
- 9
...
tarantool> decimal.scale(a)
---
- 6
...
tarantool> decimal.round(a, 4)
---
- '123.4568'
...
```

- (Server) Multikey index support:

```
-- Multikey indexes (for memtx tree & vinyl);
-- cannot be primary; may be non-unique
s = box.schema.space.create('clients', {engine = 'vinyl'})
pk = s:create_index('pk')
phone_type = s:create_index('phone_type', {
    unique = false,
    parts = {{'[3][*].type', 'str'}}})

s:insert({1, 'James',
        {{type = 'home', number = '999'},
         {type = 'work', number = '777'}
        }})
s:insert({2, 'Bob',
         {{type = 'work', number = '888'}}})
s:insert({3, 'Alice', {{type = 'home', number = '333'}}})
```

```
tarantool> phone_type:select('work')
---
```

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```
- - [1, 'James', [{'type': 'home', 'number': '999'},
                 {'type': 'work', 'number': '777'}]]
  - [2, 'Bob', [{'type': 'work', 'number': '888'}]]
...
```

- (Server) Now it is possible to make functions persistent:

```
box.schema.func.create('summarize',
                       {body = [[function(a,b) return a+b end]],
                       is_deterministic = true})
```

```
tarantool> box.func.summarize
- aggregate: none
  returns: any
  exports:
    lua: true
    sql: false
  id: 66
  is_sandboxed: false
  setuid: false
  is_multikey: false
  is_deterministic: true
  body: function(a,b) return a+b end
  name: summarize
  language: LUA

tarantool> box.func.summarize:call({1, 2})
---
- 3
...
```

- (Server) Functional indexes implemented:

```
-- Functional multikey indexes: define is_multikey = true
-- in function definition and return a table of keys from function
lua_code = [[function(tuple)
                local address = string.split(tuple[2])
                local ret = {}
                for _, v in pairs(address) do table.insert(ret, {utf8.upper(v)}) end
                return ret
             end]]
box.schema.func.create('addr_extractor', {body = lua_code,
                                          is_deterministic = true,
                                          is_sandboxed = true,
                                          opts = {is_multikey = true}})
s = box.schema.space.create('withdata')
pk = s:create_index('name', {parts = {1, 'string'}})
idx = s:create_index('addr', {unique = false, func = box.func.addr_extractor.id, parts = {{1, 'string',
↪collation = 'unicode_ci'}}})

s:insert({"James", "SIS Building Lambeth London UK"})
s:insert({"Sherlock", "221B Baker St Marylebone London NW1 6XE UK"})
```

```
tarantool>  idx:select('Sis')
---
- - ['James', 'SIS Building Lambeth London UK']
```

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```
...
```

- Partial core dumps, which are now on by default. It is now possible to avoid dumping tuples at all during core dump.
- Data definition statements, such as create or alter index, which do not yield, can now be used in a transaction. This in practice includes all statements except creating an index on a non-empty space, or changing a format on a non-empty space.
- It is now possible to set a sequence not only for the first part of the index:

```
s.index.pk:alter{sequence = {field = 2}}
```

- Allow to call box.session.exists() and box.session.fd() without any arguments.
- New function introduced to get an index key from a tuple:

```
s = box.schema.space.create('withdata')
pk = s:create_index('pk')
sk = s:create_index('sk', {parts = {
      {2, 'number', path = 'a'},
      {2, 'number', path = 'b'}}})
s:insert{1, {a = 1, b = 1}}
s:insert{2, {a = 1, b = 2}}
s:insert{3, {a = 3, b = 3}}
sk:select(2)

key_def_lib = require('key_def')
key_def = key_def_lib.new(pk.parts)
for _, tuple in sk:pairs({1}) do
    local key = key_def:extract_key(tuple)
    pk:delete(key)
end
s:select()
```

- (Engines) New protocol (called SWIM) implemented to keep a table of cluster members.
- (Engines) Removed yields from Vinyl DDL on commit triggers.
- (Engines) Improved performance of SELECT-s on memtx spaces. The drawback is that now every memtx-tree tuple consumes extra 8 bytes for a search hint.
- (Engines) Indexes of memtx spaces are now built in background fibers. This means that we do not block the event loop during index build anymore.
- Replication applier now can apply transactions which were concurrent on the master concurrently on replica. This dramatically improves replication peak performance, from ~50K writes per second to 200K writes per second and higher on a single instance.
- Transaction boundaries introduced to replication protocol. This means that Tarantool replication is now transaction-safe, and also reduces load on replica write ahead log in case the master uses a lot of multi-statement transactions.
- Tuple access by field name for net.box:

```
box.cfg{listen = 3302}
box.schema.user.grant('guest','read, write, execute', 'space')
box.schema.user.grant('guest', 'create', 'space')
box.schema.create_space("named", {format = {{name = "id"}}})
```

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```
box.space.named:create_index('id', {parts = {{1, 'unsigned'}}})
box.space.named:insert({1})

require('net.box').connect('localhost', 3302).space.named:get(1).id
```

- Cluster id check is now the slave's responsibility.
- It is now possible to set the output format to Lua instead of YAML in the interactive console.
- Multiple new collations added. New collations follow this naming pattern:

  ```
  unicode_<locale>_<strength>
  ```

  Three strengths are used:

  - Primary - "s1"
  - Secondary - "s2"
  - Tertiary - "s3"

  The following list contains so-called "stable" collations - the ones whose sort order doesn't depend on the ICU version:

  ```
  unicode_am_s3
  unicode_fi_s3
  unicode_de__phonebook_s3
  unicode_haw_s3
  unicode_he_s3
  unicode_hi_s3
  unicode_is_s3
  unicode_ja_s3
  unicode_ko_s3
  unicode_lt_s3
  unicode_pl_s3
  unicode_si_s3
  unicode_es_s3
  ```

- New function utime() introduced to the fio module.
- Merger for tuples streams added.

Release 2.1.2

Release type: stable. Release date: 2019-04-05.

Announcement: https://github.com/tarantool/tarantool/releases/tag/2.1.2.

This is the first stable release in the 2.x series.

The goal of this release is to significantly extend SQL support and increase stability.

Functionality added or changed:

- (SQL) box.sql.execute() replaced with box.execute(). It now works just like netbox.execute(): returns result set metadata, row count, etc. E.g.:

  ```
  box.execute("CREATE TABLE person(id INTEGER PRIMARY KEY, birth_year INT)")
  ---
  - row_count: 1
  ...
  ```

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```
box.execute("SELECT birth_year FROM person")
---
- metadata:
  - name: birth_year
    type: INTEGER
  rows:
  - [1983]
  - [1984]
...
```

- (SQL) Type system was significantly refactored.
- (SQL) There are cases in SQL when it is possible to do Tarantool's update operation for UPDATE statement, instead of doing delete + insert. However, there are cases where SQL semantics is too complex. E.g.:

```
CREATE TABLE file (id INT PRIMARY KEY, checksum INT);
INSERT INTO stock VALUES (1, 3),(2, 4),(3,5);
CREATE UNIQUE INDEX i ON file (checksum);
SELECT * FROM file;
-- [1, 3], [2, 4], [3, 5]
UPDATE OR REPLACE file SET checksum = checksum + 1;
SELECT * FROM stock;
-- [1, 4], [3, 6]
```

  I.e. [1, 3] tuple is updated as [1, 4] and have replaced tuple [2, 4]. This logic is implemented by preventive tuple deletion from all corresponding indexes in SQL.

- (SQL) Now SQL's integer type is stored as integer in space's format. It was stored as scalar before, which made comarisons slow.
- (SQL) It is now possible to define a constraint within column definition. E.g.:

```
CREATE TABLE person (id INT PRIMARY KEY, age INT, CHECK (age > 10));
```

- (SQL) Syntax for the pragma pragma index_info is now unified with table_info. E.g. to get information on index age_index of table person you can write:

```
pragma index_info(person.age_index);
```

- (Server) It is now possible to index a field specified using JSON. E.g.:

```
person = box.schema.create_space("person")
name_idx = person:create_index('name', {parts = {{'[2]fname', 'str'}, {'[2]sname', 'str'}}})
person:insert({1, {fname='James', sname='Bond'}, {town='London', country='GB', organization=
↪'MI6'}})
```

- (Server) In case of out of space event, Tarantool is now allowed to delete backup WAL files not needed for recovery from the last checkpoint.
- (Server) Add support for tarantoolctl rocks pack / unpack subcommands. The subcommands are used to create / deploy binary rock distributions.
- (Server) string.rstrip and string.lstrip should accept symbols to strip. Add optional 'chars' parameter for specifying the unwanted characters. E.g.:

```
local chars = "#\0"
str = "##Hello world!#"
print(string.strip(str, chars)) -- "Hello world!"
```

- (Server) on_shutdown trigger added. It may be set in a way similar to space:on_replace triggers:

```
box.ctl.on_shutdown(new_trigger, old_trigger)
```

- (Server) on_schema_init trigger added. It may be set before the first call to box.cfg() and is fired during box.cfg() before user data recovery start. To set the trigger, say:

```
box.ctl.on_schema_init(new_trig, old_trig)
```

- (Server) A new option for the snapshot daemon, box.cfg.checkpoint_wal_threshold, allows to limit the maximum disk size of maintained WALs. Once the configured threshold is exceeded, the WAL thread notifies the checkpoint daemon that it's time to make a new checkpoint and delete old WAL files.
- (Server) New types of privileges – to create, alter and drop space – were introduced. In order to create, drop or alter space or index, you should have a corresponding privilege. E.g.:

```
box.schema.user.create("optimizer", { password = 'secret' })
box.schema.user.grant("optimizer", "alter", "space")
person = box.schema.space.create("person")
box.session.su("optimizer")
i = s:create_index("primary") -- success
s:insert{1} -- fail
s:select{} -- fail
s:drop() -- fail
```

  Notice the incompatible change: Tarantool 1.10 requires read/write/execute privileges on an object to allow create, drop or alter. These privileges are no longer sufficient in 2.1. To remedy the problem, Tarantool 2.1 automatically grants create/drop/alter privileges on an object if a user has read/write/execute privileges on it during schema upgrade. But old scripts may stop working if read/write/execute is granted after schema upgrade.

  Additionally, create/drop/alter privileges are already supported in 1.10, which also supports the old semantics of read/write/execute. You are encouraged to grant new privileges in 1.10 before upgrade and modify your scripts.

Release 2.1.1

Release type: beta. Release date: 2018-11-14.

Announcement: https://github.com/tarantool/tarantool/releases/tag/2.1.1.

This release resolves all major bugs since 2.0.4 alpha and extends Tarantool's SQL feature set.

Release 2.0.4

Release type: alpha. Release date: 2018-02-15.

Announcement: https://github.com/tarantool/tarantool/releases/tag/2.0.4.

This is a successor of the 1.8.x releases. It improves the overall stability of the SQL engine and has some new features.

Functionality added or changed:

- Added support for SQL collations by incorporating libICU character set and collation library.
- IPROTO interface was extended to support SQL queries.

- net.box subsystem was extended to support SQL queries.
- Enabled ANALYZE statement to produce correct results, necessary for efficient query plans.
- Enabled savepoints functionality. SAVEPOINT statement works w/o issues.
- Enabled ALTER TABLE ... RENAME statement.
- Improved rules for identifier names: now fully consistent with Lua frontend.
- Enabled support for triggers; trigger bodies now persist in Tarantool snapshots and survive server restart.
- Significant performance improvements.

7.2 Version 1.10

Release 1.10.4

Release type: stable (lts). Release date: 2019-09-26. Tag: 1-10-4.

Announcement: https://github.com/tarantool/tarantool/releases/tag/1.10.4.

Overview

1.10.4 is the next stable (lts) release in the 1.10 series. The label 'stable' means we have had systems running in production without known crashes, bad results or other showstopper bugs for quite a while now.

This release resolves about 50 issues since 1.10.3.

Compatibility

Tarantool 1.10.x is backward compatible with Tarantool 1.9.x in binary data layout, client-server protocol and replication protocol. Please upgrade using the box.schema.upgrade() procedure to unlock all the new features of the 1.10.x series when migrating from 1.9 version.

Functionality added or changed

- (Engines) Improve dump start/stop logging. When initiating memory dump, print how much memory is going to be dumped, expected dump rate, ETA, and the recent write rate. Upon dump completion, print observed dump rate in addition to dump size and duration.
- (Engines) Look up key in reader thread. If a key isn't found in the tuple cache, we fetch it from a run file. In this case disk read and page decompression is done by a reader thread, however key lookup in the fetched page is still performed by the TX thread. Since pages are immutable, this could as well be done by the reader thread, which would allow us to save some precious CPU cycles for TX. Issue 4257.
- (Core) Improve box.stat.net. Issue 4150.
- (Core) Add idle to downstream status in box.info. When a relay sends a row it updates last_row_time value with the current time. When box.info() is called, idle is set to current_time - last_row_time.
- (Replication) Print corrupted rows on decoding error. Improve row printing to log. Print the header row by row, 16 bytes in a row, and format output to match xxd output:

```
[001] 2019-04-05 18:22:46.679 [11859] iproto V> Got a corrupted row:
[001] 2019-04-05 18:22:46.679 [11859] iproto V> 00000000: A3 02 D6 5A E4 D9 E7 68 A1 53 8D 53 60 5F 20␣
↪3F
[001] 2019-04-05 18:22:46.679 [11859] iproto V> 00000010: D8 E2 D6 E2 A3 02 D6 5A E4 D9 E7 68 A1 53␣
↪8D 53
```

- (Lua) Add type of operation to space trigger parameters. For example, a trigger function may now look like this:

  ```
  function before_replace_trig(old, new, space_name, op_type)
      if op_type == 'INSERT' then
          return old
      else
          return new
      end
  end
  ```

  Issue 4099.
- (Lua) Add debug.sourcefile() and debug.sourcedir() helpers (and debug.__file__ and debug.__dir__ shortcuts) to determine the location of a current Lua source file. Part of issue 4193.
- (HTTP client) Add max_total_connections option in addition to max_connections to allow more fine-grained tuning of libcurl connection cache. Don't restrict the total connections' with a constant value by default, but use libcurl's default, which scales the threshold according to easy handles count. Issue 3945.

Bugs fixed

- (Vinyl) Fix assertion failure in vy_tx_handle_deferred_delete. Issue 4294.
- (Vinyl) Don't purge deleted runs from vylog on compaction. Cherry-picked from issue 4218.
- (Vinyl) Don't throttle DDL. Issue 4238.
- (Vinyl) Fix deferred DELETE statement lost on commit. Issue 4248.
- (Vinyl) Fix assertion while recovering dumped statement. Issue 4222.
- (Vinyl) Reset dump watermark after updating memory limit. Issue 3864.
- (Vinyl) Be pessimistic about write rate when setting dump watermark. Issue 4166.
- (Vinyl) Fix crash if space is dropped while space.get is reading from it. Issue 4109.
- (Vinyl) Fix crash during index build. Issue 4152.
- (Vinyl) Don't compress L1 runs. Issue 2389.
- (Vinyl) Account statements skipped on read.
- (Vinyl) Take into account primary key lookup in latency accounting.
- (Vinyl) Fix vy_range_update_compaction_priority hang.
- (Vinyl) Free region on vylog commit instead of resetting it and clean up region after allocating surrogate statement.
- (Vinyl) Increase even more the open file limit in systemd unit file.
- (Vinyl) Increment min range size to 128MB
- (Memtx) Cancel checkpoint thread at exit. Issue 4170.
- (Core) Fix crash for update with empty tuple. Issue 4041.
- (Core) Fix use-after-free in space_truncate. Issue 4093.
- (Core) Fix error while altering index with sequence. Issue 4214.
- (Core) Detect a new invalid json path case. Issue 4419.
- (Core) Fix empty password authentication. Issue 4327.

- (Core) Fix txn::sub_stmt_begin array size.
- (Core) Account index.pairs in box.stat.SELECT().
- (Replication) Disallow bootstrap of read-only masters. Issue 4321.
- (Replication) Enter orphan mode on manual replication configuration change. Issue 4424.
- (Replication) Set last_row_time to now in relay_new and relay_start. PR 4431.
- (Replication) Stop relay on subscribe error. Issue 4399.
- (Replication) Init coio watcher before join/subscribe. Issue 4110.
- (Replication) Allow to change instance id during join. Issue 4107.
- (Replication) Fix garbage collection logic.
- (Replication) Revert packet boundary checking for iproto.
- (Replication) Do not abort replication on ER_UNKNOWN_REPLICA.
- (Replication) Reduce effects of input buffer fragmentation on large cfg.readahead.
- (Replication) Fix upgrade from 1.7 (it doesn't recognize IPROTO_VOTE request type).
- (Replication) Fix memory leak in call / eval in the case when a transaction is not committed. Issue 4388.
- (Lua) Fix fio.mktree() error reporting. Issue 4044.
- (Lua) Fix segfault on ffi.C_say() without filename. Issue 4336.
- (Lua) Fix segfault on json.encode() on a recursive table. Issue 4366.
- (Lua) Fix pwd.getpwall() and pwd.getgrall() hang on CentOS 6 and FreeBSD 12. Issues 4447, 4428.
- (Lua) Fix a segfault during initialization of a cipher from crypto module. Issue 4223.
- (HTTP client) Reduce stack consumption during waiting for a DNS resolving result. Issue 4179.
- (HTTP client) Increase max outgoing header size to 8 KiB. Issue 3959.
- (HTTP client) Verify "headers" option stronger. Issues 4281, 3679.
- (HTTP client) Use bundled libcurl rather than system-wide by default. Issues 4318, 4180, 4288, 4389, 4397.
- (HTTP client) This closes several known problems that were fixed in recent libcurl versions, including segfaults, hangs, memory leaks and performance problems.
- (LuaJIT) Fix overflow of snapshot map offset. Part of issue 4171.
- (LuaJIT) Fix rechaining of pseudo-resurrected string keys. Part of issue 4171.
- (LuaJIT) Fix fold machinery misbehaves. Issue 4376.
- (LuaJIT) Fix for debug.getinfo(1,'>S'). Issue 3833.
- (LuaJIT) Fix string.find recording. Issue 4476.
- (LuaJIT) Fixed a segfault when unsinking 64-bit pointers.
- (Misc) Increase even more the open file limit in systemd unit file.
- (Misc) Raise error in tarantoolctl when box.cfg() isn't called. Issue 3953.
- (Misc) Support systemd's NOTIFY_SOCKET on OS X. Issue 4436.

- (Misc) Fix coio_getaddrinfo() when 0 timeout is passed (affects netbox's connect_timeout). Issue 4209.
- (Misc) Fix coio_do_copyfile() to perform truncate of destination (affects fio.copyfile()). Issue 4181.
- (Misc) Make hints in coio_getaddrinfo() optional.
- (Misc) Validate msgpack.decode() cdata size argument. Issue 4224.
- (Misc) Fix linking with static openssl library. Issue 4437.

Deprecations

- (Core) Deprecate rows_per_wal in favor of wal_max_size. Part of issue 3762.

Release 1.10.3

Release type: stable (lts). Release date: 2019-04-01. Tag: 1-10-3.

Announcement: https://github.com/tarantool/tarantool/releases/tag/1.10.3.

Overview

1.10.3 is the next stable (lts) release in the 1.10 series. The label 'stable' means we have had systems running in production without known crashes, bad results or other showstopper bugs for quite a while now.

This release resolves 69 issues since 1.10.2.

Compatibility

Tarantool 1.10.x is backward compatible with Tarantool 1.9.x in binary data layout, client-server protocol and replication protocol. Please upgrade using the box.schema.upgrade() procedure to unlock all the new features of the 1.10.x series when migrating from 1.9 version.

Functionality added or changed

- (Engines) Randomize vinyl index compaction Issue 3944.
- (Engines) Throttle tx thread if compaction doesn't keep up with dumps Issue 3721.
- (Engines) Do not apply run_count_per_level to the last level Issue 3657.
- (Server) Report the number of active iproto connections Issue 3905.
- (Replication) Never keep a dead replica around if running out of disk space Issue 3397.
- (Replication) Report join progress to the replica log Issue 3165.
- (Lua) Expose snapshot status in box.info.gc() Issue 3935.
- (Lua) Show names of Lua functions in backtraces in fiber.info() Issue 3538.
- (Lua) Check if transaction opened Issue 3518.

Bugs fixed

- (Engines) Tarantool crashes if DML races with DDL Issue 3420.
- (Engines) Recovery error if DDL is aborted Issue 4066.
- (Engines) Tarantool could commit in the read-only mode Issue 4016.
- (Engines) Vinyl iterator crashes if used throughout DDL Issue 4000.
- (Engines) Vinyl doesn't exit until dump/compaction is complete Issue 3949.
- (Engines) After re-creating secondary index no data is visible Issue 3903.
- (Engines) box.info.memory().tx underflow Issue 3897.

- (Engines) Vinyl stalls on intensive random insertion Issue 3603.
- (Server) Newer version of libcurl explodes fiber stack Issue 3569.
- (Server) SIGHUP crashes tarantool Issue 4063.
- (Server) checkpoint_daemon.lua:49: bad argument #2 to 'format' Issue 4030.
- (Server) fiber:name() show only part of name Issue 4011.
- (Server) Second hot standby switch may fail Issue 3967.
- (Server) Updating box.cfg.readahead doesn't affect existing connections Issue 3958.
- (Server) fiber.join() blocks in 'suspended' if fiber has cancelled Issue 3948.
- (Server) Tarantool can be crashed by sending gibberish to a binary socket Issue 3900.
- (Server) Stored procedure to produce push-messages never breaks on client disconnect Issue 3859.
- (Server) Tarantool crashed in lj_vm_return Issue 3840.
- (Server) Fiber executing box.cfg() may process messages from iproto Issue 3779.
- (Server) Possible regression on nosqlbench Issue 3747.
- (Server) Assertion after improper index creation Issue 3744.
- (Server) Tarantool crashes on vshard startup (lj_gc_step) Issue 3725.
- (Server) Do not restart replication on box.cfg if the configuration didn't change Issue 3711.
- (Replication) Applier times out too fast when reading large tuples Issue 4042.
- (Replication) Vinyl replica join fails Issue 3968.
- (Replication) Error during replication Issue 3910.
- (Replication) Downstream status doesn't show up in replication.info unless the channel is broken Issue 3904.
- (Replication) replication fails: tx checksum mismatch Issue 3993.
- (Replication) Rebootstrap crashes if master has replica's rows Issue 3740.
- (Replication) After restart tuples revert back to their old state which was before replica sync Issue 3722.
- (Replication) Add vclock for safer hot standby switch Issue 3002.
- (Replication) Master row is skipped forever in case of wal write failure Issue 2283.
- (Lua) space:frommap():tomap() conversion fail Issue 4045.
- (Lua) Non-informative message when trying to read a negative count of bytes from socket Issue 3979.
- (Lua) space:frommap raise "tuple field does not match…" even for nullable field Issue 3883.
- (Lua) Tarantool crashes on net.box.call after some uptime with vshard internal fiber Issue 3751.
- (Lua) Heap use after free in lbox_error Issue 1955.
- (Misc) http.client doesn't honour 'connection: keep-alive' Issue 3955.
- (Misc) net.box wait_connected is broken Issue 3856.
- (Misc) Mac build fails on Mojave Issue 3797.
- (Misc) FreeBSD build error: no SSL support Issue 3750.
- (Misc) 'http.client' sets invalid (?) reason Issue 3681.

- (Misc) Http client silently modifies headers when value is not a “string” or a “number” Issue 3679.
- (Misc) yaml.encode uses multiline format for ‘false’ and ‘true’ Issue 3662.
- (Misc) yaml.encode encodes ‘null’ incorrectly Issue 3583.
- (Misc) Error object message is empty Issue 3604.
- (Misc) Log can be flooded by warning messages Issue 2218.

Deprecations

- Deprecate console=true option for net.box.new().

Release 1.10.2

Release type: stable (lts). Release date: 2018-10-13. Tag: 1-10-2.

Announcement: https://github.com/tarantool/tarantool/releases/tag/1.10.2.

This is the first stable (lts) release in the 1.10 series. Also, Tarantool 1.10.2 is a major release that deprecates Tarantool 1.9.2. It resolves 95 issues since 1.9.2.

Tarantool 1.10.x is backward compatible with Tarantool 1.9.x in binary data layout, client-server protocol and replication protocol. You can upgrade using the box.schema.upgrade() procedure.

The goal of this release is to significantly increase vinyl stability and introduce automatic rebootstrap of a Tarantool replica set.

Functionality added or changed:

- (Engines) support ALTER for non-empty vinyl spaces. Issue 1653.
- (Engines) tuples stored in the vinyl cache are not shared among the indexes of the same space. Issue 3478.
- (Engines) keep a stack of UPSERTS in vy_read_iterator. Issue 1833.
- (Engines) box.ctl.reset_stat(), a function to reset vinyl statistics. Issue 3198.
- (Server) configurable syslog destination. Issue 3487.
- (Server) allow different nullability in indexes and format. Issue 3430.
- (Server) allow to back up any checkpoint, not just the last one. Issue 3410.
- (Server) a way to detect that a Tarantool process was started / restarted by tarantoolctl (TARANTOOLCTL and TARANTOOL_RESTARTED env vars). Issues 3384, 3215.
- (Server) net_msg_max configuration parameter to restrict the number of allocated fibers. Issue 3320.
- (Replication) display the connection status if the downstream gets disconnected from the upstream (box.info.replication.downstream.status = disconnected). Issue 3365.
- (Replication) replica-local spaces Issue 3443.
- (Replication) replication_skip_conflict, a new option in box.cfg{} to skip conflicting rows in replication. Issue 3270.
- (Replication) remove old snapshots which are not needed by replicas. Issue 3444.
- (Replication) log records which tried to commit twice. Issue 3105.
- (Lua) new function fiber.join(). Issue 1397.
- (Lua) new option names_only to tuple:tomap(). Issue 3280.
- (Lua) support custom rock servers (server and only-server options for tarantoolctl rocks command). Issue 2640.

- (Lua) expose on_commit/on_rollback triggers to Lua; Issue 857.
- (Lua) new function box.is_in_txn() to check if a transaction is open; Issue 3518.
- (Lua) tuple field access via a json path (by number, name, and path); Issue 1285.
- (Lua) new function space:frommap(); Issue 3282.
- (Lua) new module utf8 that implements libicu's bindings for use in Lua; Issues 3290, 3385.

7.3 Version 1.9

Release 1.9.0

Release type: stable. Release date: 2018-02-26. Tag: 1.9.0-4-g195d446.

Announcement: https://github.com/tarantool/tarantool/releases/tag/1.9.0.

This is the successor of the 1.7.6 stable release. The goal of this release is increased maturity of vinyl and master-master replication, and it contributes a number of features to this cause. Please follow the download instructions at https://tarantool.io/en/download/download.html to download and install a package for your operating system.

Functionality added or changed:

- (Security) it is now possible to block/unblock users. Issue 2898.
- (Security) new function box.session.euid() to return effective user. Effective user can be different from authenticated user in case of setuid functions or box.session.su. Issue 2994.
- (Security) new super role, with superuser access. Grant 'super' to guest to disable access control. Issue 3022.
- (Security) on_auth trigger is now fired in case of both successful and failed authentication. Issue 3039.
- (Replication/recovery) new replication configuration algorithm: if replication doesn't connect to replication_quorum peers in replication_connect_timeout seconds, the server start continues but the server enters the new orphan status, which is basically read-only, until the replicas connect to each other. Issues 3151 and 2958.
- (Replication/recovery) after replication connect at startup, the server does not start processing write requests before syncing up syncing up with all connected peers.
- (Replication/recovery) it is now possible to explicitly set instance_uuid and replica set uuid as configuration parameters. Issue 2967.
- (Replication/recovery) box.once() no longer fails on a read-only replica but waits. Issue 2537.
- (Replication/recovery) force_recovery can now skip a corrupted xlog file. Issue 3076.
- (Replication/recovery) improved replication monitoring: box.info.replication shows peer ip:port and correct replication lag even for idle peers. Issues 2753 and 2689.
- (Application server) new before triggers which can be used for conflict resolution in master-master replication. Issue 2993.
- (Application server) http client now correctly parses cookies and supports http+unix:// paths. Issues 3040 and 2801.
- (Application server) fio rock now supports file_exists(), rename() works across filesystems, and read() without arguments reads the whole file. Issues 2924, 2751 and 2925.

- (Application server) fio rock errors now follow Tarantool function call conventions and always return an error message in addition to the error flag.
- (Application server) digest rock now supports pbkdf2 password hashing algorithm, useful in PCI/DSS compliant applications. Issue 2874.
- (Application server) box.info.memory() provides a high-level overview of server memory usage, including networking, Lua, transaction and index memory. Issue 934.
- (Database) it is now possible to add missing tuple fields to an index, which is very useful when adding an index along with the evolution of the database schema. Issue 2988.
- (Database) lots of improvements in field type support when creating or altering spaces and indexes. Issues 2893, 3011 and 3008.
- (Database) it is now possible to turn on is_nullable property on a field even if the space is not empty, the change is instantaneous. Issue 2973.
- (Database) logging has been improved in many respects: individual messages (issues 1972, 2743, 2900), more logging in cases when it was useful (issues 3096, 2871).
- (Vinyl storage engine) it is now possible to make a unique vinyl index non-unique without index rebuild. Issue 2449.
- (Vinyl storage engine) improved UPDATE, REPLACE and recovery performance in presence of secondary keys. Issues 2289, 2875 and 3154.
- (Vinyl storage engine) space:len() and space:bsize() now work for vinyl (although they are still not exact). Issue 3056.
- (Vinyl storage engine) recovery speed has improved in presence of secondary keys. Issue 2099.
- (Builds) Alpine Linux support. Issue 3067.

7.4 Version 1.8

Release 1.8.1

Release type: alpha. Release date: 2017-05-17. Tag: 1.8.1.

Announcement: https://groups.google.com/forum/#!msg/tarantool-ru/XYaoqJpc544/mSvKrYwNAgAJ.

This is an alpha release which delivers support for a substantial subset of the ISO/IEC 9075:2011 SQL standard, including joins, subqueries and views. SQL is a major feature of the 1.8 release series, in which we plan to add support for ODBC and JDBC connectors, SQL triggers, prepared statements, security and roles, and generally ensure SQL is a first class query language in Tarantool.

Functionality added or changed:

- A new function box.sql.execute() (later changed to box.execute in Tarantool 2.1) was added to query Tarantool databases using SQL statements, e.g.:

```
tarantool> box.sql.execute([[SELECT * FROM _schema]]);
```

- SQL and Lua are fully interoperable.
- New meta-commands introduced to Tarantool's console.

  You can now set input language to either SQL or Lua, e.g.:

```
tarantool> \set language sql
tarantool> SELECT * FROM _schema;
tarantool> \set language lua
tarantool> print("Hello, world!")
```

- Most SQL statements are supported:
  - CREATE/DROP TABLE/INDEX/VIEW

    ```
    tarantool> CREATE TABLE table1 (column1 INTEGER PRIMARY KEY, column2␣
    ↪VARCHAR(100));
    ```

  - INSERT/UPDATE/DELETE statements e.g.:

    ```
    tarantool> INSERT INTO table1 VALUES (1, 'A');
    ...
    tarantool> UPDATE table1 SET column2 = 'B';
    ```

  - SELECT statements, including complex complicated variants which include multiple JOINs, nested SELECTs etc. e.g.:

    ```
    tarantool> SELECT sum(column1) FROM table1 WHERE column2 LIKE '_B' GROUP BY␣
    ↪column2;
    ```

  - WITH statements e.g.

    ```
    tarantool> WITH cte AS ( SELECT SUBSTR(column2,1,2), column1 FROM table1 WHERE␣
    ↪column1 >= 0) SELECT * FROM cte;
    ```

  - SQL schema is persistent, so it is able to survive snapshot()/restore() sequence.
  - SQL features are described in a tutorial.

7.5 Version 1.7

Release 1.7.6

Release type: stable. Release date: 2017-11-07. Tag: 1.7.6-0-g7b2945d6c.

Announcement: https://groups.google.com/forum/#!topic/tarantool/hzc7O2YDZUc.

This is the next stable release in the 1.7 series. It resolves more than 75 issues since 1.7.5.

What's new in Tarantool 1.7.6?

- In addition to rollback of a transaction, there is now rollback to a defined point within a transaction – savepoint support.
- There is a new object type: sequences. The older option, auto-increment, will be deprecated.
- String indexes can have collations.

New options are available for:

- net_box (timeouts),
- string functions,
- space formats (user-defined field names and types),
- base64 (urlsafe option), and

- index creation (collation, is-nullable, field names).

Incompatible changes:

- Layout of box.space._index has been extended to support is_nullable and collation features. All new indexes created on columns with is_nullable or collation properties will have the new definition format. Please update your client libraries if you plan to use these new features. Issue 2802
- fiber_name() now raises an exception instead of truncating long fiber names. We found that some Lua modules such as expirationd use fiber.name() as a key to identify background tasks. If a name is truncated, this fact was silently missed. The new behavior allows to detect bugs caused by fiber.name() truncation. Please use fiber.name(name, { truncate = true }) to emulate the old behavior. Issue 2622
- space:format() is now validated on DML operations. Previously space:format() was only used by client libraries, but starting from Tarantoool 1.7.6, field types in space:format() are validated on the server side on every DML operation, and field names can be used in indexes and Lua code. If you used space:format() in a non-standard way, please update layout and type names according to the official documentation for space formats.

Functionality added or changed:

- Hybrid schema-less + schemaful data model. Earlier Tarantool versions allowed to store arbitrary MessagePack documents in spaces. Starting from Tarantool 1.7.6, you can use space:format() to define schema restrictions and constraints for tuples in spaces. Defined field types are automatically validated on every DML operation, and defined field names can be used instead of field numbers in Lua code. A new function tuple:tomap() was added to convert a tuple into a key-value Lua dictionary.
- Collation and Unicode support. By default, when Tarantool compares strings, it takes into consideration only the numeric value of each byte in the string. To allow the ordering that you see in phone books and dictionaries, Tarantool 1.7.6 introduces support for collations based on the Default Unicode Collation Element Table (DUCET) and the rules described in Unicode® Technical Standard #10 Unicode Collation Algorithm (UTS #10 UCA) See collations.
- NULL values in unique and non-unique indexes. By default, all fields in Tarantool are "NOT NULL". Starting from Tarantool 1.7.6, you can use is_nullable option in space:format() or inside an index part definition to allow storing NULL in indexes. Tarantool partially implements three-valued logic from the SQL standard and allows storing multiple NULL values in unique indexes. Issue 1557.
- Sequences and a new implementation of auto_increment(). Tarantool 1.7.6 introduces new sequence number generators (like CREATE SEQUENCE in SQL). This feature is used to implement new persistent auto increment in spaces. Issue 389.
- Vinyl: introduced gap locks in Vinyl transaction manager. The new locking mechanism in Vinyl TX manager reduces the number of conflicts in transactions. Issue 2671.
- net.box: on_connect and on_disconnect triggers. Issue 2858.
- Structured logging in JSON format. Issue 2795.
- (Lua) Lua: string.strip() Issue 2785.
- (Lua) added base64_urlsafe_encode() to digest module. Issue 2777.
- Log conflicted keys in master-master replication. Issue 2779.
- Allow to disable backtrace in fiber.info(). Issue 2878.
- Implemented tarantoolctl rocks make *.spec. Issue 2846.
- Extended the default loader to look for .rocks in the parent dir hierarchy. Issue 2676.
- SOL_TCP options support in socket:setsockopt(). Issue 598.
- Partial emulation of LuaSocket on top of Tarantool Socket. Issue 2727.

Developer tools:

- Integration with IntelliJ IDEA with debugging support. Now you can use IntelliJ IDEA as an IDE to develop and debug Lua applications for Tarantool. See Using IDE.
- Integration with MobDebug remote Lua debugger. Issue 2728.
- Configured /usr/bin/tarantool as an alternative Lua interpreter on Debian/Ubuntu. Issue 2730.

New rocks:

- smtp.client - support SMTP via libcurl.

Release 1.7.5

Release type: stable. Release date: 2017-08-22. Tag: 1.7.5.

Announcement: https://github.com/tarantool/doc/issues/289.

This is a stable release in the 1.7 series. This release resolves more than 160 issues since 1.7.4.

Functionality added or changed:

- (Vinyl) a new force_recovery mode to recover broken disk files. Use box.cfg{force_recovery=true} to recover corrupted data files after hardware issues or power outages. Issue 2253.
- (Vinyl) index options can be changed on the fly without rebuild. Now page_size, run_size_ratio, run_count_per_level and bloom_fpr index options can be dynamically changed via index:alter(). The changes take effect in newly created data files only. Issue 2109.
- (Vinyl) improve box.info.vinyl() and index:info() output. Issue 1662.
- (Vinyl) introduce box.cfg.vinyl_timeout option to control quota throttling. Issue 2014.
- Memtx: stable index:pairs() iterators for the TREE index. TREE iterators are automatically restored to a proper position after index's modifications. Issue 1796.
- (Memtx) predictable order for non-unique TREE indexes. Non-unique TREE indexes preserve the sort order for duplicate entries. Issue 2476.
- (Memtx+Vinyl) dynamic configuration of max tuple size. Now box.cfg.memtx_max_tuple_size and box.cfg.vinyl_max_tuple_size configuration options can be changed on the fly without need to restart the server. Issue 2667.
- (Memtx+Vinyl) new implementation. Space truncation doesn't cause re-creation of all indexes any more. Issue 618.
- Extended the maximal length of all identifiers from 32 to 65k characters. Space, user and function names are not limited by 32 characters anymore. Issue 944.
- Heartbeat messages for replication. Replication client now sends the selective acknowledgments for processed records and automatically re-establish stalled connections. This feature also changes box.info.replication[replica_id].vclock. to display committed vclock of remote replica. Issue 2484.
- Keep track of remote replicas during WAL maintenance. Replication master now automatically preserves xlogs needed for remote replicas. Issue 748.
- Enabled box.tuple.new() to work without box.cfg(). Issue 2047.
- box.atomic(fun, . . .) wrapper to execute function in a transaction. Issue 818.
- box.session.type() helper to determine session type. Issue 2642.
- Hot code reload for stored C stored procedures. Use box.schema.func.reload('modulename.function') to reload dynamic shared libraries on the fly. Issue 910.
- string.hex() and str:hex() Lua API. Issue 2522.

- Package manager based on LuaRocks. Use tarantoolctl rocks install MODULENAME to install MODULENAME Lua module from https://rocks.tarantool.org/. Issue 2067.
- Lua 5.1 command line options. Tarantool binary now supports '-i', '-e', '-m' and '-l' command line options. Issue 1265.
- Experimental GC64 mode for LuaJIT. GC64 mode allow to operate the full address space on 64-bit hosts. Enable via -DLUAJIT_ENABLE_GC64=ON compile-time configuration option. Issue 2643.
- Syslog logger now support non-blocking mode. box.cfg{log_nonblock=true} now also works for syslog logger. Issue 2466.
- Added a VERBOSE log level beyond INFO. Issue 2467.
- Tarantool now automatically makes snapshots every hour. Please set box.cfg{checkpoint_interval=0 to restore pre-1.7.5 behaviour. Issue 2496.
- Increase precision for percentage ratios provoded by box.slab.info(). Issue 2082.
- Stack traces now contain symbols names on all supported platforms. Previous versions of Tarantool didn't display meaningful function names in fiber.info() on non-x86 platforms. Issue 2103.
- Allowed to create fiber with custom stack size from C API. Issue 2438.
- Added ipc_cond to public C API. Issue 1451.

New rocks:

- http.client (built-in) - libcurl-based HTTP client with SSL/TLS support. Issue 2083.
- iconv (built-in) - bindings for iconv. Issue 2587.
- authman - API for user registration and login in your site using email and social networks.
- document - store nested documents in Tarantool.
- synchronized - critical sections for Lua.

Release 1.7.4

Release type: release candidate. Release date: 2017-05-12. Release tag: Tag: 1.7.4.

Announcement: https://github.com/tarantool/tarantool/releases/tag/1.7.4 or https://groups.google.com/forum/#!topic/tarantool/3x88ATX9YbY

This is a release candidate in the 1.7 series. Vinyl Engine, the flagship feature of 1.7.x, is now feature complete.

Incompatible changes

- box.cfg() options were changed to add Vinyl support:
  - snap_dir renamed to memtx_dir
  - slab_alloc_arena (gigabytes) renamed to memtx_memory (bytes), default value changed from 1Gb to 256MB
  - slab_alloc_minimal renamed to memtx_min_tuple_size
  - slab_alloc_maximal renamed to memtx_max_tuple_size
  - slab_alloc_factor is deprecated, not relevant in 1.7.x
  - snapshot_count renamed to checkpoint_count
  - snapshot_period renamed to checkpoint_interval
  - logger renamed to log

  - logger_nonblock renamed to log_nonblock
  - logger_level renamed to log_level
  - replication_source renamed to replication
  - panic_on_snap_error = true and panic_on_wal_error = true superseded by force_recovery = false

  Until Tarantool 1.8, you can use deprecated parameters for both initial and runtime configuration, but such usage will print a warning in the server log. Issues 1927 and 2042.

- Hot standy mode is now off by default. Tarantool automatically detects another running instance in the same wal_dir and refuses to start. Use box.cfg {hot_standby = true} to enable the hot standby mode. Issue 775.
- UPSERT via a secondary key was banned to avoid unclear semantics. Issue 2226.
- box.info and box.info.replication format was changed to display information about upstream and downstream connections (Issue 723):
  - Added box.info.replication[instance_id].downstream.vclock to display the last sent row to remote replica.
  - Added box.info.replication[instance_id].id.
  - Added box.info.replication[instance_id].lsn.
  - Moved box.info.replication[instance_id].{vclock,status,error} to box.info.replication[instance_id].upstream.{vclock,status,error}.
  - All registered replicas from box.space._cluster are included to box.info.replication output.
  - box.info.server.id renamed box.info.id
  - box.info.server.lsn renamed box.info.lsn
  - box.info.server.uuid renamed box.info.uuid
  - box.info.cluster.signature renamed to box.info.signature
  - box.info.id and box.info.lsn now return nil instead of -1 during initial cluster bootstrap.
- net.box: added per-request options to all requests:
  - conn.call(func_name, arg1, arg2,...) changed to conn.call(func_name, {arg1, arg2, ...}, opts)
  - conn.eval(func_name, arg1, arg2,...) changed to conn.eval(func_name, {arg1, arg2, ...}, opts)
- All requests now support timeout = <seconds>, buffer = <ibuf> options.
- Added connect_timeout option to netbox.connect().
- netbox:timeout() and conn:timeout() are now deprecated. Use netbox.connect(host, port, { call_16 = true }) for 1.6.x-compatible behavior. Issue 2195.
- systemd configuration changed to support Type=Notify / sd_notify(). Now systemctl start tarantool@INSTANCE will wait until Tarantool has started and recovered from xlogs. The recovery status is reported to systemctl status tarantool@INSTANCE. Issue 1923.
- log module now doesn't prefix all messages with the full path to tarantool binary when used without box.cfg(). Issue 1876.
- require('log').logger_pid() was renamed to require('log').pid(). Issue 2917.
- Removed Lua 5.0 compatible defines and functions (Issue 2396):
  - luaL_reg removed in favor of luaL_Reg

  - luaL_getn(L, i) removed in favor of lua_objlen(L, i)
  - luaL_setn(L, i, j) removed (was no-op)
  - lua_ref(L, lock) removed in favor of luaL_ref(L, lock)
  - lua_getref(L,ref) removed in favor of lua_rawgeti(L, LUA_REGISTRYINDEX, (ref))
  - lua_unref(L, ref) removed in favor of luaL_unref(L, ref)
  - math.mod() removed in favor of math.fmod()
  - string.gfind() removed in favor of string.gmatch()

Functionality added or changed:

- (Vinyl) multi-level compaction. The compaction scheduler now groups runs of the same range into levels to reduce the write amplification during compaction. This design allows Vinyl to support 1:100+ ram:disk use-cases. Issue 1821.
- (Vinyl) bloom filters for sorted runs. Bloom filter is a probabilistic data structure which can be used to test whether a requested key is present in a run file without reading the actual file from the disk. Bloom filter may have false-positive matches but false-negative matches are impossible. This feature reduces the number of seeks needed for random lookups and speeds up REPLACE/DELETE with enabled secondary keys. Issue 1919.
- (Vinyl) key-level cache for point lookups and range queries. Vinyl storage engine caches selected keys and key ranges instead of entire disk pages like in traditional databases. This approach is more efficient because the cache is not polluted with raw disk data. Issue 1692.
- (Vinyl) implemented the common memory level for in-memory indexes. Now all in-memory indexes of a space store pointers to the same tuples instead of cached secondary key index data. This feature significantly reduces the memory footprint in case of secondary keys. Issue 1908.
- (Vinyl) new implementation of initial state transfer of JOIN command in replication protocol. New replication protocol fixes problems with consistency and secondary keys. We implemented a special kind of low-cost database-wide read-view to avoid dirty reads in JOIN procedure. This trick wasn't not possible in traditional B-Tree based databases. Issue 2001.
- (Vinyl) index-wide mems/runs. Removed ranges from in-memory and and the stop layer of LSM tree on disk. Issue 2209.
- (Vinyl) coalesce small ranges. Before dumping or compacting a range, consider coalescing it with its neighbors. Issue 1735.
- (Vinyl) implemented transnational journal for metadata. Now information about all Vinyl files is logged in a special .vylog file. Issue 1967.
- (Vinyl) implemented consistent secondary keys. Issue 2410.
- (Memtx+Vinyl) implemented low-level Lua API to create consistent backups. of Memtx + Vinyl data. The new feature provides box.backup.start()/stop() functions to create backups of all spaces. box.backup.start() pauses the Tarantool garbage collector and returns the list of files to copy. These files then can be copied be any third-party tool, like cp, ln, tar, rsync, etc. box.backup.stop() lets the garbage collector continue. Created backups can be restored instantly by copying into a new directory and starting a new Tarantool instance. No special preparation, conversion or unpacking is needed. Issue 1916.
- (Vinyl) added statistics for background workers to box.info.vinyl(). Issue 2005.
- (Memtx+Vinyl) reduced the memory footprint for indexes which keys are sequential and start from the first field. This optimization was necessary for secondary keys in Vinyl, but we optimized Memtx as well. Issue 2046.

- LuaJIT was rebased on the latest 2.1.0b3 with out patches (Issue 2396):
  - Added JIT compiler backend for ARM64
  - Added JIT compiler backend and interpreter for MIPS64
  - Added some more Lua 5.2 and Lua 5.3 extensions
  - Fixed several bugs
  - Removed Lua 5.0 legacy (see incompatible changes above).
- Enabled a new smart string hashing algorithm in LuaJIT to avoid significant slowdown when a lot of collisions are generated. Contributed by Yury Sokolov (@funny-falcon) and Nick Zavaritsky (@mejedi). See https://github.com/tarantool/luajit/pull/2.
- box.snapshot() now updates mtime of a snapshot file if there were no changes to the database since the last snapshot. Issue 2045.
- Implemented space:bsize() to return the memory size utilized by all tuples of the space. Contributed by Roman Tokarev (@rtokarev). Issue 2043.
- Exported new Lua/C functions to public API:
  - luaT_pushtuple, luaT_istuple (issue 1878)
  - luaT_error, luaT_call, luaT_cpcall (issue 2291)
  - luaT_state (issue 2416)
- Exported new Box/C functions to public API: box_key_def, box_tuple_format, tuple_compare(), tuple_compare_with_key(). Issue 2225.
- xlogs now can be rotated based on size (wal_max_size) as well as the number of written rows (rows_per_wal). Issue 173.
- Added string.split(), string.startswith(), string.endswith(), string.ljust(), string.rjust(), string.center() API. Issues 2211, 2214, 2415.
- Added table.copy() and table.deepcopy() functions. Issue 2212.
- Added pwd module to work with UNIX users and groups. Issue 2213.
- Removed noisy "client unix/: connected" messages from logs. Use box.session.on_connect()/on_disconnect() triggers instead. Issue 1938.

  box.session.on_connect()/on_disconnect()/on_auth() triggers now also fired for admin console connections.
- tarantoolctl: eval, enter, connect commands now support UNIX pipes. Issue 672.
- tarantoolctl: improved error messages and added a new man page. Issue 1488.
- tarantoolctl: added filter by replica_id to cat and play commands. Issue 2301.
- tarantoolctl: start, stop and restart commands now redirect to systemctl start/stop/restart when systemd is enabled. Issue 2254.
- net.box: added buffer = <buffer> per-request option to store raw MessagePack responses into a C buffer. Issue 2195.
- net.box: added connect_timeout option. Issue 2054.
- net.box: added on_schema_reload() hook. Issue 2021.
- net.box: exposed conn.schema_version and space.connection to API. Issue 2412.
- log: debug()/info()/warn()/error() now doesn't fail on formatting errors. Issue 889.

- crypto: added HMAC support. Contributed by Andrey Kulikov (@amdei). Issue 725.

Release 1.7.3

Release type: beta. Release date: 2016-12-24. Release tag: Tag: 1.7.3-0-gf0c92aa.

Announcement: https://github.com/tarantool/tarantool/releases/tag/1.7.3

This is the second beta release in the 1.7 series.

Incompatible changes:

- Broken coredump() Lua function was removed. Use gdb -batch -ex "generate-core-file" -p $PID instead. Issue 1886.
- Vinyl disk layout was changed since 1.7.2 to add ZStandard compression and improve the performance of secondary keys. Use the replication mechanism to upgrade from 1.7.2 beta. Issue 1656.

Functionality added or changed:

- Substantial progress on stabilizing the Vinyl storage engine:
  - Fix most known crashes and bugs with bad results.
  - Switch to use XLOG/SNAP format for all data files.
  - Enable ZStandard compression for all data files.
  - Squash UPSERT operations on the fly and merge hot keys using a background fiber.
  - Significantly improve the performance of index:pairs() and index:count().
  - Remove unnecessary conflicts from transactions.
  - In-memory level was mostly replaced by memtx data structures.
  - Specialized allocators are used in most places.
- We're still actively working on Vinyl and plan to add multi-level compaction and improve the performance of secondary keys in 1.7.4. This implies a data format change.
- Support for DML requests for space:on_replace() triggers. Issue 587.
- UPSERT can be used with the empty list of operations. Issue 1854.
- Lua functions to manipulate environment variables. Issue 1718.
- Lua library to read Tarantool snapshots and xlogs. Issue 1782.
- New play and cat commands in tarantoolctl. Issue 1861.
- Improve support for the large number of active network clients. Issue#5#1892.
- Support for space:pairs(key, iterator-type) syntax. Issue 1875.
- Automatic cluster bootstrap now also works without authorization. Issue 1589.
- Replication retries to connect to master indefinitely. Issue 1511.
- Temporary spaces now work with box.cfg { read_only = true }. Issue 1378.
- The maximum length of space names increased to 64 bytes (was 32). Issue 2008.

Release 1.7.2

Release type: beta. Release date: 2016-09-29. Release tag: Tag: 1.7.2-1-g92ed6c4.

Announcement: https://groups.google.com/forum/#!topic/tarantool-ru/qUYUesEhRQg

This is a release in the 1.7 series.

Incompatible changes:

- A new binary protocol command for CALL, which no more restricts a function to returning an array of tuples and allows returning an arbitrary MsgPack/JSON result, including scalars, nil and void (nothing). The old CALL is left intact for backward compatibility. It will be removed in the next major release. All programming language drivers will be gradually changed to use the new CALL. Issue 1296.

Functionality added or changed:

- Vinyl storage engine finally reached the beta stage. This release fixes more than 90 bugs in Vinyl, in particular, removing unpredictable latency spikes, all known crashes and bad/lost result bugs.
  - new cooperative multitasking based architecture to eliminate latency spikes,
  - support for non-sequential multi-part keys,
  - support for secondary keys,
  - support for auto_increment(),
  - number, integer, scalar field types in indexes,
  - INSERT, REPLACE and UPDATE return new tuple, like in memtx.
- We're still actively working on Vinyl and plan to add zstd compression and a new memory allocator for Vinyl in-memory index in 1.7.3. This implies a data format change which we plan to implement before 1.7 becomes generally available.
- Tab-based autocompletion in the interactive console, require(`'console'`).connect(), tarantoolctl enter and tarantoolctl connect commands. Issues 86 and 1790. Use the TAB key to auto complete the names of Lua variables, functions and meta-methods.
- A new implementation of net.box improving performance and solving problems when the Lua garbage collector handles dead connections. Issues 799, 800, 1138 and 1750.
- memtx snapshots and xlog files are now compressed on the fly using the fast ZStandard compression algorithm. Compression options are configured automatically to get an optimal trade-off between CPU utilization and disk throughput.
- fiber.cond() - a new synchronization mechanism for cooperative multitasking. Issue 1731.
- Tarantool can now be installed using universal Snappy packages (http://snapcraft.io/) with snap install tarantool --channel=beta.

New rocks and packages:

- curl - non-blocking bindings for libcurl
- prometheus - Prometheus metric collector for Tarantool
- gis - a full-featured geospatial extension for Tarantool
- mqtt - an MQTT protocol client for Tarantool
- luaossl - the most comprehensive OpenSSL module in the Lua universe

Deprecated, removed features and minor incompatibilities:

- num and str fields type names are deprecated, use unsigned and string instead. Issue 1534.
- space:inc() and space:dec() were removed (deprecated in 1.6.x) Issue 1289.
- fiber:cancel() is now asynchronous and doesn't wait for the fiber to end. Issue 1732.
- Implicit error-prone tostring() was removed from digest API. Issue 1591.

- Support for SHA-0 (digest.sha()) was removed due to OpenSSL upgrade.
- net.box now uses one-based indexes for space.name.index[x].parts. Issue 1729.
- Tarantool binary now dynamically links with libssl.so during compile time instead of loading it at the run time.
- Debian and Ubuntu packages switched to use native systemd configuration alongside with old-fashioned sysvinit scripts.

  systemd provides its own facilities for multi-instance management. To upgrade, perform the following steps:

  1. Install new 1.7.2 packages.
  2. Ensure that INSTANCENAME.lua file is present in /etc/tarantool/instace.enabled.
  3. Stop INSTANCENAME using tarantoolctl stop INSTANCENAME.
  4. Start INSTANCENAME using systemctl start tarantool@INSTANCENAME.
  5. Enable INSTANCENAME during system boot using systemctl enable tarantool@INTANCENAME.
  6. Say systemctl disable tarantool; update-rc.d tarantool remove to disable sysvinit-compatible wrappers.

  Refer to issue 1291 comment and the administration chapter for additional information.
- Debian and Ubuntu packages start a ready-to-use example.lua instance on a clean installation of the package. The default instance grants universe permissions for guest user and listens on "locahost:3313".
- Fedora 22 packages were deprecated (EOL).

Release 1.7.1

Release type: alpha. Release date: 2016-07-11.

Announcement: https://groups.google.com/forum/#!topic/tarantool/KGYj3VKJKb8

This is the first alpha in the 1.7 series. The main feature of this release is a new storage engine, called "vinyl". Vinyl is a write optimized storage engine, allowing the amount of data stored exceed the amount of available RAM 10-100x times. Vinyl is a continuation of the Sophia engine from 1.6, and effectively a fork and a distant relative of Dmitry Simonenko's Sophia. Sophia is superseded and replaced by Vinyl. Internally it is organized as a log structured merge tree. However, it takes a serious effort to improve on the traditional deficiencies of log structured storage, such as poor read performance and unpredictable write latency. A single index is range partitioned among many LSM data structures, each having its own in-memory buffers of adjustable size. Range partitioning allows merges of LSM levels to be more granular, as well as to prioritize hot ranges over cold ones in access to resources, such as RAM and I/O. The merge scheduler is designed to minimize write latency while ensuring read performance stays within acceptable limits. Vinyl today only supports a primary key index. The index can consist of up to 256 parts, like in MemTX, up from 8 in Sophia. Partial key reads are supported. Support of non-sequential multi part keys, as well as secondary keys is on the short term todo. Our intent is to remove all limitations currently present in Vinyl, making it a first class citizen in Tarantool.

Functionality added or changed:

- The disk-based storage engine, which was called sophia or phia in earlier versions, is superseded by the vinyl storage engine.
- There are new types for indexed fields.
- The LuaJIT version is updated.
- Automatic replica set bootstrap (for easier configuration of a new replica set) is supported.

- The space_object:inc() function is removed.
- The space_object:dec() function is removed.
- The space_object:bsize() function is added.
- The box.coredump() function is removed, for an alternative see Core dumps.
- The hot_standby configuration option is added.
- Configuration parameters revised or renamed:
  - slab_alloc_arena (in gigabytes) to memtx_memory (in bytes),
  - slab_alloc_minimal to memtx_min_tuple_size,
  - slab_alloc_maximal to memtx_max_tuple_size,
  - replication_source to replication,
  - snap_dir to memtx_dir,
  - logger to log,
  - logger_nonblock to log_nonblock,
  - snapshot_count to checkpoint_count,
  - snapshot_period to checkpoint_interval,
  - panic_on_wal_error and panic_on_snap_error united under force_recovery.
- Until Tarantool 1.8, you can use deprecated parameters for both initial and runtime configuration, but Tarantool will display a warning. Also, you can specify both deprecated and up-to-date parameters, provided that their values are harmonized. If not, Tarantool will display an error.
- Automatic replication cluster bootstrap; it's now much easier to configure a new replication cluster.
- New indexable data types: INTEGER and SCALAR.
- Code refactoring and performance improvements.
- Updated LuaJIT to 2.1-beta116.

7.6 Version 1.6

Release 1.6.9

Release type: maintenance. Release date: 2016-09-27. Release tag: 1.6.9-4-gcc9ddd7.

Since February 15, 2017, due to Tarantool issue#2040 Remove sophia engine from 1.6 there no longer is a storage engine named sophia. It will be superseded in version 1.7 by the vinyl storage engine.

Incompatible changes:

- Support for SHA-0 (digest.sha()) was removed due to OpenSSL upgrade.
- Tarantool binary now dynamically links with libssl.so during compile time instead of loading it at the run time.
- Fedora 22 packages were deprecated (EOL).

Functionality added or changed:

- Tab-based autocompletion in the interactive console. Issue 86

- LUA_PATH and LUA_CPATH environment variables taken into account, like in PUC-RIO Lua. Issue 1428
- Search for .dylib as well as for .so libraries in OS X. Issue 810.
- A new box.cfg { read_only = true } option to emulate master-slave behavior. Issue 246
- if_not_exists = true option added to box.schema.user.grant. Issue 1683
- clock_realtime()/monotonic() functions added to the public C API. Issue 1455
- space:count(key, opts) introduced as an alias for space.index.primary:count(key, opts). Issue 1391
- Upgrade script for 1.6.4 -> 1.6.8 -> 1.6.9. Issue 1281
- Support for OpenSSL 1.1. Issue 1722

New rocks and packages:

- curl - non-blocking bindings for libcurl
- prometheus - Prometheus metric collector for Tarantool
- gis - full-featured geospatial extension for Tarantool.
- mqtt - MQTT protocol client for Tarantool
- luaossl - the most comprehensive OpenSSL module in the Lua universe

Release 1.6.8

Release type: maintenance. Release date: 2016-02-25. Release tag: 1.6.8-525-ga571ac0.

Incompatible changes:

- RPM packages for CentOS 7 / RHEL 7 and Fedora 22+ now use native systemd configuration without legacy sysvinit shell scripts. Systemd provides its own facilities for multi-instance management. To upgrade, perform the following steps:

  1. Ensure that INSTANCENAME.lua file is present in /etc/tarantool/instace.available.
  2. Stop INSTANCENAME using tarantoolctl stop INSTANCENAME.
  3. Start INSTANCENAME using systemctl start tarantool@INSTANCENAME.
  4. Enable INSTANCENAME during system boot using systemctl enable tarantool@INTANCENAME.

  /etc/tarantool/instance.enabled directory is now deprecated for systemd-enabled platforms.

  See the administration chapter for additional information.

- Sophia was upgraded to v2.1 to fix upsert, memory corruption and other bugs. Sophia v2.1 doesn't support old v1.1 data format. Please use Tarantool replication to upgrade. Issue 1222
- Ubuntu Vivid, Fedora 20, Fedora 21 were deprecated due to EOL.
- i686 packages were deprecated. Please use our RPM and DEB specs to build these on your own infrastructure.
- Please update your yum.repos.d and/or apt sources.list.d according to instructions at http://tarantool.org/download.html

Functionality added or changed:

- Tarantool 1.6.8 fully supports ARMv7 and ARMv8 (aarch64) processors. Now it is possible to use Tarantool on a wide range of consumer devices, starting from popular Raspberry PI 2 to coin-size embedded boards and no-name mini-micro-nano-PCs. Issue 1153. (Also qemu works well, but we don't have real hardware to check.)

- Tuple comparator functions were optimized, providing up to 30% performance boost when an index key consists of 2, 3 or more parts. Issue 969.
- Tuple allocator changes give another 15% performance improvement. Issue 1298
- Replication relay performance was improved by reducing the amount of data directory re-scans. Issue 11150
- A random delay was introduced into snapshot daemon, reducing the chance that multiple instances take a snapshot at the same time. Issue 732.
- Sophia storage engine was upgraded to v2.1:
  - serializable Snapshot Isolation (SSI),
  - RAM storage mode,
  - anti-cache storage mode,
  - persistent caching storage mode,
  - implemented AMQ Filter,
  - LRU mode,
  - separate compression for hot and cold data,
  - snapshot implementation for Faster Recovery,
  - upsert reorganizations and fixes,
  - new performance metrics.

  Please note "Incompatible changes" above.
- Allow to remove servers with non-zero LSN from _cluster space. Issue 1219.
- net.box now automatically reloads space and index definitions. Issue 1183.
- The maximal number of indexes in space was increased to 128. Issue 1311.
- New native systemd configuration with support of instance management and daemon supervision (CentOS 7 and Fedora 22+ only). Please note "Incompatible changes" above. Issue 1264.
- Tarantool package was accepted to the official Fedora repositories (https://apps.fedoraproject.org/packages/tarantool).
- Tarantool brew formula (OS X) was accepted to the official Homebrew repository (http://brewformulas.org/tarantool).
- Clang compiler support was added on FreeBSD. Issue 786.
- Support for musl libc, used by Alpine Linux and Docker images, was added. Issue 1249.
- Added support for GCC 6.0.
- Ubuntu Wily, Xenial and Fedora 22, 23 and 24 are now supported distributions for which we build official packages.
- box.info.cluster.uuid can be used to retrieve cluster UUID. Issue 1117.
- Numerous improvements in the documentation, added documentation for syslog, clock, fiber.storage packages, updated the built-in tutorial.

New rocks and packages:

- Tarantool switched to a new Docker-based cloud build infrastructure The new buildbot significantly decreases commit-to-package time. The official repositories at http://tarantool.org now contain the latest version of the server, rocks and connectors. See http://github.com/tarantool/build
- The repositories at http://tarantool.org/download.html were moved to http://packagecloud.io cloud hosting (backed by Amazon AWS). Thanks to packagecloud.io for their support of open source!
- memcached - memcached text and binary protocol implementation for Tarantool. Turns Tarantool into a persistent memcached with master-master replication. See https://github.com/tarantool/memcached
- migrate - a Tarantool rock for migration from Tarantool 1.5 to 1.6. See https://github.com/bigbes/migrate
- cqueues - a Lua asynchronous networking, threading, and notification framework (contributed by @daurnimator). PR 1204.

Release 1.6.7

Release type: maintenance. Release date: 2015-11-17.

Incompatible changes:

- The syntax of upsert command has been changed and an extra key argument was removed from it. The primary key for look up is now always taken from the tuple, which is the second argument of upsert. upsert() was added fairly late at a release cycle and the design had an obvious bug which we had to fix. Sorry for this.
- fiber.channel.broadcast() was removed since it wasn't used by anyone and didn't work properly.
- tarantoolctl reload command renamed to eval.

Functionality added or changed:

- logger option now accepts a syntax for syslog output. Use uri-style syntax for file, pipe or syslog log destination.
- replication_source now accepts an array of URIs, so each replica can have up to 30 peers.
- RTREE index now accept two types of distance functions: euclid and manhattan.
- fio.abspath() - a new function in fio rock to convert a relative path to absolute.
- The process title now can be set with an on-board title rock.
- This release uses LuaJIT 2.1.

New rocks:

- memcached - makes Tarantool understand Memcached binary protocol. Text protocol support is in progress and will be added to the rock itself, without changes to the server core.

Release 1.6.6

Release type: maintenance. Release date: 2015-08-28.

Tarantool 1.6 is no longer getting major new features, although it will be maintained. The developers are concentrating on Tarantool version 1.9.

Incompatible changes:

- A new schema of _index system space which accommodates multi-dimensional RTREE indexes. Tarantool 1.6.6 works fine with an old snapshot and system spaces, but you will not be able to start Tarantool 1.6.5 with a data directory created by Tarantool 1.6.6, neither will you be able to query Tarantool 1.6.6 schema with 1.6.5 net.box.
- box.info.snapshot_pid is renamed to box.info.snapshot_in_progress

Functionality added or changed:

- Threaded architecture for network. Network I/O has finally been moved to a separate thread, increasing single instance performance by up to 50%.
- Threaded architecture for checkpointing. Tarantool no longer forks to create a snapshot, but uses a separate thread, accessing data via a consistent read view. This eliminates all known latency spikes caused by snapshotting.
- Stored procedures in C/C++. Stored procedures in C/C++ provide speed (3-4 times, compared to a Lua version in our measurements), as well as unlimited extensibility power. Since C/C++ procedures run in the same memory space as the database, they are also an easy tool to corrupt database memory. See The C API description.
- Multidimensional RTREE index. RTREE index type now support a large (up to 32) number of dimensions. RTREE data structure has been optimized to actually use R*-TREE. We're working on further improvements of the index, in particular, configurable distance function. See https://github.com/tarantool/tarantool/wiki/R-tree-index-quick-start-and-usage
- Sophia 2.1.1, with support of compression and multipart primary keys. See https://groups.google.com/forum/#!topic/sophia-database/GfcbEC7ksRg
- New upsert command available in the binary protocol and in stored functions. The key advantage of upsert is that it's much faster with write-optimized storage (sophia storage engine), but some caveats exists as well. See Issue 905 for details. Even though upsert performance advantage is most prominent with sophia engine, it works with all storage engines.
- Better memory diagnostics information for fibers, tuple and index arena Try a new command box.slab.stats(), for detailed information about tuple/index slabs, fiber.info() now displays information about memory used by the fiber.
- Update and delete now work using a secondary index, if the index is unique.
- Authentication triggers. Set box.session.on_auth triggers to catch authentication events. Trigger API is improved to display all defined triggers, easily remove old triggers.
- Manifold performance improvements of net.box built-in package.
- Performance optimizations of BITSET index.
- panic_on_wal_error is a dynamic configuration option now.
- iproto sync field is available in Lua as session.sync().
- box.once() - a new method to invoke code once in an instance and replica set lifetime. Use once() to set up spaces and uses, as well as do schema upgrade in production.
- box.error.last() to return the last error in a session.

New rocks:

- jit.*, jit.dump, jit.util, jit.vmdef modules of LuaJIT 2.0 are now available as built-ins. See http://luajit.org/ext_jit.html
- strict built-in package, banning use of undeclared variables in Lua. Strict mode is on when Tarantool is compiled with debug. Turn on/off with require('strict').on()/require('strict').off().
- pg and mysql rocks, available at http://rocks.tarantool.org - working with MySQL and PostgreSQL from Tarantool.
- gperftools rock, availble at http://rocks.tarantool.org - getting perfromance data using Google's gperf from Tarantool.
- csv built-in rock, to parse and load CSV (comma-separated values) data.

New supported platforms:

- Fedora 22, Ubuntu Vivid

CHAPTER 8

Contributor's Guide

8.1 Build and contribute

8.1.1 Building from source

For downloading Tarantool source and building it, the platforms can differ and the preferences can differ. But strategically the steps are always the same.

1. Get tools and libraries that will be necessary for building and testing.

   The absolutely necessary ones are:

   - A program for downloading source repositories. For all platforms, this is git. It allows downloading the latest complete set of source files from the Tarantool repository on GitHub.
   - A C/C++ compiler. Ordinarily, this is gcc and g++ version 4.6 or later. On Mac OS X, this is Clang version 3.2+.
   - A program for managing the build process. For all platforms, this is CMake version 2.8+.
   - A build automation tool. For all platforms this is GNU Make.
   - ReadLine library, any version
   - ncurses library, any version
   - OpenSSL library, version 1.0.1+
   - ICU library, recent version
   - Autoconf library, any version
   - Automake library, any version
   - Libtool library, any version
   - Zlib-devel library, any version

- Python and modules. Python interpreter is not necessary for building Tarantool itself, unless you intend to use the "Run the test suite" option in step 5. For all platforms, this is python version 2.7+ (but not 3.x). You need the following Python modules:
  - pyyaml version 3.10
  - argparse version 1.1
  - msgpack-python version 0.4.6
  - gevent version 1.1.2
  - six version 1.8.0

To install all required dependencies, follow the instructions for your OS:

- For Debian/Ubuntu, say:

```
$ apt install -y build-essential cmake make coreutils sed \
      autoconf automake libtool zlib1g-dev \
      libreadline-dev libncurses5-dev libssl-dev \
      libunwind-dev libicu-dev \
      python python-pip python-setuptools python-dev \
      python-msgpack python-yaml python-argparse python-six python-gevent
```

- For RHEL/CentOS (versions under 8)/Fedora, say:

```
$ yum install -y gcc gcc-c++ cmake make coreutils sed \
      autoconf automake libtool zlib-devel \
      readline-devel ncurses-devel openssl-devel \
      libunwind-devel libicu-devel \
      python python-pip python-setuptools python-devel \
      python-msgpack python-yaml python-argparse python-six python-gevent
```

- For CentOS 8, say:

```
$ yum install epel-release
$ curl -s https://packagecloud.io/install/repositories/packpack/backports/script.rpm.sh | sudo bash
$ yum install -y gcc gcc-c++ cmake make coreutils sed \
      autoconf automake libtool zlib-devel \
      readline-devel ncurses-devel openssl-devel \
      libunwind-devel libicu-devel \
      python2 python2-pip python2-setuptools python2-devel \
      python2-yaml python2-six
```

- For Mac OS X (instructions below are for OS X El Capitan):

  If you're using Homebrew as your package manager, say:

```
$ brew install cmake make autoconf binutils zlib \
       autoconf automake libtool \
       readline ncurses openssl libunwind-headers icu4c \
       && pip install python-daemon \
       msgpack-python pyyaml configargparse six gevent
```

  Note: You can not install zlib-devel package this way.

  Alternatively, download Apple's default Xcode toolset:

```
$ xcode-select --install
$ xcode-select -switch /Applications/Xcode.app/Contents/Developer
```

- For FreeBSD (instructions below are for FreeBSD 10.1+ release), say:

```
$ pkg install -y sudo git cmake gmake gcc coreutils \
    autoconf automake libtool \
    readline ncurses openssl libunwind icu \
    python27 py27-pip py27-setuptools py27-daemon \
    py27-msgpack py27-yaml py27-argparse py27-six py27-gevent
```

If some Python modules are not available in a repository, it is best to set up the modules by getting a tarball and doing the setup with python setup.py like this:

```
$ # On some machines, this initial command may be necessary:
$ wget https://bootstrap.pypa.io/ez_setup.py -O - | sudo python

$ # Python module for parsing YAML (pyYAML), for test suite:
$ # (If wget fails, check at http://pyyaml.org/wiki/PyYAML
$ # what the current version is.)
$ cd ~
$ wget http://pyyaml.org/download/pyyaml/PyYAML-3.10.tar.gz
$ tar -xzf PyYAML-3.10.tar.gz
$ cd PyYAML-3.10
$ sudo python setup.py install
```

Finally, use Python pip to bring in Python packages that may not be up-to-date in the distro repositories. (On CentOS 7, it will be necessary to install pip first, with sudo yum install epel-release followed by sudo yum install python-pip.)

```
$ pip install -r \
    https://raw.githubusercontent.com/tarantool/test-run/master/requirements.txt \
    --user
```

This step is only necessary once, the first time you do a download.

2. Use git to download the latest Tarantool source code from the GitHub repository tarantool/tarantool, branch 2.2, to a local directory named ~/tarantool, for example:

```
$ git clone --recursive https://github.com/tarantool/tarantool.git -b 2.2 ~/tarantool
```

On rare occasions, the submodules need to be updated again with the command:

```
cd ~/tarantool
$ git submodule update --init --recursive
```

3. Use CMake to initiate the build.

```
$ cd ~/tarantool
$ make clean         # unnecessary, added for good luck
$ rm CMakeCache.txt  # unnecessary, added for good luck
$ cmake .            # start initiating with build type=Debug
```

On some platforms, it may be necessary to specify the C and C++ versions, for example:

```
$ CC=gcc-4.8 CXX=g++-4.8 cmake .
```

The CMake option for specifying build type is -DCMAKE_BUILD_TYPE=type, where type can be:

- Debug – used by project maintainers
- Release – used only if the highest performance is required
- RelWithDebInfo – used for production, also provides debugging capabilities

The CMake option for hinting that the result will be distributed is -DENABLE_DIST=ON. If this option is on, then later make install will install tarantoolctl files in addition to tarantool files.

4. Use make to complete the build.

```
$ make
```

Note: For FreeBSD, use gmake instead.

This creates the 'tarantool' executable in the src/ directory.

Note: If you encounter a curl or OpenSSL errors on this step try installing openssl111 package of the specific 1.1.1d version.

Next, it's highly recommended to say make install to install Tarantool to the /usr/local directory and keep your system clean. However, it is possible to run the Tarantool executable without installation.

5. Run the test suite.

This step is optional. Tarantool's developers always run the test suite before they publish new versions. You should run the test suite too, if you make any changes in the code. Assuming you downloaded to ~/tarantool, the principal steps are:

```
$ # make a subdirectory named `bin`
$ mkdir ~/tarantool/bin

$ # link Python to bin (this may require superuser privileges)
$ ln /usr/bin/python ~/tarantool/bin/python

$ # get to the test subdirectory
$ cd ~/tarantool/test

$ # run tests using Python
$ PATH=~/tarantool/bin:$PATH ./test-run.py
```

The output should contain reassuring reports, for example:

```
======================================================================
TEST                                            RESULT
------------------------------------------------------------
box/bad_trigger.test.py                         [ pass ]
box/call.test.py                                [ pass ]
box/iproto.test.py                              [ pass ]
box/xlog.test.py                                [ pass ]
box/admin.test.lua                              [ pass ]
box/auth_access.test.lua                        [ pass ]
... etc.
```

To prevent later confusion, clean up what's in the bin subdirectory:

```
$ rm ~/tarantool/bin/python
$ rmdir ~/tarantool/bin
```

6. Make RPM and Debian packages.

   This step is optional. It's only for people who want to redistribute Tarantool. We highly recommend to use official packages from the tarantool.org web-site. However, you can build RPM and Debian packages using PackPack or using the dpkg-buildpackage or rpmbuild tools. Please consult dpkg or rpmbuild documentation for details.

7. Verify your Tarantool installation:

```
$ # if you installed tarantool locally after build
$ tarantool
$ # - OR -
$ # if you didn't install tarantool locally after build
$ ./src/tarantool
```

   This starts Tarantool in the interactive mode.

See also:

- Tarantool README.md

8.1.2 Release management

Release policy

A Tarantool release is identified by three digits, for example, 1.10.7:

- The first digit stands for a MAJOR release series that introduces some major changes. Up to now, there has been only one major release jump when we delivered the 2.x release series with the SQL support.
- The second digit stands for a MINOR release series that is used for introducing new features. Backward incompatible changes are possible between these release series.
- The third digit is for PATCH releases by which we reflect how stable the MINOR release series is:
  - 0 meaning alpha
  - 1 meaning beta
  - 2 and above meaning stable.

So, each MINOR release series goes through a development-maturity life cycle as follows:

1. Alpha. Once a quarter, we start off with a new alpha version, such as 2.3.0, 2.4.0, and so on. This is not what an alpha release usually means in the typical software release life cycle but rather the current trunk version which is under heavy development and can be unstable. The current alpha version always lives in the master branch.
2. Beta. When all the features planned are implemented, we fork a new branch from the master branch and tag it as a new beta version. It contains 1 for the PATCH digit, e.g., 2.3.1, 2.4.1, and so on. This version cannot be called stable yet (feature freeze has just been done) although there're no known critical regressions in it since the last stable release.
3. Stable. Finally, after we see our beta version runs successfully in a production or development environment during another quarter while we fix incoming bugs, we declare this version stable. It is tagged with 2 for the PATCH digit, e.g., 2.3.2, 2.4.2, and so on.

> We support such version for 3 months while making another stable release by fixing all bugs found. We release it in a quarter. This last tag contains 3 for the PATCH digit, e.g., 2.3.3, 2.4.3, and so on. After the tag is set, no new changes are allowed to the release branch, and it is declared deprecated and superseded by a newer MINOR version.
>
> Stable versions don't receive any new features and only get backward compatible fixes.

Like Ubuntu, in terms of support, we distinguish between two kinds of stable release series:

- LTS (Long Term Support) is a release series that is supported for 3 years (community) and up to 5 years (paying customers). Current LTS release series is 1.10, and it receives only PATCH level releases.
- Standard is a release series that is supported only for a few months until the next release series enters the stable state.

Below is a diagram that illustrates the release sequence issuing described above by an example of some latest releases and release series:

```
1.10 series -- 1.10.4 -- 1.10.5 -- 1.10.6 -- 1.10.7
(LTS)

....

2.2 series --- 2.2.1 --- 2.2.2 --- 2.2.3 (end of support)
                 |
                 V
2.3 series ... 2.3.0 --- 2.3.1 --- 2.3.2 --- 2.3.3 (end of support)
                           |
                           V
2.4 series ............ 2.4.0 --- 2.4.1 --- 2.4.2
                                     |
                                     V
2.5 series ...................... 2.5.0 --- 2.5.1
                                               |
                                               V
2.6 series ................................ 2.6.0

-----------------|---------|---------|---------|------> (time)
                   1/4 yr.   1/4 yr.   1/4 yr.
```

Support means that we continue fixing bugs. We add bug fixes simultaneously into the following release series: LTS, last stable, beta, and alpha. If we look at the release diagram above, it means that the bug fixes are to be added into 1.10, 2.4, 2.5, and 2.6 release series.

To sum it up, once a quarter we release (see the release diagram above for reference):

- next LTS release, e.g., 1.10.7
- two stable releases, e.g., 2.3.3 and 2.4.2
- beta version of the next release series, e.g., 2.5.1.

In all supported releases, when we find and fix an outstanding CVE/vulnerability, we deliver a patch for that but do not tag a new PATCH level version. Users will be informed about such critical patches via the official Tarantool news channel (tarantool_news).

We also publish nightly builds, and use the fourth slot in the version identifier to designate the nightly build number.

Note: A release series may introduce backward incompatible changes in a sense that existing Lua, SQL or C code that are run on a current release series may not be run with the same effect on a future series.

However, we don't exploit this rule and don't make incompatible changes without appropriate reason. We usually deliver information how mature a functionality is via release notes.

Please note that binary data layout is always compatible with the previous series as well as with the LTS series (an instance of X.Y version can be started on top of X.(Y+1) or 1.10.z data); binary protocol is compatible too (client-server as well as replication protocol).

Release list

Below is the table containing all Tarantool releases starting from 1.10.0 up to the current latest versions (as of September 1, 2020). For each release series, releases are sorted out as alpha, beta, and stable ones.

Release series	Alpha	Beta	Stable
1.10 (LTS)	1.10.0	1.10.1	1.10.2 1.10.3 1.10.4 1.10.5 1.10.6 1.10.7
2.1	2.1.0	2.1.1	2.1.2 2.1.3
2.2	2.2.0	2.2.1	2.2.2 2.2.3
2.3	2.3.0	2.3.1	2.3.2 2.3.3
2.4	2.4.0	2.4.1	2.4.2
2.5	2.5.0	2.5.1	
2.6	2.6.0		

How to make a minor release

```
$ git tag -a 2.4 -m "Next minor in 2.x series"
$ vim CMakeLists.txt # edit CPACK_PACKAGE_VERSION_PATCH
$ git push --tags
```

A tag which is made on a git branch can be taken along with a merge, or left on the branch. The technique to "keep the tag on the branch it was originally set on" is to use --no-fast-forward when merging this branch.

With --no-ff, a merge changeset is created to represent the received changes, and only that merge changeset ends up in the destination branch. This technique can be useful when there are two active lines of development, e.g. "stable" and "next", and it's necessary to be able to tag both lines independently.

To make sure that a tag doesn't end up in the destination branch, it is necessary to have the commit to which the tag is attached, "stay on the original branch". That's exactly what a merge with disabled "fast-forward" does – creates a "merge" commit and adds it to both branches.

Here's what it may look like:

```
kostja@shmita:~/work/tarantool$ git checkout master
Already on 'master'
kostja@shmita:~/work/tarantool$ git tag -a 2.4 -m "Next development"
kostja@shmita:~/work/tarantool$ git describe
2.4
kostja@shmita:~/work/tarantool$ git checkout master-stable
Switched to branch 'master-stable'
kostja@shmita:~/work/tarantool$ git tag -a 2.3 -m "Next stable"
kostja@shmita:~/work/tarantool$ git describe
2.3
kostja@shmita:~/work/tarantool$ git checkout master
Switched to branch 'master'
kostja@shmita:~/work/tarantool$ git describe
```

(continues on next page)

(continued from previous page)

```
2.4
kostja@shmita:~/work/tarantool$ git merge --no-ff master-stable
Auto-merging CMakeLists.txt
Merge made by recursive.
 CMakeLists.txt |    1 +
 1 files changed, 1 insertions(+), 0 deletions(-)
kostja@shmita:~/work/tarantool$ git describe
2.4.0-0-g0a98576
```

Also, don't forget this:

1. Update all issues. Upload the ChangeLog based on git log output.

   The ChangeLog must only include items which are mentioned as issues on GitHub. If anything significant is there, which is not mentioned, something went wrong in release planning and the release should be held up until this is cleared.

2. Click 'Release milestone'. Create a milestone for the next minor release. Alert the driver to target bugs and blueprints to the new milestone.

8.2 Guidelines

8.2.1 Developer guidelines

How to work on a bug

Any defect, even minor, if it changes the user-visible server behavior, needs a bug report. Report a bug at http://github.com/tarantool/tarantool/issues.

When reporting a bug, try to come up with a test case right away. Set the current maintenance milestone for the bug fix, and specify the series. Assign the bug to yourself. Put the status to 'In progress' Once the patch is ready, put the bug the bug to 'In review' and solicit a review for the fix.

Once there is a positive code review, push the patch and set the status to 'Closed'

Patches for bugs should contain a reference to the respective Launchpad bug page or at least bug id. Each patch should have a test, unless coming up with one is difficult in the current framework, in which case QA should be alerted.

There are two things you need to do when your patch makes it into the master:

- put the bug to 'fix committed',
- delete the remote branch.

How to write a commit message

Any commit needs a helpful message. Mind the following guidelines when committing to any of Tarantool repositories at GitHub.

1. Separate subject from body with a blank line.
2. Try to limit the subject line to 50 characters or so.
3. Start the subject line with a capital letter unless it prefixed with a subsystem name and semicolon:
   - memtx:

  - vinyl:
  - xlog:
  - replication:
  - recovery:
  - iproto:
  - net.box:
  - lua:
  - sql:

4. Do not end the subject line with a period.
5. Do not put "gh-xx", "closes #xxx" to the subject line.
6. Use the imperative mood in the subject line. A properly formed Git commit subject line should always be able to complete the following sentence: "If applied, this commit will /your subject line here/".
7. Wrap the body to 72 characters or so.
8. Use the body to explain what and why vs. how.
9. Link GitHub issues on the lasts lines (see how).
10. Use your real name and real email address. For Tarantool team members, @tarantool.org email is preferred, but not mandatory.

A template:

```
Summarize changes in 50 characters or less

More detailed explanatory text, if necessary.
Wrap it to 72 characters or so.
In some contexts, the first line is treated as the subject of the
commit, and the rest of the text as the body.
The blank line separating the summary from the body is critical
(unless you omit the body entirely); various tools like `log`,
`shortlog` and `rebase` can get confused if you run the two together.

Explain the problem that this commit is solving. Focus on why you
are making this change as opposed to how (the code explains that).
Are there side effects or other unintuitive consequences of this
change? Here's the place to explain them.

Further paragraphs come after blank lines.

- Bullet points are okay, too.

- Typically a hyphen or asterisk is used for the bullet, preceded
  by a single space, with blank lines in between, but conventions
  vary here.

Fixes: #123
Closes: #456
Needed for: #859
See also: #343, #789
```

Some real-world examples:

- tarantool/tarantool@2993a75
- tarantool/tarantool@ccacba2
- tarantool/tarantool@386df3d
- tarantool/tarantool@076a842

Based on [1] and [2].

How to submit a patch for review

We don't accept GitHub pull requests. Instead, all patches should be sent as plain-text messages to tarantool-patches@dev.tarantool.org. Please subscribe to our mailing list at https://lists.tarantool.org/mailman/listinfo/tarantool-patches to ensure that your messages are added to the archive.

1. Preparing a patch

Once you have committed a patch to your local git repository, you can submit it for review.

To prepare an email, use git format-patch command:

```
$ git format-patch -1
```

It will format the commit at the top of your local git repository as a plain-text email and write it to a file in the current directory. The file name will look like 0001-your-commit-subject-line.patch. To specify a different directory, use -o option:

```
$ git format-patch -1 -o ~/patches-to-send
```

Once the patch has been formatted, you can view and edit it with your favorite text editor (after all, it is a plain-text file!). We strongly recommend adding:

- a hyperlink to the branch where this patch can be found at GitHub, and
- a hyperlink to the GitHub issue your patch is supposed to fix, if any.

If there is just one patch, the change log should go right after --- in the message body (it will be ignored by git am then).

If there are multiple patches you want to submit in one go (e.g. this is a big feature which requires some preparatory patches to be committed first), you should send each patch in a separate email in reply to a cover letter. To format a patch series accordingly, pass the following options to git format-patch:

```
$ git format-patch --cover-letter --thread=shallow HEAD~2
```

where:

- --cover-letter will make git format-patch generate a cover letter;
- --thread=shallow will mark each formatted patch email to be sent in reply to the cover letter;
- HEAD~2 (we now use it instead of -1) will make git format-patch format the first two patches at the top of your local git branch instead of just one. To format three patches, use HEAD~3, and so forth.

After the command has been successfully executed, you will find all your patches formatted as separate emails in your current directory (or in the directory specified via -o option):

```
0000-cover-letter.patch
0001-first-commit.patch
0002-second-commit.patch
...
```

The cover letter will have BLURB in its subject and body. You'll have to edit it before submitting (again, it is a plain text file). Please write:

- a short series description in the subject line;
- a few words about each patch of the series in the body.

And don't forget to add hyperlinks to the GitHub issue and branch where your series can be found. In this case you don't need to put links or any additional information to each individual email – the cover letter will cover everything.

Note: To omit --cover-letter and --thread=shallow options, you can add the following lines to your gitconfig:

```
[format]
    thread = shallow
    coverLetter = auto
```

2. Sending a patch

Once you have formatted your patches, they are ready to be sent via email. Of course, you can send them with your favorite mail agent, but it is much easier to use git send-email for this. Before using this command, you need to configure it.

If you use a GMail account, add the following code to your .gitconfig:

```
[sendemail]
    smtpencryption = tls
    smtpserver = smtp.gmail.com
    smtpserverport = 587
    smtpuser = your.name@gmail.com
    smtppass = topsecret
```

For mail.ru users, the configuration will be slightly different:

```
[sendemail]
    smtpencryption = ssl
    smtpserver = smtp.mail.ru
    smtpserverport = 465
    smtpuser = your.name@mail.ru
    smtppass = topsecret
```

If your email account is hosted by another service, consult your service provider about your SMTP settings.

Once configured, use the following command to send your patches:

```
$ git send-email --to tarantool-patches@dev.tarantool.org 00*
```

(00* wildcard will be expanded by your shell to the list of patches generated at the previous step.)

If you want someone in particular to review your patch, add them to the list of recipients by passing --to or --cc once per each recipient.

Note: It is useful to check that git send-email will work as expected without sending anything to the world. Use --dry-run option for that.

3. Review process

After having sent your patches, you just wait for a review. The reviewer will send their comments back to you in reply to the email that contains the patch that in their opinion needs to be fixed.

Upon receiving an email with review remarks, you carefully read it and reply about whether you agree or disagree with. Please note that we use the interleaved reply style (aka "inline reply") for communications over email.

Upon reaching an agreement, you send a fixed patch in reply to the email that ended the discussion. To send a patch, you can either attach a plain diff (created by git diff or git format-patch) to email and send it with your favorite mail agent, or use --in-reply-to option of git send-email command.

If you feel that the accumulated change set is large enough to send the whole series anew and restart the review process in a different thread, you generate the patch email(s) again with git format-patch, this time adding v2 (then v3, v4, and so forth) to the subject and a change log to the message body. To modify the subject line accordingly, use the --subject-prefix option to git format-patch command:

```
$ git format-patch -1 --subject-prefix='PATCH v2'
```

To add a change log, open the generated email with you favorite text editor and edit the message body. If there is just one patch, the change log should go right after --- in the message body (it will be ignored by git am then). If there is more than one patch, the change log should be added to the cover letter. Here is an example of a good change log:

```
Changes in v3:
  - Fixed comments as per review by Alex
  - Added more tests
Changes in v2:
  - Fixed a crash if the user passes invalid options
  - Fixed a memory leak at exit
```

It is also a good practice to add a reference to the previous version of your patch set (via a hyperlink or message id).

Note:

- Do not disagree with the reviewer without providing a good argument supporting your point of view.
- Do not take every word the reviewer says for granted. Reviewers are humans too, hence fallible.
- Do not expect that the reviewer will tell you how to do your thing. It is not their job. The reviewer might suggest alternative ways to tackle the problem, but in general it is your responsibility.
- Do not forget to update your remote git branch every time you send a new version of your patch.
- Do follow the guidelines above. If you do not comply, your patches are likely to be silently ignored.

8.2.2 Documentation guidelines

These guidelines are updated on the on-demand basis, covering only those issues that cause pains to the existing writers. At this point, we do not aim to come up with an exhaustive Documentation Style Guide for the Tarantool project.

Markup issues

Wrapping text

The limit is 80 characters per line for plain text, and no limit for any other constructions when wrapping affects ReST readability and/or HTML output. Also, it makes no sense to wrap text into lines shorter than 80 characters unless you have a good reason to do so.

The 80-character limit comes from the ISO/ANSI 80x24 screen resolution, and it's unlikely that readers/writers will use 80-character consoles. Yet it's still a standard for many coding guidelines (including Tarantool). As for writers, the benefit is that an 80-character page guide allows keeping the text window rather narrow most of the time, leaving more space for other applications in a wide-screen environment.

Formatting code snippets

For code snippets, we mainly use the code-block directive with an appropriate highlighting language. The most commonly used highlighting languages are:

- .. code-block:: tarantoolsession
- .. code-block:: console
- .. code-block:: lua

For example (a code snippet in Lua):

```lua
for page in paged_iter("X", 10) do
  print("New Page. Number Of Tuples = " .. #page)
  for i=1,#page,1 do print(page[i]) end
end
```

In rare cases, when we need custom highlight for specific parts of a code snippet and the code-block directive is not enough, we use the per-line codenormal directive together and explicit output formatting (defined in doc/sphinx/_static/sphinx_design.css).

Examples:

- Function syntax (the placeholder space-name is displayed in italics):

  box.space.*space-name*:create_index('index-name')

- A tdb session (user input is in bold, command prompt is in blue, computer output is in green):

```
$ tarantool example.lua
(TDB)  Tarantool debugger v.0.0.3. Type h for help
example.lua
(TDB)  [example.lua]
(TDB)  3: i = 1
```

Warning: Every entry of explicit output formatting (codenormal, codebold, etc) tends to cause troubles when this documentation is translated to other languages. Please avoid using explicit output formatting unless it is REALLY needed.

Using separated links

Avoid separating the link and the target definition (ref), like this:

```
This is a paragraph that contains `a link`_.

.. _a link: http://example.com/
```

Use non-separated links instead:

```
This is a paragraph that contains `a link <http://example.com/>`_.
```

Warning: Every separated link tends to cause troubles when this documentation is translated to other languages. Please avoid using separated links unless it is REALLY needed (e.g. in tables).

Creating labels for local links

We avoid using links that sphinx generates automatically for most objects. Instead, we add our own labels for linking to any place in this documentation.

Our naming convention is as follows:

- Character set: a through z, 0 through 9, dash, underscore.
- Format: path dash filename dash tag

  Example: _c_api-box_index-iterator_type where: c_api is the directory name, box_index is the file name (without ".rst"), and iterator_type is the tag.

The file name is useful for knowing, when you see "ref", where it is pointing to. And if the file name is meaningful, you see that better.

The file name alone, without a path, is enough when the file name is unique within doc/sphinx. So, for fiber.rst it should be just "fiber", not "reference-fiber". While for "index.rst" (we have a handful of "index.rst" in different directories) please specify the path before the file name, e.g. "reference-index".

Use a dash "-" to delimit the path and the file name. In the documentation source, we use only underscores "_" in paths and file names, reserving dash "-" as the delimiter for local links.

The tag can be anything meaningful. The only guideline is for Tarantool syntax items (such as members), where the preferred tag syntax is module_or_object_name dash member_name. For example, box_space-drop.

Making comments

Sometimes we may need to leave comments in a ReST file. To make sphinx ignore some text during processing, use the following per-line notation with ".. //" as the comment marker:

```
.. // your comment here
```

The starting symbols ".. //" do not interfere with the other ReST markup, and they are easy to find both visually and using grep. There are no symbols to escape in grep search, just go ahead with something like this:

```
$ grep ".. //" doc/sphinx/dev_guide/*.rst
```

These comments don't work properly in nested documentation, though (e.g. if you leave a comment in module -> object -> method, sphinx ignores the comment and all nested content that follows in the method description).

Language and style issues

US vs British spelling

We use English US spelling.

Instance vs server

We say "instance" rather than "server" to refer to an instance of Tarantool server. This keeps the manual terminology consistent with names like /etc/tarantool/instances.enabled in the Tarantool environment.

Wrong usage: "Replication allows multiple Tarantool servers to work on copies of the same databases."

Correct usage: "Replication allows multiple Tarantool instances to work on copies of the same databases."

Examples and templates

Module and function

Here is an example of documenting a module (my_fiber) and a function (my_fiber.create).

my_fiber.create(function[, function-arguments])

Create and start a my_fiber object. The object is created and begins to run immediately.

Parameters

- function – the function to be associated with the my_fiber object
- function-arguments – what will be passed to function

Return created my_fiber object

Rtype userdata

Example:

```
tarantool> my_fiber = require('my_fiber')
---
...
tarantool> function function_name()
         >   my_fiber.sleep(1000)
         > end
---
...
tarantool> my_fiber_object = my_fiber.create(function_name)
---
...
```

Module, class and method

Here is an example of documenting a module (my_box.index), a class (my_index_object) and a function (my_index_object.rename).

object my_index_object

my_index_object:rename(index-name)

Rename an index.

Parameters

- index_object – an object reference
- index_name – a new name for the index (type = string)

Return nil

Possible errors: index_object does not exist.

Example:

```
tarantool> box.space.space55.index.primary:rename('secondary')
---
...
```

Complexity Factors: Index size, Index type, Number of tuples accessed.

8.2.3 C Style Guide

The project's coding style is based on a version of the Linux kernel coding style.

The latest version of the Linux style can be found at: http://www.kernel.org/doc/Documentation/CodingStyle

Since it is open for changes, the version of style that we follow, one from 2007-July-13, will be also copied later in this document.

There are a few additional guidelines, either unique to Tarantool or deviating from the Kernel guidelines.

A. Chapters 10 "Kconfig configuration files", 11 "Data structures", 13 "Printing kernel messages", 14 "Allocating memory" and 17 "Don't re-invent the kernel macros" do not apply, since they are specific to Linux kernel programming environment.

B. The rest of Linux Kernel Coding Style is amended as follows:

General guidelines

We use Git for revision control. The latest development is happening in the default branch (currently master). Our git repository is hosted on github, and can be checked out with git clone git://github.com/tarantool/tarantool.git (anonymous read-only access).

If you have any questions about Tarantool internals, please post them on the developer discussion list, https://groups.google.com/forum/#!forum/tarantool. However, please be warned: Launchpad silently deletes posts from non-subscribed members, thus please be sure to have subscribed to the list prior to posting. Additionally, some engineers are always present on #tarantool channel on irc.freenode.net.

Commenting style

Use Doxygen comment format, Javadoc flavor, i.e. @tag rather than \tag. The main tags in use are @param, @retval, @return, @see, @note and @todo.

Every function, except perhaps a very short and obvious one, should have a comment. A sample function comment may look like below:

```
/** Write all data to a descriptor.
 *
 * This function is equivalent to 'write', except it would ensure
 * that all data is written to the file unless a non-ignorable
 * error occurs.
 *
 * @retval 0  Success
 *
 * @retval  1  An error occurred (not EINTR)
 * /
static int
write_all(int fd, void \*data, size_t len);
```

Public structures and important structure members should be commented as well.

Header files

Use header guards. Put the header guard in the first line in the header, before the copyright or declarations. Use all-uppercase name for the header guard. Derive the header guard name from the file name, and append _INCLUDED to get a macro name. For example, core/log_io.h -> CORE_LOG_IO_H_INCLUDED. In .c (implementation) file, include the respective declaration header before all other headers, to ensure that the header is self- sufficient. Header "header.h" is self-sufficient if the following compiles without errors:

```
#include "header.h"
```

Allocating memory

Prefer the supplied slab (salloc) and pool (palloc) allocators to malloc()/free() for any performance-intensive or large memory allocations. Repetitive use of malloc()/free() can lead to memory fragmentation and should therefore be avoided.

Always free all allocated memory, even allocated at start-up. We aim at being valgrind leak-check clean, and in most cases it's just as easy to free() the allocated memory as it is to write a valgrind suppression. Freeing all allocated memory is also dynamic-load friendly: assuming a plug-in can be dynamically loaded and unloaded multiple times, reload should not lead to a memory leak.

Function naming

Our convention is to use:

- new/delete for functions which allocate + initialize and destroy + deallocate an object,
- create/destroy for functions which initialize/destroy an object but do not handle memory management,
- init/free for functions which initialize/destroy libraries and subsystems.

Other

Select GNU C99 extensions are acceptable. It's OK to mix declarations and statements, use true and false.

The not-so-current list of all GCC C extensions can be found at: http://gcc.gnu.org/onlinedocs/gcc-4.3.5/gcc/C-Extensions.html

Linux kernel coding style

This is a short document describing the preferred coding style for the linux kernel. Coding style is very personal, and I won't _force_ my views on anybody, but this is what goes for anything that I have to be able to maintain, and I'd prefer it for most other things too. Please at least consider the points made here.

First off, I'd suggest printing out a copy of the GNU coding standards, and NOT read it. Burn them, it's a great symbolic gesture.

Anyway, here goes:

Chapter 1: Indentation

Tabs are 8 characters, and thus indentations are also 8 characters. There are heretic movements that try to make indentations 4 (or even 2!) characters deep, and that is akin to trying to define the value of PI to be 3.

Rationale: The whole idea behind indentation is to clearly define where a block of control starts and ends. Especially when you've been looking at your screen for 20 straight hours, you'll find it a lot easier to see how the indentation works if you have large indentations.

Now, some people will claim that having 8-character indentations makes the code move too far to the right, and makes it hard to read on a 80-character terminal screen. The answer to that is that if you need more than 3 levels of indentation, you're screwed anyway, and should fix your program.

In short, 8-char indents make things easier to read, and have the added benefit of warning you when you're nesting your functions too deep. Heed that warning.

The preferred way to ease multiple indentation levels in a switch statement is to align the "switch" and its subordinate "case" labels in the same column instead of "double-indenting" the "case" labels. e.g.:

```
switch (suffix) {
case 'G':
case 'g':
    mem <<= 30;
    break;
case 'M':
case 'm':
    mem <<= 20;
    break;
case 'K':
case 'k':
    mem <<= 10;
    /* fall through */
default:
    break;
}
```

Don't put multiple statements on a single line unless you have something to hide:

```
if (condition) do_this;
  do_something_everytime;
```

Don't put multiple assignments on a single line either. Kernel coding style is super simple. Avoid tricky expressions.

Outside of comments, documentation and except in Kconfig, spaces are never used for indentation, and the above example is deliberately broken.

Get a decent editor and don't leave whitespace at the end of lines.

Chapter 2: Breaking long lines and strings

Coding style is all about readability and maintainability using commonly available tools.

The limit on the length of lines is 80 columns, and this is a strongly preferred limit. As for comments, the same limit of 80 columns is applied.

Statements longer than 80 columns will be broken into sensible chunks. Descendants are always substantially shorter than the parent and are placed substantially to the right. The same applies to function headers with a long argument list. Long strings are as well broken into shorter strings. The only exception to this is where exceeding 80 columns significantly increases readability and does not hide information.

```
void fun(int a, int b, int c)
{
    if (condition)
        printk(KERN_WARNING "Warning this is a long printk with "
                "3 parameters a: %u b: %u "
                "c: %u \n", a, b, c);
    else
        next_statement;
}
```

Chapter 3: Placing Braces and Spaces

The other issue that always comes up in C styling is the placement of braces. Unlike the indent size, there are few technical reasons to choose one placement strategy over the other, but the preferred way, as shown to us by the prophets Kernighan and Ritchie, is to put the opening brace last on the line, and put the closing brace first, thusly:

```
if (x is true) {
    we do y
}
```

This applies to all non-function statement blocks (if, switch, for, while, do). e.g.:

```
switch (action) {
case KOBJ_ADD:
    return "add";
case KOBJ_REMOVE:
    return "remove";
case KOBJ_CHANGE:
    return "change";
default:
    return NULL;
}
```

However, there is one special case, namely functions: they have the opening brace at the beginning of the next line, thus:

```
int function(int x)
{
    body of function;
}
```

Heretic people all over the world have claimed that this inconsistency is ... well ... inconsistent, but all right-thinking people know that (a) K&R are _right_ and (b) K&R are right. Besides, functions are special anyway (you can't nest them in C).

Note that the closing brace is empty on a line of its own, _except_ in the cases where it is followed by a continuation of the same statement, ie a "while" in a do-statement or an "else" in an if-statement, like this:

```
do {
    body of do-loop;
} while (condition);
```

and

```
if (x == y) {
    ..
} else if (x > y) {
    ...
} else {
    ....
}
```

Rationale: K&R.

Also, note that this brace-placement also minimizes the number of empty (or almost empty) lines, without any loss of readability. Thus, as the supply of new-lines on your screen is not a renewable resource (think 25-line terminal screens here), you have more empty lines to put comments on.

Do not unnecessarily use braces where a single statement will do.

```
if (condition)
    action();
```

This does not apply if one branch of a conditional statement is a single statement. Use braces in both branches.

```
if (condition) {
    do_this();
    do_that();
} else {
    otherwise();
}
```

Chapter 3.1: Spaces

Linux kernel style for use of spaces depends (mostly) on function-versus-keyword usage. Use a space after (most) keywords. The notable exceptions are sizeof, typeof, alignof, and __attribute__, which look somewhat like functions (and are usually used with parentheses in Linux, although they are not required in the language, as in: "sizeof info" after "struct fileinfo info;" is declared).

So use a space after these keywords: if, switch, case, for, do, while but not with sizeof, typeof, alignof, or __attribute__. E.g.,

```
s = sizeof(struct file);
```

Do not add spaces around (inside) parenthesized expressions. This example is bad:

```
s = sizeof( struct file );
```

When declaring pointer data or a function that returns a pointer type, the preferred use of '*' is adjacent to the data name or function name and not adjacent to the type name. Examples:

```
char *linux_banner;
unsigned long long memparse(char *ptr, char **retptr);
char *match_strdup(substring_t *s);
```

Use one space around (on each side of) most binary and ternary operators, such as any of these:

> = + - < > * / % | & ^ <= >= == != ? :

but no space after unary operators:

> & * + - ~ ! sizeof typeof alignof __attribute__ defined

no space before the postfix increment & decrement unary operators:

> ++ –

no space after the prefix increment & decrement unary operators:

> ++ –

and no space around the '.' and "->" structure member operators.

Do not leave trailing whitespace at the ends of lines. Some editors with "smart" indentation will insert whitespace at the beginning of new lines as appropriate, so you can start typing the next line of code right away. However, some such editors do not remove the whitespace if you end up not putting a line of code there, such as if you leave a blank line. As a result, you end up with lines containing trailing whitespace.

Git will warn you about patches that introduce trailing whitespace, and can optionally strip the trailing whitespace for you; however, if applying a series of patches, this may make later patches in the series fail by changing their context lines.

Chapter 4: Naming

C is a Spartan language, and so should your naming be. Unlike Modula-2 and Pascal programmers, C programmers do not use cute names like ThisVariableIsATemporaryCounter. A C programmer would call that variable "tmp", which is much easier to write, and not the least more difficult to understand.

HOWEVER, while mixed-case names are frowned upon, descriptive names for global variables are a must. To call a global function "foo" is a shooting offense.

GLOBAL variables (to be used only if you _really_ need them) need to have descriptive names, as do global functions. If you have a function that counts the number of active users, you should call that "count_active_users()" or similar, you should _not_ call it "cntusr()".

Encoding the type of a function into the name (so-called Hungarian notation) is brain damaged - the compiler knows the types anyway and can check those, and it only confuses the programmer. No wonder MicroSoft makes buggy programs.

LOCAL variable names should be short, and to the point. If you have some random integer loop counter, it should probably be called "i". Calling it "loop_counter" is non-productive, if there is no chance of it being mis-understood. Similarly, "tmp" can be just about any type of variable that is used to hold a temporary value.

If you are afraid to mix up your local variable names, you have another problem, which is called the function-growth-hormone-imbalance syndrome. See chapter 6 (Functions).

Chapter 5: Typedefs

Please don't use things like "vps_t".

It's a _mistake_ to use typedef for structures and pointers. When you see a

```
vps_t a;
```

in the source, what does it mean?

In contrast, if it says

```
struct virtual_container *a;
```

you can actually tell what "a" is.

Lots of people think that typedefs "help readability". Not so. They are useful only for:

(a) totally opaque objects (where the typedef is actively used to _hide_ what the object is).

  Example: "pte_t" etc. opaque objects that you can only access using the proper accessor functions.

  NOTE! Opaqueness and "accessor functions" are not good in themselves. The reason we have them for things like pte_t etc. is that there really is absolutely _zero_ portably accessible information there.

(b) Clear integer types, where the abstraction _helps_ avoid confusion whether it is "int" or "long".

  u8/u16/u32 are perfectly fine typedefs, although they fit into category (d) better than here.

  NOTE! Again - there needs to be a _reason_ for this. If something is "unsigned long", then there's no reason to do

  ```
  typedef unsigned long myflags_t;
  ```

  but if there is a clear reason for why it under certain circumstances might be an "unsigned int" and under other configurations might be "unsigned long", then by all means go ahead and use a typedef.

(c) when you use sparse to literally create a _new_ type for type-checking.

(d) New types which are identical to standard C99 types, in certain exceptional circumstances.

  Although it would only take a short amount of time for the eyes and brain to become accustomed to the standard types like 'uint32_t', some people object to their use anyway.

  Therefore, the Linux-specific 'u8/u16/u32/u64' types and their signed equivalents which are identical to standard types are permitted – although they are not mandatory in new code of your own.

  When editing existing code which already uses one or the other set of types, you should conform to the existing choices in that code.

(e) Types safe for use in userspace.

  In certain structures which are visible to userspace, we cannot require C99 types and cannot use the 'u32' form above. Thus, we use __u32 and similar types in all structures which are shared with userspace.

Maybe there are other cases too, but the rule should basically be to NEVER EVER use a typedef unless you can clearly match one of those rules.

In general, a pointer, or a struct that has elements that can reasonably be directly accessed should never be a typedef.

Chapter 6: Functions

Functions should be short and sweet, and do just one thing. They should fit on one or two screenfuls of text (the ISO/ANSI screen size is 80x24, as we all know), and do one thing and do that well.

The maximum length of a function is inversely proportional to the complexity and indentation level of that function. So, if you have a conceptually simple function that is just one long (but simple) case-statement, where you have to do lots of small things for a lot of different cases, it's OK to have a longer function.

However, if you have a complex function, and you suspect that a less-than-gifted first-year high-school student might not even understand what the function is all about, you should adhere to the maximum limits all the more closely. Use helper functions with descriptive names (you can ask the compiler to in-line them if you think it's performance-critical, and it will probably do a better job of it than you would have done).

Another measure of the function is the number of local variables. They shouldn't exceed 5-10, or you're doing something wrong. Re-think the function, and split it into smaller pieces. A human brain can generally easily keep track of about 7 different things, anything more and it gets confu/sed. You know you're brilliant, but maybe you'd like to understand what you did 2 weeks from now.

In source files, separate functions with one blank line. If the function is exported, the EXPORT* macro for it should follow immediately after the closing function brace line. E.g.:

```
int system_is_up(void)
{
    return system_state == SYSTEM_RUNNING;
}
EXPORT_SYMBOL(system_is_up);
```

In function prototypes, include parameter names with their data types. Although this is not required by the C language, it is preferred in Linux because it is a simple way to add valuable information for the reader.

Chapter 7: Centralized exiting of functions

Albeit deprecated by some people, the equivalent of the goto statement is used frequently by compilers in form of the unconditional jump instruction.

The goto statement comes in handy when a function exits from multiple locations and some common work such as cleanup has to be done.

The rationale is:

- unconditional statements are easier to understand and follow
- nesting is reduced
- errors by not updating individual exit points when making modifications are prevented
- saves the compiler work to optimize redundant code away ;)

```
int fun(int a)
{
    int result = 0;
    char *buffer = kmalloc(SIZE);

    if (buffer == NULL)
        return -ENOMEM;

    if (condition1) {
        while (loop1) {
            ...
        }
        result = 1;
        goto out;
    }
```

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```
    ...
out:
    kfree(buffer);
    return result;
}
```

Chapter 8: Commenting

Comments are good, but there is also a danger of over-commenting. NEVER try to explain HOW your code works in a comment: it's much better to write the code so that the _working_ is obvious, and it's a waste of time to explain badly written code. c Generally, you want your comments to tell WHAT your code does, not HOW. Also, try to avoid putting comments inside a function body: if the function is so complex that you need to separately comment parts of it, you should probably go back to chapter 6 for a while. You can make small comments to note or warn about something particularly clever (or ugly), but try to avoid excess. Instead, put the comments at the head of the function, telling people what it does, and possibly WHY it does it.

When commenting the kernel API functions, please use the kernel-doc format. See the files Documentation/kernel-doc-nano-HOWTO.txt and scripts/kernel-doc for details.

Linux style for comments is the C89 /* ... */` style. Don't use C99-style // ... comments.

The preferred style for long (multi-line) comments is:

```
/*
 * This is the preferred style for multi-line
 * comments in the Linux kernel source code.
 * Please use it consistently.
 *
 * Description:  A column of asterisks on the left side,
 * with beginning and ending almost-blank lines.
 */
```

It's also important to comment data, whether they are basic types or derived types. To this end, use just one data declaration per line (no commas for multiple data declarations). This leaves you room for a small comment on each item, explaining its use.

Chapter 9: You've made a mess of it

That's OK, we all do. You've probably been told by your long-time Unix user helper that "GNU emacs" automatically formats the C sources for you, and you've noticed that yes, it does do that, but the defaults it uses are less than desirable (in fact, they are worse than random typing - an infinite number of monkeys typing into GNU emacs would never make a good program).

So, you can either get rid of GNU emacs, or change it to use saner values. To do the latter, you can stick the following in your .emacs file:

```
(defun c-lineup-arglist-tabs-only (ignored)
"Line up argument lists by tabs, not spaces"
(let* ((anchor (c-langelem-pos c-syntactic-element))
    (column (c-langelem-2nd-pos c-syntactic-element))
    (offset (- (1+ column) anchor))
    (steps (floor offset c-basic-offset)))
```

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```
    (* (max steps 1)
    c-basic-offset)))

(add-hook 'c-mode-common-hook
        (lambda ()
            ;; Add kernel style
            (c-add-style
            "linux-tabs-only"
            '("linux" (c-offsets-alist
                        (arglist-cont-nonempty
                        c-lineup-gcc-asm-reg
                        c-lineup-arglist-tabs-only))))))

(add-hook 'c-mode-hook
        (lambda ()
            (let ((filename (buffer-file-name)))
            ;; Enable kernel mode for the appropriate files
            (when (and filename
                        (string-match (expand-file-name "~/src/linux-trees")
                                    filename))
                (setq indent-tabs-mode t)
                (c-set-style "linux-tabs-only")))))
```

This will make emacs go better with the kernel coding style for C files below ~/src/linux-trees.

But even if you fail in getting emacs to do sane formatting, not everything is lost: use "indent".

Now, again, GNU indent has the same brain-dead settings that GNU emacs has, which is why you need to give it a few command line options. However, that's not too bad, because even the makers of GNU indent recognize the authority of K&R (the GNU people aren't evil, they are just severely misguided in this matter), so you just give indent the options "-kr -i8" (stands for "K&R, 8 character indents"), or use "scripts/Lindent", which indents in the latest style.

"indent" has a lot of options, and especially when it comes to comment re-formatting you may want to take a look at the man page. But remember: "indent" is not a fix for bad programming.

Chapter 10: Kconfig configuration files

For all of the Kconfig* configuration files throughout the source tree, the indentation is somewhat different. Lines under a "config" definition are indented with one tab, while help text is indented an additional two spaces. Example:

```
config AUDIT
    bool "Auditing support"
    depends on NET
    help
    Enable auditing infrastructure that can be used with another
    kernel subsystem, such as SELinux (which requires this for
    logging of avc messages output).  Does not do system-call
    auditing without CONFIG_AUDITSYSCALL.
```

Features that might still be considered unstable should be defined as dependent on "EXPERIMENTAL":

```
config SLUB
    depends on EXPERIMENTAL && !ARCH_USES_SLAB_PAGE_STRUCT
```

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```
    bool "SLUB (Unqueued Allocator)"
    ...
```

while seriously dangerous features (such as write support for certain filesystems) should advertise this prominently in their prompt string:

```
config ADFS_FS_RW
    bool "ADFS write support (DANGEROUS)"
    depends on ADFS_FS
    ...
```

For full documentation on the configuration files, see the file Documentation/kbuild/kconfig-language.txt.

Chapter 11: Data structures

Data structures that have visibility outside the single-threaded environment they are created and destroyed in should always have reference counts. In the kernel, garbage collection doesn't exist (and outside the kernel garbage collection is slow and inefficient), which means that you absolutely _have_ to reference count all your uses.

Reference counting means that you can avoid locking, and allows multiple users to have access to the data structure in parallel - and not having to worry about the structure suddenly going away from under them just because they slept or did something else for a while.

Note that locking is _not_ a replacement for reference counting. Locking is used to keep data structures coherent, while reference counting is a memory management technique. Usually both are needed, and they are not to be confused with each other.

Many data structures can indeed have two levels of reference counting, when there are users of different "classes". The subclass count counts the number of subclass users, and decrements the global count just once when the subclass count goes to zero.

Examples of this kind of "multi-level-reference-counting" can be found in memory management ("struct mm_struct": mm_users and mm_count), and in filesystem code ("struct super_block": s_count and s_active).

Remember: if another thread can find your data structure, and you don't have a reference count on it, you almost certainly have a bug.

Chapter 12: Macros, Enums and RTL

Names of macros defining constants and labels in enums are capitalized.

```
#define CONSTANT 0x12345
```

Enums are preferred when defining several related constants.

CAPITALIZED macro names are appreciated but macros resembling functions may be named in lower case.

Generally, inline functions are preferable to macros resembling functions.

Macros with multiple statements should be enclosed in a do - while block:

```
#define macrofun(a, b, c)   \
    do {                    \
        if (a == 5)         \
            do_this(b, c);  \
    } while (0)
```

Things to avoid when using macros:

1. macros that affect control flow:

   ```
   #define FOO(x)                  \
       do {                        \
           if (blah(x) < 0)        \
               return -EBUGGERED;  \
       } while(0)
   ```

   is a _very_ bad idea. It looks like a function call but exits the "calling" function; don't break the internal parsers of those who will read the code.

2. macros that depend on having a local variable with a magic name:

   ```
   #define FOO(val) bar(index, val)
   ```

   might look like a good thing, but it's confusing as hell when one reads the code and it's prone to breakage from seemingly innocent changes.

3. macros with arguments that are used as l-values: FOO(x) = y; will bite you if somebody e.g. turns FOO into an inline function.

4. forgetting about precedence: macros defining constants using expressions must enclose the expression in parentheses. Beware of similar issues with macros using parameters.

   ```
   #define CONSTANT 0x4000
   #define CONSTEXP (CONSTANT | 3)
   ```

   The cpp manual deals with macros exhaustively. The gcc internals manual also covers RTL which is used frequently with assembly language in the kernel.

Chapter 13: Printing kernel messages

Kernel developers like to be seen as literate. Do mind the spelling of kernel messages to make a good impression. Do not use crippled words like "dont"; use "do not" or "don't" instead. Make the messages concise, clear, and unambiguous.

Kernel messages do not have to be terminated with a period.

Printing numbers in parentheses (%d) adds no value and should be avoided.

There are a number of driver model diagnostic macros in <linux/device.h> which you should use to make sure messages are matched to the right device and driver, and are tagged with the right level: dev_err(), dev_warn(), dev_info(), and so forth. For messages that aren't associated with a particular device, <linux/kernel.h> defines pr_debug() and pr_info().

Coming up with good debugging messages can be quite a challenge; and once you have them, they can be a huge help for remote troubleshooting. Such messages should be compiled out when the DEBUG symbol is not defined (that is, by default they are not included). When you use dev_dbg() or pr_debug(), that's automatic. Many subsystems have Kconfig options to turn on -DDEBUG. A related convention uses VERBOSE_DEBUG to add dev_vdbg() messages to the ones already enabled by DEBUG.

Chapter 14: Allocating memory

The kernel provides the following general purpose memory allocators: kmalloc(), kzalloc(), kcalloc(), and vmalloc(). Please refer to the API documentation for further information about them.

The preferred form for passing a size of a struct is the following:

```
p = kmalloc(sizeof(*p), ...);
```

The alternative form where struct name is spelled out hurts readability and introduces an opportunity for a bug when the pointer variable type is changed but the corresponding sizeof that is passed to a memory allocator is not.

Casting the return value which is a void pointer is redundant. The conversion from void pointer to any other pointer type is guaranteed by the C programming language.

Chapter 15: The inline disease

There appears to be a common misperception that gcc has a magic “make me faster” speedup option called “inline”. While the use of inlines can be appropriate (for example as a means of replacing macros, see Chapter 12), it very often is not. Abundant use of the inline keyword leads to a much bigger kernel, which in turn slows the system as a whole down, due to a bigger icache footprint for the CPU and simply because there is less memory available for the pagecache. Just think about it; a pagecache miss causes a disk seek, which easily takes 5 milliseconds. There are a LOT of cpu cycles that can go into these 5 milliseconds.

A reasonable rule of thumb is to not put inline at functions that have more than 3 lines of code in them. An exception to this rule are the cases where a parameter is known to be a compiletime constant, and as a result of this constantness you know the compiler will be able to optimize most of your function away at compile time. For a good example of this later case, see the kmalloc() inline function.

Often people argue that adding inline to functions that are static and used only once is always a win since there is no space tradeoff. While this is technically correct, gcc is capable of inlining these automatically without help, and the maintenance issue of removing the inline when a second user appears outweighs the potential value of the hint that tells gcc to do something it would have done anyway.

Chapter 16: Function return values and names

Functions can return values of many different kinds, and one of the most common is a value indicating whether the function succeeded or failed. Such a value can be represented as an error-code integer (-Exxx = failure, 0 = success) or a “succeeded” boolean (0 = failure, non-zero = success).

Mixing up these two sorts of representations is a fertile source of difficult-to-find bugs. If the C language included a strong distinction between integers and booleans then the compiler would find these mistakes for us… but it doesn’t. To help prevent such bugs, always follow this convention:

```
If the name of a function is an action or an imperative command,
the function should return an error-code integer.  If the name
is a predicate, the function should return a "succeeded" boolean.
```

For example, “add work” is a command, and the add_work() function returns 0 for success or -EBUSY for failure. In the same way, “PCI device present” is a predicate, and the pci_dev_present() function returns 1 if it succeeds in finding a matching device or 0 if it doesn’t.

All EXPORTed functions must respect this convention, and so should all public functions. Private (static) functions need not, but it is recommended that they do.

Functions whose return value is the actual result of a computation, rather than an indication of whether the computation succeeded, are not subject to this rule. Generally they indicate failure by returning some out-of-range result. Typical examples would be functions that return pointers; they use NULL or the ERR_PTR mechanism to report failure.

Chapter 17: Don't re-invent the kernel macros

The header file include/linux/kernel.h contains a number of macros that you should use, rather than explicitly coding some variant of them yourself. For example, if you need to calculate the length of an array, take advantage of the macro

```
#define ARRAY_SIZE(x) (sizeof(x) / sizeof((x)[0]))
```

Similarly, if you need to calculate the size of some structure member, use

```
#define FIELD_SIZEOF(t, f) (sizeof(((t*)0)->f))
```

There are also min() and max() macros that do strict type checking if you need them. Feel free to peruse that header file to see what else is already defined that you shouldn't reproduce in your code.

Chapter 18: Editor modelines and other cruft

Some editors can interpret configuration information embedded in source files, indicated with special markers. For example, emacs interprets lines marked like this:

```
-*- mode: c -*-
```

Or like this:

```
/*
Local Variables:
compile-command: "gcc -DMAGIC_DEBUG_FLAG foo.c"
End:
*/
```

Vim interprets markers that look like this:

```
/* vim:set sw=8 noet */
```

Do not include any of these in source files. People have their own personal editor configurations, and your source files should not override them. This includes markers for indentation and mode configuration. People may use their own custom mode, or may have some other magic method for making indentation work correctly.

Appendix I: References

- The C Programming Language, Second Edition by Brian W. Kernighan and Dennis M. Ritchie. Prentice Hall, Inc., 1988. ISBN 0-13-110362-8 (paperback), 0-13-110370-9 (hardback).
- The Practice of Programming by Brian W. Kernighan and Rob Pike. Addison-Wesley, Inc., 1999. ISBN 0-201-61586-X.
- GNU manuals - where in compliance with K&R and this text - for cpp, gcc, gcc internals and indent

- WG14 International standardization workgroup for the programming language C
- Kernel CodingStyle, by greg@kroah.com at OLS 2002

8.2.4 Python Style Guide

Introduction

This document gives coding conventions for the Python code comprising the standard library in the main Python distribution. Please see the companion informational PEP describing style guidelines for the C code in the C implementation of Python[1].

This document and PEP 257 (Docstring Conventions) were adapted from Guido's original Python Style Guide essay, with some additions from Barry's style guide[2].

A Foolish Consistency is the Hobgoblin of Little Minds

One of Guido's key insights is that code is read much more often than it is written. The guidelines provided here are intended to improve the readability of code and make it consistent across the wide spectrum of Python code. As PEP 20 says, "Readability counts".

A style guide is about consistency. Consistency with this style guide is important. Consistency within a project is more important. Consistency within one module or function is the most important.

But most importantly: know when to be inconsistent – sometimes the style guide just doesn't apply. When in doubt, use your best judgment. Look at other examples and decide what looks best. And don't hesitate to ask!

Two good reasons to break a particular rule:

1. When applying the rule would make the code less readable, even for someone who is used to reading code that follows the rules.
2. To be consistent with surrounding code that also breaks it (maybe for historic reasons) – although this is also an opportunity to clean up someone else's mess (in true XP style).

Code lay-out

Indentation

Use 4 spaces per indentation level.

For really old code that you don't want to mess up, you can continue to use 8-space tabs.

Continuation lines should align wrapped elements either vertically using Python's implicit line joining inside parentheses, brackets and braces, or using a hanging indent. When using a hanging indent the following considerations should be applied; there should be no arguments on the first line and further indentation should be used to clearly distinguish itself as a continuation line.

Yes:

[1] PEP 7, Style Guide for C Code, van Rossum
[2] Barry's GNU Mailman style guide

```
# Aligned with opening delimiter
foo = long_function_name(var_one, var_two,
                         var_three, var_four)

# More indentation included to distinguish this from the rest.
def long_function_name(
        var_one, var_two, var_three,
        var_four):
    print(var_one)
```

No:

```
# Arguments on first line forbidden when not using vertical alignment
foo = long_function_name(var_one, var_two,
    var_three, var_four)

# Further indentation required as indentation is not distinguishable
def long_function_name(
    var_one, var_two, var_three,
    var_four):
    print(var_one)
```

Optional:

```
# Extra indentation is not necessary.
foo = long_function_name(
  var_one, var_two,
  var_three, var_four)
```

The closing brace/bracket/parenthesis on multi-line constructs may either line up under the first non-whitespace character of the last line of list, as in:

```
my_list = [
    1, 2, 3,
    4, 5, 6,
    ]
result = some_function_that_takes_arguments(
    'a', 'b', 'c',
    'd', 'e', 'f',
    )
```

or it may be lined up under the first character of the line that starts the multi-line construct, as in:

```
my_list = [
    1, 2, 3,
    4, 5, 6,
]
result = some_function_that_takes_arguments(
    'a', 'b', 'c',
    'd', 'e', 'f',
)
```

Tabs or Spaces?

Never mix tabs and spaces.

The most popular way of indenting Python is with spaces only. The second-most popular way is with tabs only. Code indented with a mixture of tabs and spaces should be converted to using spaces exclusively. When invoking the Python command line interpreter with the -t option, it issues warnings about code that illegally mixes tabs and spaces. When using -tt these warnings become errors. These options are highly recommended!

For new projects, spaces-only are strongly recommended over tabs. Most editors have features that make this easy to do.

Maximum Line Length

Limit all lines to a maximum of 79 characters.

There are still many devices around that are limited to 80 character lines; plus, limiting windows to 80 characters makes it possible to have several windows side-by-side. The default wrapping on such devices disrupts the visual structure of the code, making it more difficult to understand. Therefore, please limit all lines to a maximum of 79 characters. For flowing long blocks of text (docstrings or comments), limiting the length to 72 characters is recommended.

The preferred way of wrapping long lines is by using Python's implied line continuation inside parentheses, brackets and braces. Long lines can be broken over multiple lines by wrapping expressions in parentheses. These should be used in preference to using a backslash for line continuation.

Backslashes may still be appropriate at times. For example, long, multiple with-statements cannot use implicit continuation, so backslashes are acceptable:

```
with open('/path/to/some/file/you/want/to/read') as file_1, \
        open('/path/to/some/file/being/written', 'w') as file_2:
    file_2.write(file_1.read())
```

Another such case is with assert statements.

Make sure to indent the continued line appropriately. The preferred place to break around a binary operator is after the operator, not before it. Some examples:

```
class Rectangle(Blob):

    def __init__(self, width, height,
                 color='black', emphasis=None, highlight=0):
        if (width == 0 and height == 0 and
            color == 'red' and emphasis == 'strong' or
            highlight > 100):
            raise ValueError("sorry, you lose")
        if width == 0 and height == 0 and (color == 'red' or
                                           emphasis is None):
            raise ValueError("I don't think so -- values are %s, %s" %
                             (width, height))
        Blob.__init__(self, width, height,
                      color, emphasis, highlight)
```

Blank Lines

Separate top-level function and class definitions with two blank lines.

Method definitions inside a class are separated by a single blank line.

Extra blank lines may be used (sparingly) to separate groups of related functions. Blank lines may be omitted between a bunch of related one-liners (e.g. a set of dummy implementations).

Use blank lines in functions, sparingly, to indicate logical sections.

Python accepts the control-L (i.e. ^L) form feed character as whitespace; Many tools treat these characters as page separators, so you may use them to separate pages of related sections of your file. Note, some editors and web-based code viewers may not recognize control-L as a form feed and will show another glyph in its place.

Encodings (PEP 263)

Code in the core Python distribution should always use the ASCII or Latin-1 encoding (a.k.a. ISO-8859-1). For Python 3.0 and beyond, UTF-8 is preferred over Latin-1, see PEP 3120.

Files using ASCII should not have a coding cookie. Latin-1 (or UTF-8) should only be used when a comment or docstring needs to mention an author name that requires Latin-1; otherwise, using \x, \u or \U escapes is the preferred way to include non-ASCII data in string literals.

For Python 3.0 and beyond, the following policy is prescribed for the standard library (see PEP 3131): All identifiers in the Python standard library MUST use ASCII-only identifiers, and SHOULD use English words wherever feasible (in many cases, abbreviations and technical terms are used which aren't English). In addition, string literals and comments must also be in ASCII. The only exceptions are (a) test cases testing the non-ASCII features, and (b) names of authors. Authors whose names are not based on the latin alphabet MUST provide a latin transliteration of their names.

Open source projects with a global audience are encouraged to adopt a similar policy.

Imports

- Imports should usually be on separate lines, e.g.:

  ```
  Yes: import os
       import sys

  No:  import sys, os
  ```

  It's okay to say this though:

  ```
  from subprocess import Popen, PIPE
  ```

- Imports are always put at the top of the file, just after any module comments and docstrings, and before module globals and constants.

  Imports should be grouped in the following order:

  1. standard library imports
  2. related third party imports
  3. local application/library specific imports

  You should put a blank line between each group of imports.

  Put any relevant `__all__` specification after the imports.

- Relative imports for intra-package imports are highly discouraged. Always use the absolute package path for all imports. Even now that PEP 328 is fully implemented in Python 2.5, its style of explicit relative imports is actively discouraged; absolute imports are more portable and usually more readable.

- When importing a class from a class-containing module, it's usually okay to spell this:

  ```
  from myclass import MyClass
  from foo.bar.yourclass import YourClass
  ```

  If this spelling causes local name clashes, then spell them

  ```
  import myclass
  import foo.bar.yourclass
  ```

  and use "myclass.MyClass" and "foo.bar.yourclass.YourClass".

Whitespace in Expressions and Statements

Pet Peeves

Avoid extraneous whitespace in the following situations:

- Immediately inside parentheses, brackets or braces.

  ```
  Yes: spam(ham[1], {eggs: 2})
  No:  spam( ham[ 1 ], { eggs: 2 } )
  ```

- Immediately before a comma, semicolon, or colon:

  ```
  Yes: if x == 4: print x, y; x, y = y, x
  No:  if x == 4 : print x , y ; x , y = y , x
  ```

- Immediately before the open parenthesis that starts the argument list of a function call:

  ```
  Yes: spam(1)
  No:  spam (1)
  ```

- Immediately before the open parenthesis that starts an indexing or slicing:

  ```
  Yes: dict['key'] = list[index]
  No:  dict ['key'] = list [index]
  ```

- More than one space around an assignment (or other) operator to align it with another.

  Yes:

  ```
  x = 1
  y = 2
  long_variable = 3
  ```

  No:

  ```
  x             = 1
  y             = 2
  long_variable = 3
  ```

Other Recommendations

- Always surround these binary operators with a single space on either side: assignment (=), augmented assignment (+=, -= etc.), comparisons (==, <, >, !=, <>, <=, >=, in, not in, is, is not), Booleans (and, or, not).

- If operators with different priorities are used, consider adding whitespace around the operators with the lowest priority(ies). Use your own judgement; however, never use more than one space, and always have the same amount of whitespace on both sides of a binary operator.

  Yes:

```
i = i + 1
submitted += 1
x = x*2 - 1
hypot2 = x*x + y*y
c = (a+b) * (a-b)
```

  No:

```
i=i+1
submitted +=1
x = x * 2 - 1
hypot2 = x * x + y * y
c = (a + b) * (a - b)
```

- Don't use spaces around the = sign when used to indicate a keyword argument or a default parameter value.

  Yes:

```
def complex(real, imag=0.0):
    return magic(r=real, i=imag)
```

  No:

```
def complex(real, imag = 0.0):
    return magic(r = real, i = imag)
```

- Compound statements (multiple statements on the same line) are generally discouraged.

  Yes:

```
if foo == 'blah':
    do_blah_thing()
do_one()
do_two()
do_three()
```

  Rather not:

```
if foo == 'blah': do_blah_thing()
do_one(); do_two(); do_three()
```

- While sometimes it's okay to put an if/for/while with a small body on the same line, never do this for multi-clause statements. Also avoid folding such long lines!

  Rather not:

```
if foo == 'blah': do_blah_thing()
for x in lst: total += x
while t < 10: t = delay()
```

  Definitely not:

```
if foo == 'blah': do_blah_thing()
else: do_non_blah_thing()

try: something()
finally: cleanup()

do_one(); do_two(); do_three(long, argument,
                             list, like, this)

if foo == 'blah': one(); two(); three()
```

Comments

Comments that contradict the code are worse than no comments. Always make a priority of keeping the comments up-to-date when the code changes!

Comments should be complete sentences. If a comment is a phrase or sentence, its first word should be capitalized, unless it is an identifier that begins with a lower case letter (never alter the case of identifiers!).

If a comment is short, the period at the end can be omitted. Block comments generally consist of one or more paragraphs built out of complete sentences, and each sentence should end in a period.

You should use two spaces after a sentence-ending period.

When writing English, Strunk and White apply.

Python coders from non-English speaking countries: please write your comments in English, unless you are 120% sure that the code will never be read by people who don't speak your language.

Block Comments

Block comments generally apply to some (or all) code that follows them, and are indented to the same level as that code. Each line of a block comment starts with a # and a single space (unless it is indented text inside the comment).

Paragraphs inside a block comment are separated by a line containing a single #.

Inline Comments

Use inline comments sparingly.

An inline comment is a comment on the same line as a statement. Inline comments should be separated by at least two spaces from the statement. They should start with a # and a single space.

Inline comments are unnecessary and in fact distracting if they state the obvious. Don't do this:

```
x = x + 1                 # Increment x
```

But sometimes, this is useful:

```
x = x + 1                 # Compensate for border
```

Documentation Strings

Conventions for writing good documentation strings (a.k.a. "docstrings") are immortalized in PEP 257.

- Write docstrings for all public modules, functions, classes, and methods. Docstrings are not necessary for non-public methods, but you should have a comment that describes what the method does. This comment should appear after the def line.
- PEP 257 describes good docstring conventions. Note that most importantly, the """ that ends a multiline docstring should be on a line by itself, and preferably preceded by a blank line, e.g.:

  ```
  """Return a foobang

  Optional plotz says to frobnicate the bizbaz first.

  """
  ```

- For one liner docstrings, it's okay to keep the closing """ on the same line.

Version Bookkeeping

If you have to have Subversion, CVS, or RCS crud in your source file, do it as follows.

```
__version__ = "$Revision$"
# $Source$
```

These lines should be included after the module's docstring, before any other code, separated by a blank line above and below.

Naming Conventions

The naming conventions of Python's library are a bit of a mess, so we'll never get this completely consistent – nevertheless, here are the currently recommended naming standards. New modules and packages (including third party frameworks) should be written to these standards, but where an existing library has a different style, internal consistency is preferred.

Descriptive: Naming Styles

There are a lot of different naming styles. It helps to be able to recognize what naming style is being used, independently from what they are used for.

The following naming styles are commonly distinguished:

- b (single lowercase letter)
- B (single uppercase letter)
- lowercase
- lower_case_with_underscores
- UPPERCASE
- UPPER_CASE_WITH_UNDERSCORES

- CapitalizedWords (or CapWords, or CamelCase – so named because of the bumpy look of its letters[3]). This is also sometimes known as StudlyCaps.

  Note: When using abbreviations in CapWords, capitalize all the letters of the abbreviation. Thus HTTPServerError is better than HttpServerError.

- mixedCase (differs from CapitalizedWords by initial lowercase character!)
- Capitalized_Words_With_Underscores (ugly!)

There's also the style of using a short unique prefix to group related names together. This is not used much in Python, but it is mentioned for completeness. For example, the os.stat() function returns a tuple whose items traditionally have names like st_mode, st_size, st_mtime and so on. (This is done to emphasize the correspondence with the fields of the POSIX system call struct, which helps programmers familiar with that.)

The X11 library uses a leading X for all its public functions. In Python, this style is generally deemed unnecessary because attribute and method names are prefixed with an object, and function names are prefixed with a module name.

In addition, the following special forms using leading or trailing underscores are recognized (these can generally be combined with any case convention):

- _single_leading_underscore: weak "internal use" indicator. E.g. from M import * does not import objects whose name starts with an underscore.
- single_trailing_underscore_: used by convention to avoid conflicts with Python keyword, e.g.

```
Tkinter.Toplevel(master, class_='ClassName')
```

- __double_leading_underscore: when naming a class attribute, invokes name mangling (inside class FooBar, __boo becomes _FooBar__boo; see below).
- __double_leading_and_trailing_underscore__: "magic" objects or attributes that live in user-controlled namespaces. E.g. __init__, __import__ or __file__. Never invent such names; only use them as documented.

Prescriptive: Naming Conventions

Names to Avoid

Never use the characters 'l' (lowercase letter el), 'O' (uppercase letter oh), or 'I' (uppercase letter eye) as single character variable names.

In some fonts, these characters are indistinguishable from the numerals one and zero. When tempted to use 'l', use 'L' instead.

Package and Module Names

Modules should have short, all-lowercase names. Underscores can be used in the module name if it improves readability. Python packages should also have short, all-lowercase names, although the use of underscores is discouraged.

Since module names are mapped to file names, and some file systems are case insensitive and truncate long names, it is important that module names be chosen to be fairly short – this won't be a problem on Unix, but it may be a problem when the code is transported to older Mac or Windows versions, or DOS.

[3] CamelCase Wikipedia page

When an extension module written in C or C++ has an accompanying Python module that provides a higher level (e.g. more object oriented) interface, the C/C++ module has a leading underscore (e.g. _socket).

Class Names

Almost without exception, class names use the CapWords convention. Classes for internal use have a leading underscore in addition.

Exception Names

Because exceptions should be classes, the class naming convention applies here. However, you should use the suffix "Error" on your exception names (if the exception actually is an error).

Global Variable Names

(Let's hope that these variables are meant for use inside one module only.) The conventions are about the same as those for functions.

Modules that are designed for use via from M import * should use the __all__ mechanism to prevent exporting globals, or use the older convention of prefixing such globals with an underscore (which you might want to do to indicate these globals are "module non-public").

Function Names

Function names should be lowercase, with words separated by underscores as necessary to improve readability.

mixedCase is allowed only in contexts where that's already the prevailing style (e.g. threading.py), to retain backwards compatibility.

Function and method arguments

Always use self for the first argument to instance methods.

Always use cls for the first argument to class methods.

If a function argument's name clashes with a reserved keyword, it is generally better to append a single trailing underscore rather than use an abbreviation or spelling corruption. Thus class_ is better than clss. (Perhaps better is to avoid such clashes by using a synonym.)

Method Names and Instance Variables

Use the function naming rules: lowercase with words separated by underscores as necessary to improve readability.

Use one leading underscore only for non-public methods and instance variables.

To avoid name clashes with subclasses, use two leading underscores to invoke Python's name mangling rules.

Python mangles these names with the class name: if class Foo has an attribute named __a, it cannot be accessed by Foo.__a. (An insistent user could still gain access by calling Foo._Foo__a.) Generally, double leading underscores should be used only to avoid name conflicts with attributes in classes designed to be subclassed.

Note: there is some controversy about the use of __names (see below).

Constants

Constants are usually defined on a module level and written in all capital letters with underscores separating words. Examples include MAX_OVERFLOW and TOTAL.

Designing for inheritance

Always decide whether a class's methods and instance variables (collectively: "attributes") should be public or non-public. If in doubt, choose non-public; it's easier to make it public later than to make a public attribute non-public.

Public attributes are those that you expect unrelated clients of your class to use, with your commitment to avoid backward incompatible changes. Non-public attributes are those that are not intended to be used by third parties; you make no guarantees that non-public attributes won't change or even be removed.

We don't use the term "private" here, since no attribute is really private in Python (without a generally unnecessary amount of work).

Another category of attributes are those that are part of the "subclass API" (often called "protected" in other languages). Some classes are designed to be inherited from, either to extend or modify aspects of the class's behavior. When designing such a class, take care to make explicit decisions about which attributes are public, which are part of the subclass API, and which are truly only to be used by your base class.

With this in mind, here are the Pythonic guidelines:

- Public attributes should have no leading underscores.
- If your public attribute name collides with a reserved keyword, append a single trailing underscore to your attribute name. This is preferable to an abbreviation or corrupted spelling. (However, not withstanding this rule, 'cls' is the preferred spelling for any variable or argument which is known to be a class, especially the first argument to a class method.)

  Note 1: See the argument name recommendation above for class methods.
- For simple public data attributes, it is best to expose just the attribute name, without complicated accessor/mutator methods. Keep in mind that Python provides an easy path to future enhancement, should you find that a simple data attribute needs to grow functional behavior. In that case, use properties to hide functional implementation behind simple data attribute access syntax.

  Note 1: Properties only work on new-style classes.

  Note 2: Try to keep the functional behavior side-effect free, although side-effects such as caching are generally fine.

  Note 3: Avoid using properties for computationally expensive operations; the attribute notation makes the caller believe that access is (relatively) cheap.
- If your class is intended to be subclassed, and you have attributes that you do not want subclasses to use, consider naming them with double leading underscores and no trailing underscores. This invokes Python's name mangling algorithm, where the name of the class is mangled into the attribute name. This helps avoid attribute name collisions should subclasses inadvertently contain attributes with the same name.

  Note 1: Note that only the simple class name is used in the mangled name, so if a subclass chooses both the same class name and attribute name, you can still get name collisions.

Note 2: Name mangling can make certain uses, such as debugging and __getattr__(), less convenient. However the name mangling algorithm is well documented and easy to perform manually.

Note 3: Not everyone likes name mangling. Try to balance the need to avoid accidental name clashes with potential use by advanced callers.

References

Copyright

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8.2.5 Lua Style Guide

Inspiration:

- https://github.com/Olivine-Labs/lua-style-guide
- http://dev.minetest.net/Lua_code_style_guidelines
- http://sputnik.freewisdom.org/en/Coding_Standard

Programming style is an art. There is some arbitrariness to the rules, but there are sound rationales for them. It is useful not only to provide sound advice on style but to understand the underlying rationale and human aspect of why the style recommendations are formed:

- http://mindprod.com/jgloss/unmain.html
- http://www.oreilly.com/catalog/perlbp/
- http://books.google.com/books?id=QnghAQAAIAAJ

Zen of Python is good; understand it and use wisely:

> Beautiful is better than ugly.
> Explicit is better than implicit.
> Simple is better than complex.
> Complex is better than complicated.
> Flat is better than nested.
> Sparse is better than dense.
> Readability counts.
> Special cases aren't special enough to break the rules.
> Although practicality beats purity.
> Errors should never pass silently.
> Unless explicitly silenced.
> In the face of ambiguity, refuse the temptation to guess.
> There should be one – and preferably only one – obvious way to do it.
> Although that way may not be obvious at first unless you're Dutch.
> Now is better than never.
> Although never is often better than right now.
> If the implementation is hard to explain, it's a bad idea.
> If the implementation is easy to explain, it may be a good idea.

Namespaces are one honking great idea – let's do more of those!

https://www.python.org/dev/peps/pep-0020/

Indentation and Formatting

- 4 spaces instead tabs. PIL suggests using of two spaces, but programmer looks at code 4 up to 8 hours a day, so it's simplier to distinguish indentation with 4 spaces. Why spaces? Similar representation everywhere.

  You can use vim modelines:

```
-- vim:ts=4 ss=4 sw=4 expandtab
```

- A file should ends w/ one newline symbol, but shouldn't ends w/ blank line (two newline symbols).
- Every do/while/for/if/function should indent 4 spaces.
- related or/and in if must be enclosed in the round brackets (). Example:

```
if (a == true and b == false) or (a == false and b == true) then
    <...>
end -- good

if a == true and b == false or a == false and b == true then
    <...>
end -- bad

if a ^ b == true then
end -- good, but not explicit
```

- Type conversion

  Do not use concatenation to convert to string or addition to convert to number (use tostring/tonumber instead):

```
local a = 123
a = a .. ''
-- bad

local a = 123
a = tostring(a)
-- good

local a = '123'
a = a + 5 -- 128
-- bad

local a = '123'
a = tonumber(a) + 5 -- 128
-- good
```

- Try to avoid multiple nested if's with common body:

```
if (a == true and b == false) or (a == false and b == true) then
    do_something()
end
```

(continues on next page)

(continued from previous page)

```
-- good

if a == true then
    if b == false then
        do_something()
    end
if b == true then
    if a == false then
        do_something()
    end
end
-- bad
```

- Avoid multiple concatenations in one statement, use string.format instead:

```
function say_greeting(period, name)
    local a = "good  " .. period .. ", " .. name
end
-- bad

function say_greeting(period, name)
    local a = string.format("good %s, %s", period, name)
end
-- good

local say_greeting_fmt = "good %s, %s"
function say_greeting(period, name)
    local a = say_greeting_fmt:format(period, name)
end
-- best
```

- Use and/or for default variable values

```
function(input)
    input = input or 'default_value'
end -- good

function(input)
    if input == nil then
        input = 'default_value'
    end
end -- ok, but excessive
```

- if's and return statements:

```
if a == true then
    return do_something()
end
do_other_thing() -- good

if a == true then
    return do_something()
else
    do_other_thing()
end -- bad
```

- Using spaces:

– one shouldn't use spaces between function name and opening round bracket, but arguments must be splitted with one whitespace charachter

```
function name (arg1,arg2,...)
end -- bad

function name(arg1, arg2, ...)
end -- good
```

– use space after comment marker

```
while true do -- inline comment
-- comment
do_something()
end
--[[
  multiline
  comment
]]--
```

– surrounding operators

```
local thing=1
thing = thing-1
thing = thing*1
thing = 'string'..'s'
-- bad

local thing = 1
thing = thing - 1
thing = thing * 1
thing = 'string' .. 's'
-- good
```

– use space after commas in tables

```
local thing = {1,2,3}
thing = {1 , 2 , 3}
thing = {1 ,2 ,3}
-- bad

local thing = {1, 2, 3}
-- good
```

– use space in map definitions around equality sign and commas

```
return {1,2,3,4} -- bad
return {
    key1 = val1,key2=val2
} -- bad

return {
    1, 2, 3, 4
    key1 = val1, key2 = val2,
    key3 = vallll
} -- good
```

also, you may use alignment:

```
return {
    long_key  = 'vaaaaalue',
    key       = 'val',
    something = 'even better'
}
```

– extra blank lines may be used (sparingly) to separate groups of related functions. Blank lines may be omitted between a bunch of related one-liners (e.g. a set of dummy implementations)

use blank lines in function, sparingly, to indicate logical sections

```
if thing then
    -- ...stuff...
end
function derp()
    -- ...stuff...
end
local wat = 7
-- bad

if thing then
    -- ...stuff...
end

function derp()
    -- ...stuff...
end

local wat = 7
-- good
```

– Delete whitespace at EOL (strongly forbidden. Use :s/\s\+$//gc in vim to delete them)

Avoid global variable

You must avoid global variables. If you have an exceptional case, use _G variable to set it, add prefix or add table instead of prefix:

```
function bad_global_example()
end -- very, very bad

function good_local_example()
end
_G.modulename_good_local_example = good_local_example -- good
_G.modulename = {}
_G.modulename.good_local_example = good_local_example -- better
```

Always use prefix to avoid name clash

Naming

- names of variables/"objects" and "methods"/functions: snake_case
- names of "classes": CamelCase
- private variables/methods (properties in the future) of object starts with underscores <object>._<name>. Avoid using of local function private_methods(self) end

- boolean - naming is_<...>, isnt_<...>, has_, hasnt_ is a good style.
- for "very local" variables: - t is for tables - i, j are for indexing - n is for counting - k, v is what you get out of pairs() (are acceptable, _ if unused) - i, v is what you get out of ipairs() (are acceptable, _ if unused) - k/key is for table keys - v/val/value is for values that are passed around - x/y/z is for generic math quantities - s/str/string is for strings - c is for 1-char strings - f/func/cb are for functions - status, <rv>.. or ok, <rv>.. is what you get out of pcall/xpcall - buf, sz is a (buffer, size) pair - <name>_p is for pointers - t0.. is for timestamps - err is for errors
- abbrevations are acceptable if they're unambigous and if you'll document (or they're too common) them.
- global variables are written with ALL_CAPS. If it's some system variable, then they're using underscore to define it (_G/_VERSION/..)
- module naming snake_case (avoid underscores and dashes) - 'luasql', instead of 'Lua-SQL'
- *_mt and *_methods defines metatable and methods table

Idioms and patterns

Always use round brackets in call of functions except multiple cases (common lua style idioms):

- *.cfg{ } functions (box.cfg/memcached.cfg/..)
- ffi.cdef[[ ]] function

Avoid these kind of constructions:

- <func>'<name>' (strongly avoid require'..')
- function object:method() end (use functon object.method(self) end instead)
- do not use semicolon as table separator (only comma)
- semicolons at the end of line (only to split multiple statements on one line)
- try to avoid unnecessary function creation (closures/..)

Modules

Don't start modules with license/authors/descriptions, you can write it in LICENSE/AUTHORS/README files. For writing modules use one of the two patterns (dont use modules()):

```
local M = {}

function M.foo()
...
end

function M.bar()
...
end

return M
```

or

```
local function foo()
...
end

local function bar()
...
end

return {
foo = foo,
bar = bar,
}
```

Commenting

You should write code the way it shouldn't be described, but don't forget about commenting it. You shouldn't comment Lua syntax (assume that reader already knows Lua language). Try to tell about functions/variable names/etc.

Multiline comments: use matching (--[[ ]]--) instead of simple (--[[ ]]).

Public function comments (??):

```
--- Copy any table (shallow and deep version)
-- * deepcopy: copies all levels
-- * shallowcopy: copies only first level
-- Supports __copy metamethod for copying custom tables with metatables
-- @function gsplit
-- @table         inp  original table
-- @shallow[opt]  sep  flag for shallow copy
-- @returns            table (copy)
```

Testing

Use tap module for writing efficient tests. Example of test file:

```
#!/usr/bin/env tarantool

local test = require('tap').test('table')
test:plan(31)

do -- check basic table.copy (deepcopy)
    local example_table = {
        {1, 2, 3},
        {"help, I'm very nested", {{{ }}} }
    }

    local copy_table = table.copy(example_table)

    test:is_deeply(
        example_table,
        copy_table,
        "checking, that deepcopy behaves ok"
    )
    test:isnt(
```

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(continued from previous page)

```
        example_table,
        copy_table,
        "checking, that tables are different"
    )
    test:isnt(
        example_table[1],
        copy_table[1],
        "checking, that tables are different"
    )
    test:isnt(
        example_table[2],
        copy_table[2],
        "checking, that tables are different"
    )
    test:isnt(
        example_table[2][2],
        copy_table[2][2],
        "checking, that tables are different"
    )
    test:isnt(
        example_table[2][2][1],
        copy_table[2][2][1],
        "checking, that tables are different"
    )
end

<...>

os.exit(test:check() and 0 or 1)
```

When you'll test your code output will be something like this:

```
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1..31
ok - checking, that deepcopy behaves ok
ok - checking, that tables are different
ok - checking, that tables are different
ok - checking, that tables are different
ok - checking, that tables are different
ok - checking, that tables are different
...
```

Error Handling

Be generous in what you accept and strict in what you return.

With error handling this means that you must provide an error object as second multi-return value in case of error. The error object can be a string, a Lua table or cdata, in the latter cases it must have __tostring metamethod defined.

In case of error, use nil for the first return value. This makes the error hard to ignore.

When checking function return values, check the first argument first. If it's nil, look for error in the second argument:

```
local data, err = foo()
if not data then
    return nil, err
end
return bar(data)
```

Unless performance of your code is paramount, try to avoid using more than two return values.

In rare cases you may want to return nil as a legal return value. In this case it's OK to check for error first, and return second:

```
local data, err = foo()
if not err then
    return data
end
return nil, err
```

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