

Cloudera Runtime 7.0.0

Apache Kudu Administration

Date published: 2019-08-21

Date modified:

CLOUDERA

<https://docs.cloudera.com/>

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Apache Kudu administration

You can perform the following common administrative tasks and workflows with Apache Kudu:

Starting and stopping Kudu processes

You can start, stop, and configure Kudu services to start automatically by using the CLI commands.

Start Kudu services using the following commands:

```
sudo service kudu-master start
sudo service kudu-tserver start
```

To stop Kudu services, use the following commands:

```
sudo service kudu-master stop
sudo service kudu-tserver stop
```

Configure the Kudu services to start automatically when the server starts, by adding them to the default runlevel.

```
sudo chkconfig kudu-master on          # RHEL / CentOS
sudo chkconfig kudu-tserver on         # RHEL / CentOS
sudo update-rc.d kudu-master defaults # Ubuntu
sudo update-rc.d kudu-tserver defaults # Ubuntu
```

Kudu web interfaces

Kudu tablet servers and masters expose useful operational information on a built-in web interface.

Kudu master web interface

Kudu master processes serve their web interface on port 8051. The interface exposes several pages with information about the state of the cluster.

- A list of tablet servers, their host names, and the time of their last heartbeat.
- A list of tables, including schema and tablet location information for each.
- SQL code which you can paste into Impala Shell to add an existing table to Impala's list of known data sources.

Kudu tablet server web interface

Each tablet server serves a web interface on port 8050. The interface exposes information about each tablet hosted on the server, its current state, and debugging information about maintenance background operations.

Common web interface pages

Both Kudu masters and tablet servers expose the following information via their web interfaces:

- HTTP access to server logs.
- An /rpcz endpoint which lists currently running RPCs via JSON.
- Details about the memory usage of different components of the process.
- The current set of configuration flags.
- Currently running threads and their resource consumption.
- A JSON endpoint exposing metrics about the server.
- The version number of the daemon deployed on the cluster.

These interfaces are linked from the landing page of each daemon's web UI.

Kudu metrics

Kudu daemons expose a large number of metrics. Some metrics are associated with an entire server process, whereas others are associated with a particular tablet replica.

Listing available metrics

The full set of available metrics for a Kudu server can be dumped using a special command line flag:

```
$ kudu-tserver --dump_metrics_json
$ kudu-master --dump_metrics_json
```

This will output a large JSON document. Each metric indicates its name, label, description, units, and type. Because the output is JSON-formatted, this information can easily be parsed and fed into other tooling which collects metrics from Kudu servers.

If you are using Cloudera Manager, see *Cloudera Manager metrics for Kudu* for the complete list of metrics collected by Cloudera Manager for a Kudu service.

Related Information

[Cloudera Manager metrics](#)

Collecting metrics via HTTP

Metrics can be collected from a server process via its HTTP interface by visiting `/metrics`. The output of this page is JSON for easy parsing by monitoring services. This endpoint accepts several GET parameters in its query string:

- `/metrics?metrics=<substring1>,<substring2>,...` - Limits the returned metrics to those which contain at least one of the provided substrings. The substrings also match entity names, so this may be used to collect metrics for a specific tablet.
- `/metrics?include_schema=1` - Includes metrics schema information such as unit, description, and label in the JSON output. This information is typically omitted to save space.
- `/metrics?compact=1` - Eliminates unnecessary whitespace from the resulting JSON, which can decrease bandwidth when fetching this page from a remote host.
- `/metrics?include_raw_histograms=1` - Include the raw buckets and values for histogram metrics, enabling accurate aggregation of percentile metrics over time and across hosts.

For example:

```
$ curl -s 'http://example-ts:8050/metrics?include_schema=1&metrics=connections_accepted'
```

```
[
  {
    "type": "server",
    "id": "kudu.tabletserver",
    "attributes": {},
    "metrics": [
      {
        "name": "rpc_connections_accepted",
        "label": "RPC Connections Accepted",
        "type": "counter",
        "unit": "connections",
        "description": "Number of incoming TCP connections made to the RPC server",
        "value": 92
      }
    ]
  }
]
```

```

    }
  ]

$ curl -s 'http://example-ts:8050/metrics?metrics=log_append_latency'

[
  {
    "type": "tablet",
    "id": "c0ebf9fef1b847e2a83c7bd35c2056b1",
    "attributes": {
      "table_name": "lineitem",
      "partition": "hash buckets: (55), range: [(<start>), (<end>))",
      "table_id": ""
    },
    "metrics": [
      {
        "name": "log_append_latency",
        "total_count": 7498,
        "min": 4,
        "mean": 69.3649,
        "percentile_75": 29,
        "percentile_95": 38,
        "percentile_99": 45,
        "percentile_99_9": 95,
        "percentile_99_99": 167,
        "max": 367244,
        "total_sum": 520098
      }
    ]
  }
]

```

Diagnostics logging

Kudu may be configured to periodically dump all of its metrics to a local log file using the `--metrics_log_interval_msflag`. Set this flag to the interval at which metrics should be written to a diagnostics log file.

The diagnostics log will be written to the same directory as the other Kudu log files, with a similar naming format, substituting diagnostics instead of a log level like INFO. After any diagnostics log file reaches 64MB uncompressed, the log will be rolled and the previous file will be gzip-compressed.

The log file generated has three space-separated fields. The first field is the word metrics. The second field is the current timestamp in microseconds since the Unix epoch. The third is the current value of all metrics on the server, using a compact JSON encoding. The encoding is the same as the metrics fetched via HTTP described above.

Rack awareness (Location awareness)

Starting in CDH 6.2, Kudu supports a rack awareness feature. Kudu's ordinary re-replication methods ensure the availability of the cluster in the event of a single node failure. However, clusters can be vulnerable to correlated failures of multiple nodes. For example, all of the physical hosts on the same rack in a datacenter may become unavailable simultaneously if the top-of-rack switch fails. Kudu's rack awareness feature provides protection from certain kinds of correlated failures, such as the failure of a single rack in a datacenter.

The first element of Kudu's rack awareness feature is location assignment. When a tablet server registers with a master, the master assigns it a location. A location is a `/`-separated string that begins with a `/` and where each `/`-separated component consists of characters from the set `[a-zA-Z0-9_-]`. For example, `/dc-0/rack-09` is a valid location, while `rack-04` and `/rack=1` are not valid locations. Thus location strings resemble absolute UNIX file paths where characters in directory and file names are restricted to the set `[a-zA-Z0-9_-]`. Presently, Kudu does not use the hierarchical structure of locations, but it may in the future. Location assignment is done by a user-provided command,

whose path should be specified using the `--location_mapping_cmd` master flag. The command should take a single argument, the IP address or hostname of a tablet server, and return the location for the tablet server. Make sure that all Kudu masters are using the same location mapping command.

The second element of Kudu's rack awareness feature is the placement policy: Do not place a majority of replicas of a tablet on tablet servers in the same location.

The leader master, when placing newly created replicas on tablet servers and when re-replicating existing tablets, will attempt to place the replicas in a way that complies with the placement policy. For example, in a cluster with five tablet servers A, B, C, D, and E, with respective locations `/L0`, `/L0`, `/L1`, `/L1`, `/L2`, to comply with the placement policy a new 3x replicated tablet could have its replicas placed on A, C, and E, but not on A, B, and C, because then the tablet would have 2/3 replicas in location `/L0`. As another example, if a tablet has replicas on tablet servers A, C, and E, and then C fails, the replacement replica must be placed on D in order to comply with the placement policy.

In the case where it is impossible to place replicas in a way that complies with the placement policy, Kudu will violate the policy and place a replica anyway. For example, using the setup described in the previous paragraph, if a tablet has replicas on tablet servers A, C, and E, and then E fails, Kudu will re-replicate the tablet onto one of B or D, violating the placement policy, rather than leaving the tablet under-replicated indefinitely. The kudu cluster rebalance tool can reestablish the placement policy if it is possible to do so. The kudu cluster rebalance tool can also be used to reimpose the placement policy on a cluster if the cluster has just been configured to use the rack awareness feature and existing replicas need to be moved to comply with the placement policy. See [Running a tablet rebalancing tool on a rack-aware cluster](#) on page 28 for more information.

Common Kudu workflows

Some common Kudu administrative tasks include migrating to multiple Kudu masters, recovering from a dead Kudu master, removing unwanted masters from a multi-master deployment, adding or updating hostnames of the masters within the clusters without aliases, monitoring the health of the cluster using `ksck`, changing directory configuration, recovering from disk failures, bringing a tablet that has lost a majority of replicas back online, rebuilding a Kudu filesystem layout, taking physical backups of an entire node, and scale the storage for the Kudu master and the tablet servers in the cloud.

Migrating to multiple Kudu masters

To provide high availability and to avoid a single point of failure, Kudu clusters should be created with multiple masters. Many Kudu clusters were created with just a single master, either for simplicity or because Kudu multi-master support was still experimental at the time. This workflow demonstrates how to migrate to a multi-master configuration. It can also be used to migrate from two masters to three with straightforward modifications.



Important:

- This workflow is unsafe for adding new masters to an existing multi-master configuration that already has three or more masters. Do not use it for that purpose.
- An even number of masters doesn't provide any benefit over having one fewer masters. This guide should always be used for migrating to three masters.
- This workflow presumes you are familiar with Kudu configuration management, with or without Cloudera Manager.
- All of the command line steps below should be executed as the Kudu UNIX user. The example commands assume the Kudu Unix user is `kudu`, which is typical.

Prepare for the migration

To prepare for the migration, record the port, UUID, and the location of the write-ahead log on the existing master. Decide the number of masters that you want to use. Then select an unused machine from the cluster and configure it as the new master.

Procedure

1. Establish a maintenance window (one hour should be sufficient). During this time the Kudu cluster will be unavailable.
2. Decide how many masters to use. The number of masters should be odd. Three or five node master configurations are recommended; they can tolerate one or two failures respectively.
3. Perform the following preparatory steps for the existing master:
 - Identify and record the directories where the master's write-ahead log (WAL) and data live. If using Kudu system packages, their default locations are `/var/lib/kudu/master`, but they may be customized using the `fs_wal_dir` and `fs_data_dirs` configuration parameters. The command below assume that `fs_wal_dir` is `/data/kudu/master/wal` and `fs_data_dirs` is `/data/kudu/master/data`. Your configuration may differ. For more information on configuring these directories, see *Apache Kudu configuration*.
 - Identify and record the port the master is using for RPCs. The default port value is 7051, but it may have been customized using the `rpc_bind_addresses` configuration parameter.
 - Identify the master's UUID. It can be fetched using the following command:

```
$ sudo -u kudu kudu fs dump uuid --fs_wal_dir=<master_wal_dir> [--fs_data_dirs=<master_data_dir>] 2>/dev/null
```

master_data_dir

The location of the existing master's previously recorded data directory.

For example:

```
$ sudo -u kudu kudu fs dump uuid --fs_wal_dir=/var/lib/kudu/master 2>/dev/null
4aab798a69e94fab8d77069edff28ce0
```

- (Optional) Configure a DNS alias for the master. The alias could be a DNS cname (if the machine already has an A record in DNS), an A record (if the machine is only known by its IP address), or an alias in `/etc/hosts`. The alias should be an abstract representation of the master (e.g. `master-1`).



Important: Without DNS aliases, it is not possible to recover from permanent master failures without bringing the cluster down for maintenance. It is highly recommended that you use DNS aliases.

4. If you have Kudu tables that are accessed from Impala, you must update the master addresses in the Apache Hive Metastore (HMS) database.
 - If you set up the DNS aliases, run the following statement in `impala-shell`, replacing `master-1`, `master-2`, and `master-3` with your actual aliases.

```
ALTER TABLE table_name
SET TBLPROPERTIES
('kudu.master_addresses' = 'master-1,master-2,master-3');
```

- If you do not have DNS aliases set up, see Step #11 in the Performing the migration section for updating HMS.
5. Perform the following preparatory steps for each new master:
 - Choose an unused machine in the cluster. The master generates very little load so it can be colocated with other data services or load-generating processes, though not with another Kudu master from the same configuration.
 - Ensure Kudu is installed on the machine, either using system packages (in which case the `kudu` and `kudu-master` packages should be installed), or some other means.
 - Choose and record the directory where the master's data will live.
 - Choose and record the port the master should use for RPCs.
 - (Optional) Configure a DNS alias for the master (e.g. `master-2`, `master-3`, etc).

Perform the migration

For migrating to multiple Kudu masters, you need to bring the Kudu clusters down. Therefore, identify at least a one-hour maintenance window for this task.

Procedure

1. Stop all the Kudu processes in the entire cluster.
2. Format the data directory on each new master machine, and record the generated UUID. Use the following commands:

```
$ sudo -u kudu kudu fs format --fs_wal_dir=<master_wal_dir> [--fs_data_dirs=<master_data_dir>]
$ sudo -u kudu kudu fs dump uuid --fs_wal_dir=<master_wal_dir> [--fs_data_dirs=<master_data_dir>] 2>/dev/null
```

master_data_dir

The new master's previously recorded data directory.

For example:

```
$ sudo -u kudu kudu fs format --fs_wal_dir=/data/kudu/master/wal
--fs_data_dirs=/data/kudu/master/data
sudo -u kudu kudu fs dump uuid --fs_wal_dir=/data/kudu/master/wal
--fs_data_dirs=/data/kudu/master/data 2>/dev/null
f5624e05f40649b79a757629a69d061e
```

3. If you are using Cloudera Manager, add the new Kudu master roles now, but do not start them.
 - If using DNS aliases, override the empty value of the Master Address parameter for each role (including the existing master role) with that master's alias.
 - Add the port number (separated by a colon) if using a non-default RPC port value.

4. Rewrite the master's Raft configuration with the following command, executed on the existing master:

```
$ sudo -u kudu kudu local_replica cmeta rewrite_raft_config --fs_wal_dir
=<master_wal_dir> [--fs_data_dirs=<master_data_dir>] <tablet_id> <all_masters>
```

master_data_dir

The existing master's previously recorded data directory

tablet_id

This must be set to the string, 00000000000000000000000000000000.

all_masters

A space-separated list of masters, both new and existing. Each entry in the list must be a string of the form <uuid>:<hostname>:<port>.

uuid

The master's previously recorded UUID.

hostname

The master's previously recorded hostname or alias.

port

The master's previously recorded RPC port number.

For example:

```
$ sudo -u kudu kudu local_replica cmeta rewrite_raft_config --fs
_wal_dir=/data/kudu/master/wal --fs_data_dirs=/data/kudu/master/
data 00000000000000000000000000000000 4aab798a69e94fab8d77069edf
f28ce0:master-1:7051 f5624e05f40649b79a757629a69d061e:master-2:7
051 988d8ac6530f426cbe180be5ba52033d:master-3:7051
```



Important: If you are using Cloudera Manager, skip the next step.

5. Modify the value of the master_addresses configuration parameter for both existing master and new masters. The new value must be a comma-separated list of all of the masters. Each entry is a string of the form, <hostname>:<port>.

hostname

The master's previously recorded hostname or alias.

port

The master's previously recorded RPC port number.

6. Start the existing master.

- Copy the master data to each new master with the following command, executed on each new master machine.



Important: If your Kudu cluster is secure, in addition to running as the Kudu UNIX user, you must authenticate as the Kudu service user prior to running this command.

```
$ sudo -u kudu kudu local_replica copy_from_remote --fs_wal_dir=<master_data_dir> <tablet_id> <existing_master>
```

master_data_dir

The new master's previously recorded data directory.

tablet_id

Must be set to the string, 00000000000000000000000000000000.

existing_master

RPC address of the existing master. It must be a string of the form <hostname>:<port>.

hostname

The existing master's previously recorded hostname or alias.

port

The existing master's previously recorded RPC port number.

Example

```
$ sudo -u kudu kudu local_replica copy_from_remote --fs_wal_dir=/data/kudu/master/wal --fs_data_dirs=/data/kudu/master/data 00000000000000000000000000000000 master-1:7051
```

- Start all the new masters.



Important: If you are using Cloudera Manager, skip the next step.

- Modify the value of the `tserver_master_addrs` configuration parameter for each tablet server. The new value must be a comma-separated list of masters where each entry is a string of the form <hostname>:<port>

hostname

The master's previously recorded hostname or alias

port

The master's previously recorded RPC port number

- Start all the tablet servers.

- If you have Kudu tables that are accessed from Impala and you didn't set up DNS aliases, update the HMS database manually in the underlying database that provides the storage for HMS.

- The following is an example SQL statement you would run in the HMS database:

```
UPDATE TABLE_PARAMS
SET PARAM_VALUE =
'master-1.example.com,master-2.example.com,master-3.example.com'
WHERE PARAM_KEY = 'kudu.master_addresses' AND PARAM_VALUE = 'old-master';
```

- Invalidate the metadata by running the command in `impala-shell`:

```
INVALIDATE METADATA;
```

What to do next

To verify that all masters are working properly, consider performing the following sanity checks:

- Using a browser, visit each master's web UI and navigate to the /masters page. All the masters should now be listed there with one master in the LEADER role and the others in the FOLLOWER role. The contents of /masters on each master should be the same.
- Run a Kudu system check (ksck) on the cluster using the kudu command line tool.

Related Information

[Monitoring cluster health with ksck](#)

Recovering from a dead Kudu master in a multi-master deployment

Kudu multi-master deployments function normally in the event of a master loss. However, it is important to replace the dead master. Otherwise a second failure may lead to a loss of availability, depending on the number of available masters. This workflow describes how to replace the dead master.

Due to [KUDU-1620](#), it is not possible to perform this workflow without also restarting the live masters. As such, the workflow requires a maintenance window, albeit a potentially brief one if the cluster was set up with DNS aliases.



Important:

- Kudu does not yet support live Raft configuration changes for masters. As such, it is only possible to replace a master if the deployment was created with DNS aliases or if every node in the cluster is first shut down. See the previous [multi-master migration workflow](#) for more details on deploying with DNS aliases.
- The workflow presupposes at least basic familiarity with Kudu configuration management. If using Cloudera Manager, the workflow also presupposes familiarity with it.
- All of the command line steps below should be executed as the Kudu UNIX user, typically kudu.

Prepare for the recovery

It is crucial to make sure that the master node is truly dead and does not accidentally restart while you are preparing for the recovery.

Procedure

1. If the cluster was configured without DNS aliases perform the following steps. Otherwise move on to step 2:
 - a) Establish a maintenance window (one hour should be sufficient). During this time the Kudu cluster will be unavailable.
 - b) Shut down all Kudu tablet server processes in the cluster.
2. Ensure that the dead master is well and truly dead. Take whatever steps needed to prevent it from accidentally restarting; this can be quite dangerous for the cluster post-recovery.
3. Choose one of the remaining live masters to serve as a basis for recovery. The rest of this workflow will refer to this master as the "reference" master.
4. Choose an unused machine in the cluster where the new master will live. The master generates very little load so it can be co-located with other data services or load-generating processes, though not with another Kudu master from the same configuration. The rest of this workflow will refer to this master as the "replacement" master.
5. Perform the following preparatory steps for the replacement master:
 - Ensure Kudu is installed on the machine, either via system packages (in which case the kudu and kudu-master packages should be installed), or via some other means.
 - Choose and record the directory where the master's data will live.
6. Perform the following preparatory steps for each live master:
 - Identify and record the directory where the master's data lives. If using Kudu system packages, the default value is /var/lib/kudu/master, but it may be customized via the fs_wal_dir and fs_data_dirs configuration parameter. Please note if you've set fs_data_dirs to some directories other than the value of fs_wal_dir, it should be explicitly included in every command below where fs_wal_dir is also included. For more information on configuring these directories, see *Apache Kudu configuration*.

- Identify and record the master's UUID. It can be fetched using the following command:

```
$ sudo -u kudu kudu fs dump uuid --fs_wal_dir=<master_wal_dir> [--fs_data_dirs=<master_data_dir>] 2>/dev/null
```

master_data_dir

live master's previously recorded data directory

Example

```
$ sudo -u kudu kudu fs dump uuid --fs_wal_dir=/data/kudu/master/wal --fs_data_dirs=/data/kudu/master/data 2>/dev/null
80a82c4b8a9f4c819bab744927ad765c
```

7. Perform the following preparatory steps for the reference master:

- Identify and record the directory where the master's data lives. If using Kudu system packages, the default value is /var/lib/kudu/master, but it may be customized using the fs_wal_dir and fs_data_dirs configuration parameter. If you have set fs_data_dirs to some directories other than the value of fs_wal_dir, it should be explicitly included in every command below where fs_wal_dir is also included. For more information on configuring these directories, see the Kudu Configuration docs.
- Identify and record the UUIDs of every master in the cluster, using the following command:

```
$ sudo -u kudu kudu local_replica cmeta print_replica_uuids --fs_wal_dir=<master_data_dir> <tablet_id> 2>/dev/null
```

master_data_dir

The reference master's previously recorded data directory.

tablet_id

Must be set to the string, 00000000000000000000000000000000.

For example

```
$ sudo -u kudu kudu local_replica cmeta print_replica_uuids --fs_wal_dir=/data/kudu/master/wal --fs_data_dirs=/data/kudu/master/data 00000000000000000000000000000000 2>/dev/null
80a82c4b8a9f4c819bab744927ad765c 2a73eeee5d47413981d9a1c637cce170
1c3f3094256347528d02ec107466aef3
```

- Using the two previously-recorded lists of UUIDs (one for all live masters and one for all masters), determine and record (by process of elimination) the UUID of the dead master.

Perform the recovery

After you have identified a reference master, you need to copy the master data to the replacement master node. You need to bring the Kudu clusters down. Therefore, identify at least a one-hour maintenance window for this task.

Procedure

1. Format the data directory on the replacement master machine using the previously recorded UUID of the dead master. Use the following command sequence:

```
$ sudo -u kudu kudu fs format --fs_wal_dir=<master_wal_dir> [--fs_data_dirs=<master_data_dir>] --uuid=<uuid>
```

master_data_dir

The replacement master's previously recorded data directory.

uuid

The dead master's previously recorded UUID.

For example:

```
$ sudo -u kudu kudu fs format --fs_wal_dir=/data/kudu/master/wal
--fs_data_dirs=/data/kudu/master/data --uuid=80a82c4b8a9f4c819b
ab744927ad765c
```

2. Copy the master data to the replacement master with the following command.



Important: If your Kudu cluster is secure, in addition to running as the Kudu UNIX user, you must authenticate as the Kudu service user prior to running this command.

```
$ sudo -u kudu kudu local_replica copy_from_remote --fs_wal_dir=<master_wal_dir>
[--fs_data_dirs=<master_data_dir>] <tablet_id> <reference_master>
```

master_data_dir

The replacement master's previously recorded data directory.

tablet_id

Must be set to the string, 00000000000000000000000000000000.

reference_master

The RPC address of the reference master. It must be a string of the form <hostname>:<port>.

hostname

The reference master's previously recorded hostname or alias.

port

The reference master's previously recorded RPC port number.

For example:

```
$ sudo -u kudu kudu local_replica copy_from_remote --fs_wal_dir=
/data/kudu/master/wal --fs_data_dirs=/data/kudu/master/data 0000
00000000000000000000000000000000 master-2:7051
```

3. If you are using Cloudera Manager, add the replacement Kudu master role now, but do not start it.
 - Override the empty value of the Master Address parameter for the new role with the replacement master's alias.
 - If you are using a non-default RPC port, add the port number (separated by a colon) as well.
4. If the cluster was set up with DNS aliases, reconfigure the DNS alias for the dead master to point at the replacement master.

5. If the cluster was set up without DNS aliases, perform the following steps:
 - a) Stop the remaining live masters.
 - b) Rewrite the Raft configurations on these masters to include the replacement master. See [Step 4](#) in the *Perform the migration* topic for more details.
6. Start the replacement master.
7. Restart the remaining masters in the new multi-master deployment. While the masters are shut down, there will be an availability outage, but it should last only as long as it takes for the masters to come back up.

What to do next

To verify that all masters are working properly, consider performing the following sanity checks:

- Using a browser, visit each master's web UI and navigate to the /masters page. All the masters should now be listed there with one master in the LEADER role and the others in the FOLLOWER role. The contents of /masters on each master should be the same.
- Run a Kudu system check (ksck) on the cluster using the kudu command line tool.

Removing Kudu masters from a multi-master deployment

In the event that a multi-master deployment has been overallocated nodes, the following steps should be taken to remove the unwanted masters.



Important:

- In planning the new multi-master configuration, keep in mind that the number of masters should be odd and that three or five node master configurations are recommended.
- Dropping the number of masters below the number of masters currently needed for a Raft majority can incur data loss. To mitigate this, ensure that the leader master is not removed during this process.

Prepare for removal

In order to remove the unwanted masters from a multi-master deployment, you need to identify them and note their UUID and RPC addresses.

Procedure

1. Establish a maintenance window (one hour should be sufficient). During this time the Kudu cluster will be unavailable.
2. Identify the UUID and RPC address current leader of the multi-master deployment by visiting the /masters page of any master's web UI. This master must not be removed during this process; its removal may result in severe data loss.
3. Stop all the Kudu processes in the entire cluster.
4. If you are using Cloudera Manager, remove the unwanted Kudu master from your cluster's Kudu service.

Perform the removal

When you remove any Kudu masters from a multi-master deployment, you need to rewrite the Raft configuration on the remaining masters, remove data and WAL directories from the unwanted masters, and finally modify the value of the tserver_master_addrs configuration parameter for the tablet servers to remove the unwanted masters. You need to bring the Kudu clusters down. Therefore, identify at least a one-hour maintenance window for this task.

Procedure

1. Rewrite the Raft configuration on the remaining masters to include only the remaining masters.

```
$ sudo -u kudu kudu local_replica cmeta rewrite_raft_config --fs_wal_dir
=<master_wal_dir> [--fs_data_dirs=<master_data_dir>] <tablet_id> <all_masters>
```

master_data_dir

The existing master's previously recorded data directory

tablet_id

This must be set to the string, 00000000000000000000000000000000.

all_masters

A space-separated list of masters, both new and existing. Each entry in the list must be a string of the form <uuid>:<hostname>:<port>.

uuid

The master's previously recorded UUID.

hostname

The master's previously recorded hostname or alias.

port

The master's previously recorded RPC port number.

For example:

```
$ sudo -u kudu kudu local_replica cmeta rewrite_raft_config --fs
_wal_dir=/data/kudu/master/wal --fs_data_dirs=/data/kudu/master/
data 00000000000000000000000000000000 4aab798a69e94fab8d77069edf
f28ce0:master-1:7051 f5624e05f40649b79a757629a69d061e:master-2:7
051 988d8ac6530f426cbe180be5ba52033d:master-3:7051
```



Important: If you are using Cloudera Manager, skip the next step.

2. Remove the data directories and WAL directory on the unwanted masters. This is a precaution to ensure that they cannot start up again and interfere with the new multi-master deployment.
3. Modify the value of the master_addresses configuration parameter for the masters of the new multi-master deployment. See *Apache Kudu configuration* for the steps to modify a configuration parameter. If migrating to a single-master deployment, the master_addresses flag should be omitted entirely.
4. Start all of the masters that were not removed.



Important: If you are using Cloudera Manager, skip the next step.

5. Modify the value of the tserver_master_addrs configuration parameter for the tablet servers to remove any unwanted masters. See *Apache Kudu configuration* for the steps to modify a configuration parameter.
6. Start all of the tablet servers.

What to do next

To verify that all masters are working properly, consider performing the following sanity checks:

- Using a browser, visit each master's web UI and navigate to the /masters page. All the masters should now be listed there with one master in the LEADER role and the others in the FOLLOWER role. The contents of /masters on each master should be the same.
- Run a Kudu system check (ksck) on the cluster using the kudu command line tool.

Related Information

[Monitoring cluster health with ksck](#)

Changing master hostnames

When replacing dead masters, use DNS aliases to prevent long maintenance windows. If the cluster was set up without aliases, change the host names as described in this section.

Prepare for hostname changes

In this step, you need to identify a down-time window, and note the UUID and the RPC address of each master.

Procedure

1. Establish a maintenance window during which the Kudu cluster will be unavailable. One hour should be sufficient.
2. On the **Masters** page in Kudu Web UI, note the UUID and RPC address of each master.
3. Stop all the Kudu processes in the cluster.
4. Set up the new hostnames to point to the masters and verify all servers and clients properly resolve them.

Perform hostname changes

You need to bring the Kudu clusters down to update the hostnames. Therefore, identify at least a one-hour maintenance window for this task.

Procedure

1. Rewrite each master's Raft configuration with the following command, executed on each master host:

```
$ sudo -u kudu kudu local_replica cmeta rewrite_raft_config --fs_wal_dir=  
=<master_wal_dir> [--fs_data_dirs=<master_data_dir>] 00000000000000000000  
0000000000000000 <all_masters>
```

For example:

```
$ sudo -u kudu kudu local_replica cmeta rewrite_raft_config --fs_wal_dir=  
data/kudu/master/wal --fs_data_dirs=/data/kudu/master/data 0000000000000000  
00000000000000000000 4aab798a69e94fab8d77069edff28ce0:new-master-name-1:705  
1 f5624e05f40649b79a757629a69d061e:new-master-name-2:7051 988d8ac6530f42  
6cbe180be5ba52033d:new-master-name-3:7051
```

2. Update the master address:
 - In an environment not managed by Cloudera Manager, change the gflag file of the masters so the master_addresses parameter reflects the new hostnames.
 - In an environment managed by Cloudera Manager, specify the new hostname in the Master Address (server.address) field on each Kudu role.
3. Change the gflag file of the tablet servers to update the tserver_master_addrs parameter with the new hostnames. In an environment managed by Cloudera Manager, this step is not needed.
4. Start the masters.

5. To verify that all masters are working properly, perform the following sanity checks:

- In each master's Web UI, click Masters on the Status Pages. All of the masters should be listed there with one master in the LEADER role field and the others in the FOLLOWER role field. The contents of Masters on all master should be the same.
- Run the below command to verify all masters are up and listening. The UUIDs are the same and belong to the same master as before the hostname change:

```
$ sudo -u kudu kudu master list new-master-name-1:7051,new-master-name-2:7051,new-master-name-3:7051
```

6. Start all of the tablet servers.

7. Run a Kudu system check (ksck) on the cluster using the kudu command line tool. After startup, some tablets may be unavailable as it takes some time to initialize all of them.

8. If you have Kudu tables that are accessed from Impala, update the HMS database manually in the underlying database that provides the storage for HMS.

- The following is an example SQL statement you run in the HMS database:

```
UPDATE TABLE_PARAMSSET PARAM_VALUE =
'new-master-name-1:7051,new-master-name-2:7051,new-master-name-3:7051'
WHERE PARAM_KEY = 'kudu.master_addresses'
AND PARAM_VALUE = 'master-1:7051,master-2:7051,master-3:7051';
```

- In impala-shell, run:

```
INVALIDATE METADATA;
```

- Verify updating the metadata worked by running a simple SELECT query on a Kudu-backed Impala table.

Related Information

[Monitoring cluster health with ksck](#)

Monitoring cluster health with ksck

The kudu CLI includes a tool called ksck that can be used for gathering information about the state of a Kudu cluster, including checking its health. ksck will identify issues such as under-replicated tablets, unreachable tablet servers, or tablets without a leader.

ksck should be run from the command line as the Kudu admin user, and requires the full list of master addresses to be specified:

```
$ sudo -u kudu kudu cluster ksck master-01.example.com,master-02.example.com,master-03.example.com
```

To see a full list of the options available with ksck, use the --help flag. If the cluster is healthy, ksck will print information about the cluster, a success message, and return a zero (success) exit status.

Master Summary		
UUID	Address	Status
a811c07b99394df799e6650e7310f282	master-01.example.com	HEALTHY
b579355eaaaa446e998606bcb7e87844	master-02.example.com	HEALTHY
cfdcc8592711485fad32ec4eea4fbfcd	master-02.example.com	HEALTHY
Tablet Server Summary		
UUID	Address	Status
a598f75345834133a39c6e51163245db	tserver-01.example.com	HEALTHY
e05ca6b6573b4e1f9a518157c0c0c637	tserver-02.example.com	HEALTHY
e7e53a91fe704296b3a59ad304e7444a	tserver-03.example.com	HEALTHY

```

Version Summary
-----
Version | Servers
-----
1.7.1 | all 6 server(s) checked

Summary by table
Name | RF | Status | Total Tablets | Healthy | Recovering | Under-replicated | Unavailable
-----+-----+-----+-----+-----+-----+-----
my_table | 3 | HEALTHY | 8 | 8 | 0 | 0

Total Count
-----
Masters | 3
Tablet Servers | 3
Tables | 1
Tablets | 8
Replicas | 24
OK

```

If the cluster is unhealthy, for instance if a tablet server process has stopped, ksck will report the issue(s) and return a non-zero exit status, as shown in the abbreviated snippet of ksck output below:

```

Tablet Server Summary
-----
UUID | Address | Status
-----+-----+-----
a598f75345834133a39c6e51163245db | tserver-01.example.com | HEALTHY
e05ca6b6573b4e1f9a518157c0c0c637 | tserver-02.example.com | HEALTHY
e7e53a91fe704296b3a59ad304e7444a | tserver-03.example.com | UNAVAILABLE
Error from 127.0.0.1:7150: Network error: could not get status from server:
Client connection negotiation failed: client connection to 127.0.0.1:7150:
connect: Connection refused (error 61) (UNAVAILABLE)

... (full output elided)

-----
Errors:
-----
Network error: error fetching info from tablet servers: failed to gather i
nfo for all tablet servers: 1 of 3 had errors
Corruption: table consistency check error: 1 out of 1 table(s) are not hea
lthy

FAILED
Runtime error: ksck discovered errors

```

To verify data integrity, the optional `--checksum_scan` flag can be set, which will ensure the cluster has consistent data by scanning each tablet replica and comparing results. The `--tables` or `--tablets` flags can be used to limit the scope of the checksum scan to specific tables or tablets, respectively.

For example, checking data integrity on the `my_table` table can be done with the following command:

```
$ sudo -u kudu kudu cluster ksck --checksum_scan --tables my_table master-01
.example.com,master-02.example.com,master-03.example.com
```

By default, ksck will attempt to use a snapshot scan of the table, so the checksum scan can be done while writes continue.

Finally, `ksck` also supports output in JSON format using the `--ksck_format` flag. JSON output contains the same information as the plain text output, but in a format that can be used by other tools. See `kudu cluster ksck --help` for more information.

Changing directory configuration

For higher read parallelism and larger volumes of storage per server, you may want to configure servers to store data in multiple directories on different devices. Once a server is started, you must go through the following steps to change the directory configuration.

About this task

You can add or remove data directories to an existing master or tablet server via the `kudu fs update_dirs` tool. Data is striped across data directories, and when a new data directory is added, new data will be striped across the union of the old and new directories.



Note: Unless the `--force` flag is specified, Kudu will not allow for the removal of a directory across which tablets are configured to spread data. If `--force` is specified, all tablets configured to use that directory will fail upon starting up and be replicated elsewhere.



Note: If the metadata directory overlaps with a data directory, as was the default prior to Kudu 1.7, or if a non-default metadata directory is configured, the `--fs_metadata_dir` configuration must be specified when running the `kudu fs update_dirs` tool.



Note: Only new tablet replicas, i.e. brand new tablets' replicas and replicas that are copied to the server for high availability, will use the new directory. Existing tablet replicas on the server will not be rebalanced across the new directory.



Attention: All of the command line steps below should be executed as the Kudu UNIX user, typically `kudu`.

Procedure

1. The tool can only run while the server is offline, so establish a maintenance window to update the server. The tool itself runs quickly, so this offline window should be brief, and as such, only the server to update needs to be offline.

However, if the server is offline for too long (see the `follower_unavailable_considered_failed_sec` flag), the tablet replicas on it may be evicted from their Raft groups. To avoid this, it may be desirable to bring the entire cluster offline while performing the update.

2. Run the tool with the desired directory configuration flags. For example, if a cluster was set up with `--fs_wal_dir=/wals`, `##fs_metadata_dir=/meta`, and `##fs_data_dirs=/data/1,/data/2,/data/3`, and `/data/3` is to be removed (e.g. due to a disk error), run the command:

```
$ sudo -u kudu kudu fs update_dirs --force --fs_wal_dir=/wals --fs_metadata_dir=/meta --fs_data_dirs=/data/1,/data/2
```

3. Modify the values of the `fs_data_dirs` flags for the updated sever. If using Cloudera Manager, make sure to only update the configurations of the updated server, rather than of the entire Kudu service.
4. Once complete, the server process can be started. When Kudu is installed using system packages, service is typically used:

```
$ sudo service kudu-tserver start
```

Recovering from disk failure

Kudu nodes can only survive failures of disks on which certain Kudu directories are mounted. For more information about the different Kudu directory types, see the *Directory configuration* topic.

About this task

The following table summarizes the resilience to disk failure in different releases of Apache Kudu.

Table 1: Kudu disk failure behavior

Node Type	Kudu directory type	Kudu releases that crash on disk failure
Master	All	All
Tablet Server	Directory containing WALs	All
Tablet Server	Directory containing tablet metadata	All
Tablet Server	Directory containing data blocks only	Pre-1.6.0

When a disk failure occurs that does not lead to a crash, Kudu will stop using the affected directory, shut down tablets with blocks on the affected directories, and automatically re-replicate the affected tablets to other tablet servers. The affected server will remain alive and print messages to the log indicating the disk failure, for example:

```
E1205 19:06:24.163748 27115 data_dirs.cc:1011] Directory /data/8/kudu/data marked as failed
E1205 19:06:30.324795 27064 log_block_manager.cc:1822] Not using report from /data/8/kudu/data: IO error: Could not open container 0a6283cab82d4e75848f49772d2638fe: /data/8/kudu/data/0a6283cab82d4e75848f49772d2638fe.metadata: Read-only file system (error 30)
E1205 19:06:33.564638 27220 ts_tablet_manager.cc:946] T 4957808439314e0d97795c1394348d80 P 70f7ee61ead54b1885d819f354eb3405: aborting tablet bootstrap: tablet has data in a failed directory
```

While in this state, the affected node will avoid using the failed disk, leading to lower storage volume and reduced read parallelism. The administrator should schedule a brief window to change the directory configuration to exclude the failed disk.

When the disk is repaired, remounted, and ready to be reused by Kudu, take the following steps:

Procedure

1. Make sure that the Kudu portion of the disk is completely empty.
2. Stop the tablet server.
3. Run the `update_dirs` tool. For example, to add `/data/3`, run the following:

```
$ sudo -u kudu kudu fs update_dirs --force --fs_wal_dir=/wals --fs_data_dirs=/data/1,/data/2,/data/3
```

4. Start the tablet server.
5. Run `ksck` to verify cluster health. For example:

```
$ sudo -u kudu kudu cluster ksck master-01.example.com
```

What to do next



Note: Note that existing tablets will not stripe to the restored disk, but any new tablets will stripe to the restored disk.

Related Information

[Changing directory configuration](#)

Recovering from full disks

By default, Kudu reserves a small amount of space, 1% by capacity, in its directories. Kudu considers a disk full if there is less free space available than the reservation. Kudu nodes can only tolerate running out of space on disks on which certain Kudu directories are mounted.

The table below describes this behavior for each type of directory. The behavior is uniform across masters and tablet servers.

Kudu Directory Type	Crash on Full Disk?
Directory containing WALs	Yes
Directory containing tablet metadata	Yes
Directory containing data blocks only	No (see below)

Prior to Kudu 1.7.0, Kudu stripes tablet data across all directories, and will avoid writing data to full directories. Kudu will crash if all data directories are full.

In 1.7.0 and later, new tablets are assigned a disk group consisting of data directories. The number of data directories are as specified by the `-fs_target_data_dirs_per_tablet` flag with the default being 3. If Kudu is not configured with enough data directories for a full disk group, all data directories are used. When a data directory is full, Kudu will stop writing new data to it and each tablet that uses that data directory will write new data to other data directories within its group. If all data directories for a tablet are full, Kudu will crash. Periodically, Kudu will check if full data directories are still full, and will resume writing to those data directories if space has become available.

If Kudu does crash because its data directories are full, freeing space on the full directories will allow the affected daemon to restart and resume writing. Note that it may be possible for Kudu to free some space by running:

```
$ sudo -u kudu kudu fs check --repair
```

However, the above command may also fail if there is too little space left.

It is also possible to allocate additional data directories to Kudu in order to increase the overall amount of storage available. Note that existing tablets will not use new data directories, so adding a new data directory does not resolve issues with full disks.

Related Information

[Changing directory configuration](#)

Bringing a tablet that has lost a majority of replicas back online

If a tablet has permanently lost a majority of its replicas, it cannot recover automatically and operator intervention is required. If the tablet servers hosting a majority of the replicas are down (i.e. ones reported as "TS unavailable" by `ksck`), they should be recovered instead if possible.



Attention: The steps below may cause recent edits to the tablet to be lost, potentially resulting in permanent data loss. Only attempt the procedure below if it is impossible to bring a majority back online.

Suppose a tablet has lost a majority of its replicas. The first step in diagnosing and fixing the problem is to examine the tablet's state using `ksck`:

```
$ sudo -u kudu kudu cluster ksck --tablets=e822cab6c0584bc0858219d1539a17e6
master-00,master-01,master-02
Connected to the Master
Fetched info from all 5 Tablet Servers
Tablet e822cab6c0584bc0858219d1539a17e6 of table 'my_table' is unavailable:
  2 replica(s) not RUNNING
    638a20403e3e4ae3b55d4d07d920e6de (tserver-00:7150): RUNNING
    9a56fa85a38a4edc99c6229cba68aeea (tserver-01:7150): bad state
      State: FAILED
      Data state: TABLET_DATA_READY
```

```
Last status: <failure message>
c311fef7708a4cf9bb11a3e4cbcaab8c (tserver-02:7150): bad state
State: FAILED
Data state: TABLET_DATA_READY
Last status: <failure message>
```

This output shows that, for tablet e822cab6c0584bc0858219d1539a17e6, the two tablet replicas on tserver-01 and tserver-02 failed. The remaining replica is not the leader, so the leader replica failed as well. This means the chance of data loss is higher since the remaining replica on tserver-00 may have been lagging. In general, to accept the potential data loss and restore the tablet from the remaining replicas, divide the tablet replicas into two groups:

1. Healthy replicas: Those in RUNNING state as reported by ksck
2. Unhealthy replicas

For example, in the above ksck output, the replica on tablet server tserver-00 is healthy while the replicas on tserver-01 and tserver-02 are unhealthy. On each tablet server with a healthy replica, alter the consensus configuration to remove unhealthy replicas. In the typical case of 1 out of 3 surviving replicas, there will be only one healthy replica, so the consensus configuration will be rewritten to include only the healthy replica.

```
$ sudo -u kudu kudu remote_replica unsafe_change_config tserver-00:7150 <tablet-id> <tserver-00-uuid>
```

where <tablet-id> is e822cab6c0584bc0858219d1539a17e6 and <tserver-00-uuid> is the uuid of tserver-00, 638a20403e3e4ae3b55d4d07d920e6de.

Once the healthy replicas' consensus configurations have been forced to exclude the unhealthy replicas, the healthy replicas will be able to elect a leader. The tablet will become available for writes though it will still be under-replicated. Shortly after the tablet becomes available, the leader master will notice that it is under-replicated, and will cause the tablet to re-replicate until the proper replication factor is restored. The unhealthy replicas will be tombstoned by the master, causing their remaining data to be deleted.

Rebuilding a Kudu filesystem layout

In the event that critical files are lost, i.e. WALs or tablet-specific metadata, all Kudu directories on the server must be deleted and rebuilt to ensure correctness. Doing so will destroy the copy of the data for each tablet replica hosted on the local server. Kudu will automatically re-replicate tablet replicas removed in this way, provided the replication factor is at least three and all other servers are online and healthy.

About this task



Note: These steps use a tablet server as an example, but the steps are the same for Kudu master servers.



Warning: If multiple nodes need their FS layouts rebuilt, wait until all replicas previously hosted on each node have finished automatically re-replicating elsewhere before continuing. Failure to do so can result in permanent data loss.



Attention: Before proceeding, ensure the contents of the directories are backed up, either as a copy or in the form of other tablet replicas.

Procedure

1. The first step to rebuilding a server with a new directory configuration is emptying all of the server's existing directories. For example, if a tablet server is configured with `--fs_wal_dir=/data/0/kudu-tserver-wal`, `--fs_metadata_dir=/data/0/kudu-tserver-meta`, and `--fs_data_dirs=/data/1/kudu-tserver,/data/2/kudu-tserver`, the following commands will remove the WAL directory's and data directories' contents:

```
# Note: this will delete all of the data from the local tablet server.
```

```
$ rm -rf /data/0/kudu-tserver-wal/* /data/0/kudu-tserver-meta/* /data/1/kudu-tserver/* /data/2/kudu-tserver/*
```

2. If using Cloudera Manager, update the configurations for the rebuilt server to include only the desired directories. Make sure to only update the configurations of servers to which changes were applied, rather than of the entire Kudu service.
3. After directories are deleted, the server process can be started with the new directory configuration. The appropriate sub-directories will be created by Kudu upon starting up.

Physical backups of an entire node

Kudu does not yet provide any built-in backup and restore functionality. However, it is possible to create a physical backup of a Kudu node, either tablet server or master, and restore it later.

Before you begin



Attention: The node to be backed up must be offline during the procedure, or else the backed up or restored data will be inconsistent.



Attention: Certain aspects of the Kudu node (such as its hostname) are embedded in the on-disk data. As such, it's not yet possible to restore a physical backup of a node onto another machine.

Procedure

1. Stop all Kudu processes in the cluster. This prevents the tablets on the backed up node from being rereplicated elsewhere unnecessarily.
2. If creating a backup, make a copy of the WAL, metadata, and data directories on each node to be backed up. It is important that this copy preserve all file attributes as well as sparseness.
3. If restoring from a backup, delete the existing WAL, metadata, and data directories, then restore the backup via move or copy. As with creating a backup, it is important that the restore preserve all file attributes and sparseness.
4. Start all Kudu processes in the cluster.

Scaling storage on Kudu master and tablet servers in the cloud

If you find that the size of your Kudu cloud deployment has exceeded previous expectations, or you simply wish to allocate more storage to Kudu, use the following set of high-level steps as a guide to increasing storage on your Kudu master or tablet server hosts. You must work with your cluster's Hadoop administrators and the system administrators to complete this process. Replace the file paths in the following steps to those relevant to your setup.

Procedure

1. Run a consistency check on the cluster hosts using `ksck`.
2. On all Kudu hosts, create a new file system with the storage capacity you require. For example, `/new/data/dir`.
3. Shutdown the cluster services. For a cluster managed by Cloudera Manager, see *Stopping a cluster*.
4. Copy the contents of your existing data directory, `/current/data/dir`, to the new filesystem at `/new/data/dir`.
5. Move your existing data directory, `/current/data/dir`, to a separate temporary location such as `/tmp/data/dir`.
6. Create a new `/current/data/dir` directory.

```
mkdir /current/data/dir
```

7. Mount `/new/data/dir` as `/current/data/dir`. Make changes to `fstab` as needed.
8. Perform steps 4-7 on all Kudu hosts.
9. Startup cluster services. For a cluster managed by Cloudera Manager, see *Starting a cluster*.
10. Run a consistency check on the cluster hosts using `ksck`.

11. After 10 days, if everything is in working order on all the hosts, get approval from the Hadoop administrators to remove the `/backup/data/dir` directory.

Related Information

[Monitoring cluster health with ksck](#)

Migrating Kudu data from one directory to another on the same host

Take the following steps to move the entire Kudu data from one directory to another.

About this task



Note: The steps were verified on an environment where the master and the server instances were configured to write the WAL/Data to the same directory.

Procedure

1. Stop the Kudu service.
2. Modify the directory configurations for the Master/Server instances.
3. Move the existing data from the old directory, to the new one.
4. Make sure the file/directory ownership is set to the kudu user.
5. Restart the Kudu service.
6. Run `ksck` and verify for the healthy status.

Related Information

[Changing directory configuration](#)

Minimizing cluster disruption during temporary planned downtime of a single tablet server

If a single tablet server is brought down temporarily in a healthy cluster, all tablets will remain available and clients will function as normal, after potential short delays due to leader elections. However, if the downtime lasts for more than `--follower_unavailable_considered_failed_sec` (default 300) seconds, the tablet replicas on the down tablet server will be replaced by new replicas on available tablet servers. This will cause stress on the cluster as tablets re-replicate and, if the downtime lasts long enough, significant reduction in the number of replicas on the down tablet server. This may require the rebalancer to fix.

To work around this, increase `--follower_unavailable_considered_failed_sec` on all tablet servers so the amount of time before re-replication will start is longer than the expected downtime of the tablet server, including the time it takes the tablet server to restart and bootstrap its tablet replicas. To do this, run the following command on each tablet server:

```
$ sudo -u kudu kudu tserver set_flag <TSERVER_ADDRESS> follower_unavailable_considered_failed_sec <NUM_SECONDS>
```

where `<NUM_SECONDS>` is the number of seconds that will encompass the downtime. Once the downtime is finished, reset the flag to its original value.

```
$ sudo -u kudu kudu tserver set_flag <TSERVER_ADDRESS> follower_unavailable_considered_failed_sec <ORIGINAL_VALUE>
```



Attention: Be sure to reset the value of `--follower_unavailable_considered_failed_sec` to its original value.

In Kudu versions 1.7 and lower, the `--force` flag must be provided in the above commands.

Running tablet rebalancing tool

The kudu CLI contains a rebalancing tool that can be used to rebalance tablet replicas among tablet servers. For each table, the tool attempts to balance the number of replicas per tablet server. It will also, without unbalancing any table, attempt to even out the number of replicas per tablet server across the cluster as a whole.

The rebalancing tool should be run as the Kudu admin user, specifying all master addresses:

```
sudo -u kudu kudu cluster rebalance master-01.example.com,master-02.example.com,master-03.example.com
```

When run, the rebalancer will report on the initial tablet replica distribution in the cluster, log the replicas it moves, and print a final summary of the distribution when it terminates:

```
Per-server replica distribution summary:
  Statistic | Value
-----+-----
  Minimum Replica Count | 0
  Maximum Replica Count | 24
  Average Replica Count | 14.400000
Per-table replica distribution summary:
  Replica Skew | Value
-----+-----
  Minimum | 8
  Maximum | 8
  Average | 8.000000

I0613 14:18:49.905897 3002065792 rebalancer.cc:779] tablet e7ee9ade95b342a7a
94649b7862b345d: 206a51de1486402bbb214b5ce97a633c -> 3b4d9266ac8c45ff9a5d4d7
c3elcb326 move scheduled
I0613 14:18:49.917578 3002065792 rebalancer.cc:779] tablet 5f03944529f44626
a0d6ec8b1edc566e: 6e64c4165b864cbab0e67ccd82091d60 -> ba8c22ab030346b4baa289
d6d11d0809 move scheduled
I0613 14:18:49.928683 3002065792 rebalancer.cc:779] tablet 9373fee3bfe74ce
c9054737371a3b15d: fab382adf72c480984c6cc868fdd5f0e -> 3b4d9266ac8c45ff9a5d4
d7c3elcb326 move scheduled

... (full output elided)

I0613 14:19:01.162802 3002065792 rebalancer.cc:842] tablet f4c046f18b174cc
2974c65ac0bf52767: 206a51de1486402bbb214b5ce97a633c -> 3b4d9266ac8c45ff9a5d4
d7c3elcb326 move completed: OK

rebalancing is complete: cluster is balanced (moved 28 replicas)
Per-server replica distribution summary:
  Statistic | Value
-----+-----
  Minimum Replica Count | 14
  Maximum Replica Count | 15
  Average Replica Count | 14.400000
Per-table replica distribution summary:
  Replica Skew | Value
-----+-----
  Minimum | 1
  Maximum | 1
  Average | 1.000000
```

If more details are needed in addition to the replica distribution summary, use the `--output_replica_distribution_details` flag. If added, the flag makes the tool print per-table and per-tablet server replica distribution statistics as well.

Use the `--report_only` flag to get a report on table-wide and cluster-wide replica distribution statistics without starting any rebalancing activity.

The rebalancer can also be restricted to run on a subset of the tables by supplying the `--tables` flag. Note that, when running on a subset of tables, the tool will not attempt to balance the cluster as a whole.

The length of time rebalancing is run for can be controlled with the flag `--max_run_time_sec`. By default, the rebalancer will run until the cluster is balanced. To control the amount of resources devoted to rebalancing, modify the flag `--max_moves_per_server`. See `kudu cluster rebalance --help` for more.

It's safe to stop the rebalancer tool at any time. When restarted, the rebalancer will continue rebalancing the cluster.

The rebalancer tool requires all registered tablet servers to be up and running to proceed with the rebalancing process in order to avoid possible conflicts and races with the automatic re-replication and to keep replica placement optimal for current configuration of the cluster. If a tablet server becomes unavailable during the rebalancing session, the rebalancer will exit. As noted above, it's safe to restart the rebalancer after resolving the issue with unavailable tablet servers.

The rebalancing tool can rebalance Kudu clusters running older versions as well, with some restrictions. Consult the following table for more information. In the table, "RF" stands for "replication factor".

Version Range	Rebalances RF = 1 Tables?	Rebalances RF > 1 Tables?
$v < 1.4.0$	No	No
$1.4.0 \leq v < 1.7.1$	No	Yes
$v \geq 1.7.1$	Yes	Yes

If the rebalancer is running against a cluster where rebalancing replication factor one tables is not supported, it will rebalance all the other tables and the cluster as if those singly-replicated tables did not exist.

Running a tablet rebalancing tool on a rack-aware cluster

It is possible to use the `kudu cluster rebalance` tool to establish the placement policy on a cluster. This might be necessary when the rack awareness feature is first configured or when re-replication violated the placement policy.

About this task

The rebalancing tool breaks its work into three phases:

Procedure

1. The rack-aware rebalancer tries to establish the placement policy. Use the `##disable_policy_fixer` flag to skip this phase.
2. The rebalancer tries to balance load by location, moving tablet replicas between locations in an attempt to spread tablet replicas among locations evenly. The load of a location is measured as the total number of replicas in the location divided by the number of tablet servers in the location. Use the `##disable_cross_location_rebalancing` flag to skip this phase.
3. The rebalancer tries to balance the tablet replica distribution within each location, as if the location were a cluster on its own. Use the `##disable_intra_location_rebalancing` flag to skip this phase.

What to do next

By using the `##report_only` flag, it's also possible to check if all tablets in the cluster conform to the placement policy without attempting any replica movement.

Related Information

[Rack awareness \(Location awareness\)](#)

Running a tablet rebalancing tool in Cloudera Manager

You access and run the tablet rebalancing tool from Cloudera Manager.

Procedure

1. Browse to Clusters Kudu .
2. Click Actions and select Run Kudu Rebalancer Tool.

What to do next

In Cloudera Manager, the rebalancer runs with the default flags.

Decommissioning or permanently removing a tablet server from a cluster

Kudu does not currently support an automated way to remove a tablet server from a cluster permanently. Use the following steps to manually remove a tablet server:

Procedure

1. Ensure the cluster is in good health using ksck.
2. If the tablet server contains any replicas of tables with replication factor 1, these replicas must be manually moved off the tablet server prior to shutting it down. Use the kudu tablet change_config move_replica tool for this.
3. Shut down the tablet server. After -follower_unavailable_considered_failed_sec, which defaults to 5 minutes, Kudu will begin to re-replicate the tablet server's replicas to other servers. Wait until the process is finished. Progress can be monitored using ksck.
4. Once all the copies are complete, ksck will continue to report the tablet server as unavailable. The cluster will otherwise operate fine without the tablet server. To completely remove it from the cluster so ksck shows the cluster as completely healthy, restart the masters. In the case of a single master, this will cause cluster downtime. With multi-master, restart the masters in sequence to avoid cluster downtime.

What to do next



Important: Do not shut down multiple tablet servers at once. To remove multiple tablet servers from the cluster, follow the above instructions for each tablet server, ensuring that the previous tablet server is removed from the cluster and ksck is healthy before shutting down the next.

Related Information

[Monitoring cluster health with ksck](#)

Using cluster names in the `kudu` command line tool

When using the kudu command line tool, it can be difficult to remember the precise list of Kudu master RPC addresses needed to communicate with a cluster, especially when managing multiple clusters. As an alternative, you can use the command line tool to identify clusters by name.

Procedure

1. Create a new directory to store the Kudu configuration file.
2. Export the path to this newly created directory in the KUDU_CONFIG environment variable.
3. Create a file called kudorc in the new directory.
4. Populate kudorc as follows, substituting your own cluster names and RPC addresses:

```
clusters_info:
  cluster_name1:
```

```
master_addresses: ip1:port1,ip2:port2,ip3:port3
cluster_name2:
master_addresses: ip4:port4
```

5. When using the kudu command line tool, replace the list of Kudu master RPC addresses with the cluster name, prepended with the character @. For example:

```
$ sudo -u kudu kudu ksck @cluster_name1
```



Note: Cluster names may be used as input in any invocation of the kudu command line tool that expects a list of Kudu master RPC addresses.

Managing Kudu with Cloudera Manager

This topic describes the tasks you can perform to manage the Kudu service using Cloudera Manager. You can use Cloudera Manager to upgrade the Kudu service, start and stop the Kudu service, monitor operations, and configure the Kudu master and tablet servers, among other tasks. Depending on your deployment, there are several different configuration settings you may need to modify.

Installing and upgrading the Kudu service

You can install Kudu through the Cloudera Manager installation wizard, using either parcels or packages. For instructions, see the *Kudu Installation topics*.

Enabling core dump for the Kudu service

If Kudu crashes, you can use Cloudera Manager to generate a core dump to get more information about the crash.

Procedure

1. Go to the Kudu service.
2. Click the Configuration tab.
3. Search for core dump.
4. Check the checkbox for the Enable Core Dump property.
5. (Optional) Unless otherwise configured, the dump file is generated in the default core dump directory, `/var/log/kudu`, for both the Kudu master and the tablet servers.
 - To configure a different dump directory for the Kudu master, modify the value of the Kudu Master Core Dump Directory property.
 - To configure a different dump directory for the Kudu tablet servers, modify the value of the Kudu Tablet Server Core Dump Directory property.
6. Click Save Changes.

Verifying the Impala dependency on Kudu

In a Cloudera Manager deployment, once the Kudu service is installed, Impala will automatically identify the Kudu Master. However, if your Impala queries don't work as expected, use the following steps to make sure that the Impala service is set to be dependent on Kudu.

Procedure

1. Go to the Impala service.
2. Click the Configuration tab.
3. Search for kudu.
4. Make sure the Kudu Service property is set to the right Kudu service.
5. Click Save Changes.

Using the Charts Library with the Kudu service

By default, the Status tab for the Kudu service displays a dashboard containing a limited set of charts.

About this task

The Kudu service's Charts Library tab also displays a dashboard containing a much larger set of charts, organized by categories such as process charts, host charts, CPU charts, and so on, depending on the entity (service, role, or host) that you are viewing. You can use these charts to keep track of disk space usage, the rate at which data is being inserted/modified in Kudu across all tables, or any critical cluster events. You can also use them to keep track of individual tables. For example, to find out how much space a Kudu table is using on disk:

Procedure

1. Go to the Kudu service and navigate to the Charts Library tab.
2. On the left-hand side menu, click Tables to display the list of tables currently stored in Kudu.
3. Click on a table name to view the default dashboard for that table. The Total Tablet Size On Disk Across Kudu Replicas chart displays the total size of the table on disk using a time-series chart.

Hovering with your mouse over the line on the chart opens a small pop-up window that displays information about that data point. Click the data stream within the chart to display a larger pop-up window that includes additional information for the table at the point in time where the mouse was clicked.

Kudu security

Kudu includes security features that allow Kudu clusters to be hardened against access from unauthorized users. Kudu uses strong authentication with Kerberos, while communication between Kudu clients and servers can now be encrypted with TLS. Kudu also allows you to use HTTPS encryption to connect to the web UI.

Kudu authentication with Kerberos

Kudu can be configured to enforce secure authentication among servers, and between clients and servers. Authentication prevents untrusted actors from gaining access to Kudu, and securely identifies connecting users or services for authorization checks. Authentication in Kudu is designed to interoperate with other secure Hadoop components by utilizing Kerberos.

Configure authentication on Kudu servers using the `--rpc_authentication` flag, which can be set to one of the following options:

- required - Kudu will reject connections from clients and servers who lack authentication credentials.
- optional - Kudu will attempt to use strong authentication, but will allow unauthenticated connections.
- disabled - Kudu will only allow unauthenticated connections.

By default, the flag is set to optional. To secure your cluster, set `--rpc_authentication` to required.

Internal private key infrastructure (PKI)

Kudu uses an internal PKI to issue X.509 certificates to servers in the cluster. Connections between peers who have both obtained certificates will use TLS for authentication. In such cases, neither peer needs to contact the Kerberos KDC.

X.509 certificates are only used for internal communication among Kudu servers, and between Kudu clients and servers. These certificates are never presented in a public facing protocol. By using internally-issued certificates, Kudu offers strong authentication which scales to huge clusters, and allows TLS encryption to be used without requiring you to manually deploy certificates on every node.

Authentication tokens

After authenticating to a secure cluster, the Kudu client will automatically request an authentication token from the Kudu master. An authentication token encapsulates the identity of the authenticated user and carries the

Kudu master's RSA signature so that its authenticity can be verified. This token will be used to authenticate subsequent connections. By default, authentication tokens are only valid for seven days, so that even if a token were compromised, it cannot be used indefinitely. For the most part, authentication tokens should be completely transparent to users. By using authentication tokens, Kudu is able to take advantage of strong authentication, without paying the scalability cost of communicating with a central authority for every connection.

When used with distributed compute frameworks such as Apache Spark, authentication tokens can simplify configuration and improve security. For example, the Kudu Spark connector will automatically retrieve an authentication token during the planning stage, and distribute the token to tasks. This allows Spark to work against a secure Kudu cluster where only the planner node has Kerberos credentials.

Client authentication to secure Kudu clusters

Users running client Kudu applications must first run the `kinit` command to obtain a Kerberos ticket-granting ticket. For example:

```
kinit admin@EXAMPLE-REALM.COM
```

Once authenticated, you use the same client code to read from and write to Kudu servers with and without the Kerberos configuration.

Scalability

Kudu authentication is designed to scale to thousands of nodes, which means it must avoid unnecessary coordination with a central authentication authority (such as the Kerberos KDC) for each connection. Instead, Kudu servers and clients use Kerberos to establish initial trust with the Kudu master, and then use alternate credentials for subsequent connections. As described previously, the Kudu master issues internal X.509 certificates to tablet servers on startup, and temporary authentication tokens to clients on first contact.

Coarse-grained authorization

Kudu supports coarse-grained authorization checks for client requests based on the client's authenticated Kerberos principal (user or service). Access levels are granted based on whitelist-style Access Control Lists (ACLs), one for each level. Each ACL specifies a comma-separated list of users, or may be set to '*' to indicate that all authenticated users have access rights at the specified level.

The two levels of access which can be configured are:

- **Superuser** - Principals authorized as a superuser can perform certain administrative functions such as using the kudu command line tool to diagnose and repair cluster issues.
- **User** - Principals authorized as a user are able to access and modify all data in the Kudu cluster. This includes the ability to create, drop, and alter tables, as well as read, insert, update, and delete data. The default value for the User ACL is '*', which allows all users access to the cluster. However, if authentication is enabled, this will restrict access to only those users who are able to successfully authenticate using Kerberos. Unauthenticated users on the same network as the Kudu servers will be unable to access the cluster.



Note: Internally, Kudu has a third access level for the daemons themselves called **Service**. This is used to ensure that users cannot connect to the cluster and pose as tablet servers.

Encryption

Kudu allows you to use TLS to encrypt all communications among servers, and between clients and servers.

Configure TLS encryption on Kudu servers using the `--rpc_encryption` flag, which can be set to one of the following options:

- **required** - Kudu will reject unencrypted connections.
- **optional** - Kudu will attempt to use encryption, but will allow unencrypted connections.
- **disabled** - Kudu will not use encryption.

By default, the flag is set to optional. To secure your cluster, set `--rpc_encryption` to required.



Note: Kudu will automatically turn off encryption on local loopback connections, since traffic from these connections is never exposed externally. This allows locality-aware compute frameworks, such as Spark and Impala, to avoid encryption overhead, while still ensuring data confidentiality.

Web UI encryption

The Kudu web UI can be configured to use secure HTTPS encryption by providing each server with TLS certificates. Use the `--webserver_certificate_file` and `--webserver_private_key_file` properties to specify the certificate and private key to be used for communication.

Alternatively, you can choose to completely disable the web UI by setting `--webserver_enabled` flag to false on the Kudu servers.

Web UI redaction

To prevent sensitive data from being included in the web UI, all row data is redacted. Table metadata, such as table names, column names, and partitioning information is not redacted. Alternatively, you can choose to completely disable the web UI by setting the `--webserver_enabled` flag to false on the Kudu servers.



Note: Disabling the web UI will also disable REST endpoints such as `/metrics`. Monitoring systems rely on these endpoints to gather metrics data.

Log redaction

To prevent sensitive data from being included in Kudu server logs, all row data will be redacted. You can turn off log redaction using the `--redact` flag.

Configuring a secure Kudu cluster using Cloudera Manager

First you need to enable Kerberos authentication and RPC encryption. Next, configure coarse-grained authorization with ALCs. Lastly, configure HTTPS encryption for both the Kudu master and tablet server web UIs.



Warning: If you are upgrading from Kudu 1.2.0 / CDH 5.10.x, you must upgrade both Kudu and CDH parcels (or packages) at the same time. If you upgrade Kudu but do not upgrade CDH, new Kudu features such as Security will not be available. Note that even though you might be able to see the updated configuration options for Kudu security in Cloudera Manager, configuring them will have no effect.

Enabling Kerberos authentication and RPC encryption

You must already have a secure Cloudera Manager cluster with Kerberos authentication enabled. If this is not the case, then you first need to enable Kerberos authentication using the Cloudera Manager Wizard. See

Procedure

1. In Cloudera Manager, navigate to **Kudu Configuration**.
2. In the Search field, type Kerberos to show the relevant properties.
3. Find and edit the following properties according to your cluster configuration:

Field	Usage Notes
Kerberos Principal	Set to the default principal, kudu. Currently, Kudu does not support configuring a custom service principal for Kudu processes.
Enable Secure Authentication And Encryption	Select this checkbox to enable authentication and RPC encryption between all Kudu clients and servers, as well as between individual servers. Only enable this property after you have configured Kerberos.

4. Click **Save Changes**.
5. You will see an error message that tells you the Kudu keytab is missing. To generate the keytab, go to the top navigation bar and click **Administration Security**.
6. Go to the **Kerberos Credentials** tab. On this page you will see a list of the existing Kerberos principals for services running on the cluster.

- Click Generate Missing Credentials. Once the Generate Missing Credentials command has finished running, you will see the Kudu principal added to the list.

Configuring coarse-grained authorization with ACLs

The coarse-grained authorization can be configured with the following two ACLs: Superuser Access Control List and User Access Control List. The Superuser ACL is the list of all the superusers that can access the cluster. User-level access can be controlled by using the User ACL. By default, all the users can access the clusters. But when you enable authentication using Kerberos, only the users who are able to authenticate successfully can access the cluster.

Procedure

- Go to the Kudu service.
- Click the Configuration tab.
- Select Category Security .
- In the Search field, type ACL to show the relevant properties.
- Edit the following properties according to your cluster configuration:

Field	Usage Notes
Superuser Access Control List	Add a comma-separated list of superusers who can access the cluster. By default, this property is left blank. *' indicates that all authenticated users will be given superuser access.
User Access Control List	Add a comma-separated list of users who can access the cluster. By default, this property is set to '*'. The default value of '*' allows all users access to the cluster. However, if authentication is enabled, this will restrict access to only those users who are able to successfully authenticate using Kerberos. Unauthenticated users on the same network as the Kudu servers will be unable to access the cluster. Add the impala user to this list to allow Impala to query data in Kudu. You might choose to add any other relevant usernames if you want to give access to Spark Streaming jobs.

- Click Save Changes.

Configuring HTTPS encryption for the Kudu master and tablet server web UIs

Lastly, you enable TLS/SSL encryption (over HTTPS) for browser-based connections to both the Kudu master and tablet server web UIs.

Procedure

- Go to the Kudu service.
- Click the Configuration tab.
- Select Category Security .
- In the Search field, type TLS/SSL to show the relevant properties.
- Edit the following properties according to your cluster configuration:

Field	Usage Notes
Master TLS/SSL Server Private Key File (PEM Format)	Set to the path containing the Kudu master host's private key (PEM-format). This is used to enable TLS/SSL encryption (over HTTPS) for browser-based connections to the Kudu master web UI.
Tablet Server TLS/SSL Server Private Key File (PEM Format)	Set to the path containing the Kudu tablet server host's private key (PEM-format). This is used to enable TLS/SSL encryption (over HTTPS) for browser-based connections to Kudu tablet server web UIs.
Master TLS/SSL Server Certificate File (PEM Format)	Set to the path containing the signed certificate (PEM-format) for the Kudu master host's private key (set in Master TLS/SSL Server Private Key File). The certificate file can be created by concatenating all the appropriate root and intermediate certificates required to verify trust.

Field	Usage Notes
Tablet Server TLS/SSL Server Certificate File (PEM Format)	Set to the path containing the signed certificate (PEM-format) for the Kudu tablet server host's private key (set in Tablet Server TLS/SSL Server Private Key File). The certificate file can be created by concatenating all the appropriate root and intermediate certificates required to verify trust.
Enable TLS/SSL for Master Server	Enables HTTPS encryption on the Kudu master web UI.
Enable TLS/SSL for Tablet Server	Enables HTTPS encryption on the Kudu tablet server Web UIs.

6. Click Save Changes.

Configuring a secure Kudu cluster using the command line

You should set the configuration parameters on all the servers (master and tablet servers) to ensure that a Kudu cluster is secure.



Important: Follow these command-line instructions on systems that do not use Cloudera Manager. If you are using Cloudera Manager, see [Configuring a secure Kudu cluster using Cloudera Manager](#) on page 33.

```
# Connection Security
#-----
--rpc_authentication=required
--rpc_encryption=required
--keytab_file=<path-to-kerberos-keytab>
# Web UI Security
#-----
--webserver_certificate_file=<path-to-cert-pem>
--webserver_private_key_file=<path-to-key-pem>
# optional
--webserver_private_key_password_cmd=<password-cmd>

# If you prefer to disable the web UI entirely:
--webserver_enabled=false

# Coarse-grained authorization
#-----
# This example ACL setup allows the 'impala' user as well as the
# 'etl_service_account' principal access to all data in the
# Kudu cluster. The 'hadoopadmin' user is allowed to use administrative
# tooling. Note that by granting access to 'impala', other users
# may access data in Kudu via the Impala service subject to its own
# authorization rules.
--user_acl=impala,etl_service_account
--admin_acl=hadoopadmin
```

More information about these flags can be found in the [configuration reference documentation](#).

Related Information

[Apache Kudu Configuration Reference](#)

Apache Kudu background maintenance tasks

Kudu relies on running background tasks for many important maintenance activities. These tasks include flushing data from memory to disk, compacting data to improve performance, freeing up disk space, and more.

Maintenance manager

The maintenance manager schedules and runs background tasks. At any given point in time, the maintenance manager is prioritizing the next task based on improvements needed at that moment, such as relieving memory pressure, improving read performance, or freeing up disk space.

The number of worker threads dedicated to running background tasks can be controlled by setting `--maintenance_manager_num_threads`.

With Kudu 1.4, the maintenance manager features improved utilization of the configured maintenance threads. Previously, maintenance work would only be scheduled a maximum of 4 times per second, but now maintenance work will be scheduled immediately whenever any configured thread is available. Make sure that the `--maintenance_manager_num_threads` property is set to at most a 1:3 ratio for Maintenance Manager threads to the number of data directories (for spinning disks). This will improve the throughput of write-heavy workloads.

Flushing data to disk

Flushing data from memory to disk relieves memory pressure and can improve read performance by switching from a write-optimized, row-oriented in-memory format in the MemRowSet, to a read-optimized, column-oriented format on disk.

Background tasks that flush data include `FlushMRSOp` and `FlushDeltaMemStoresOp`. The metrics associated with these operations have the prefix `flush_mrs` and `flush_dms`, respectively.

With Kudu 1.4, the maintenance manager aggressively schedules flushes of in-memory data when memory consumption crosses 60 percent of the configured process-wide memory limit. The backpressure mechanism which begins to throttle client writes was also adjusted to not begin throttling until memory consumption reaches 80 percent of the configured limit. These two changes together result in improved write throughput, more consistent latency, and fewer timeouts due to memory exhaustion.

Compacting on-disk data

Kudu constantly performs several compaction tasks in order to maintain consistent read and write performance over time.

- A merging compaction, which combines multiple `DiskRowSets` together into a single `DiskRowSet`, is run by `CompactRowSetsOp`.
- Kudu also runs two types of delta store compaction operations: `MinorDeltaCompactionOp` and `MajorDeltaCompactionOp`.

For more information on what these compaction operations do, see the [Kudu Tablet design document](#).

The metrics associated with these tasks have the prefix `compact_rs`, `delta_minor_compact_rs`, and `delta_major_compact_rs`, respectively.

Related Information

[Kudu Tablet design document](#)

Write-ahead log garbage collection

Kudu maintains a write-ahead log (WAL) per tablet that is split into discrete fixed-size segments. A tablet periodically rolls the WAL to a new log segment when the active segment reaches a size threshold (configured by the `--log_segment_size_mb` property).

In order to save disk space and decrease startup time, a background task called `LogGCOp` attempts to garbage-collect (GC) old WAL segments by deleting them from disk once it is determined that they are no longer needed by the local node for durability.

The metrics associated with this background task have the prefix `log_gc`.

Tablet history garbage collection and the ancient history mark

Kudu uses a multiversion concurrency control (MVCC) mechanism to ensure that snapshot scans can proceed isolated from new changes to a table. Therefore, periodically, old historical data should be garbage-collected (removed) to free up disk space. While Kudu never removes rows or data that are visible in the latest version of the data, Kudu does remove records of old changes that are no longer visible.

The specific threshold in time (in the past) beyond which historical MVCC data becomes inaccessible and is free to be deleted is called the ancient history mark (AHM). The AHM can be configured by setting the `--tablet_history_max_age_sec` property.

There are two background tasks that remove historical MVCC data older than the AHM:

- The one that runs the merging compaction, called `CompactRowSetsOp` (see above).
- A separate background task deletes old undo delta blocks, called `UndoDeltaBlockGCOp`. Running `UndoDeltaBlockGCOp` reduces disk space usage in all workloads, but particularly in those with a higher volume of updates or upserts. The metrics associated with this background task have the prefix `undo_delta_block`.