Galera Replication Demystified

how does it work ?

about.me/lefred

Who am I ?

Frédéric Descamps

- @lefred

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- @lefred
- Working for Percona since 2011

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- Working for Percona since 2011
- Senior Architect
- Managing MySQL since 3.23
- devops believer
- and I installed my first Galera Cluster in February 2010 ;-)

Galera Replication

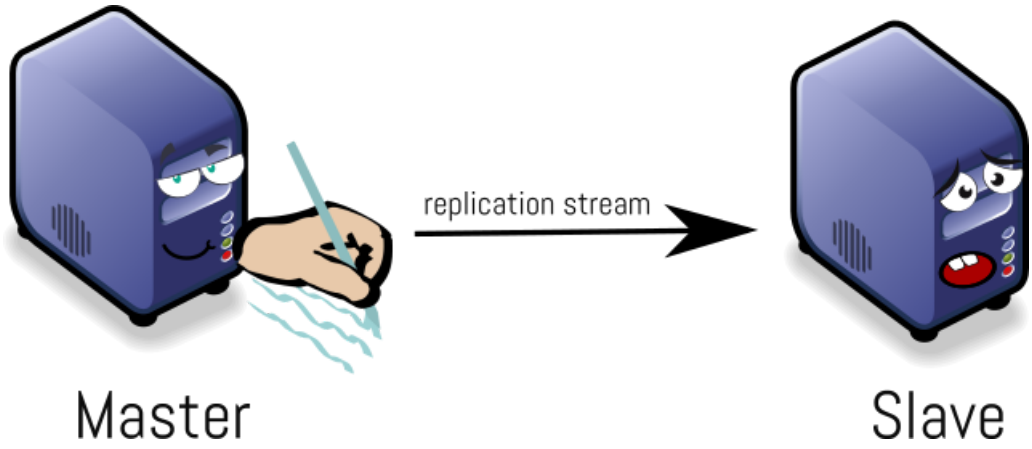
Cluster

Galera Replication - Cluster

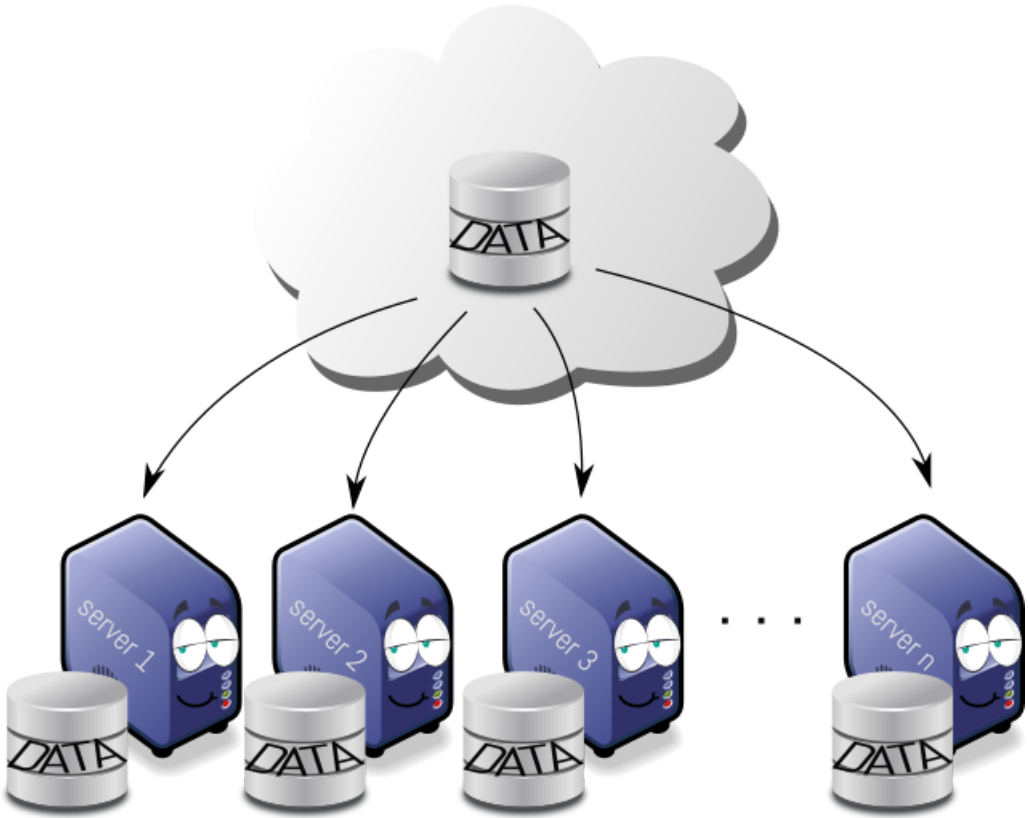
What is it ?

What does it handle ?

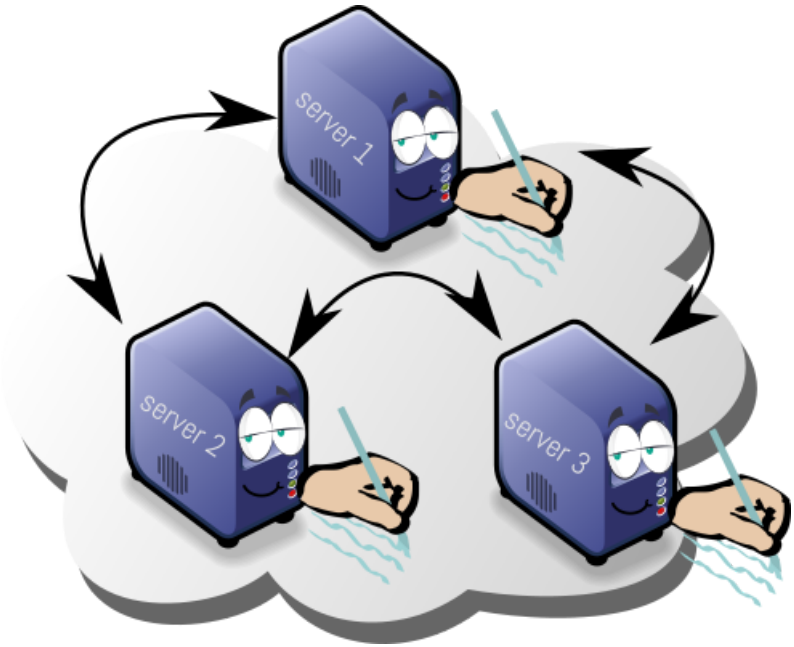
Standard asyncrhonous replication is **server-centric**, one server streams data to another one. All the nodes have a specific role.



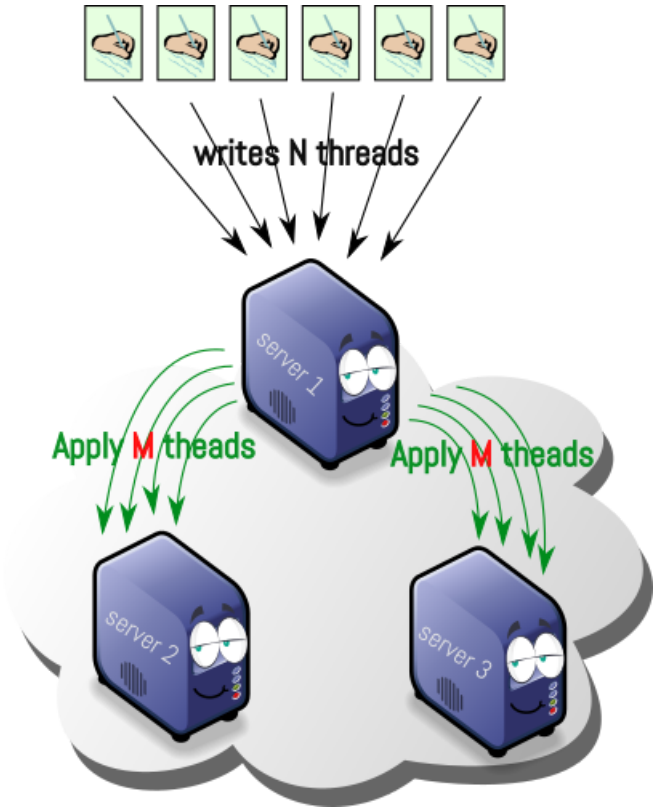
In Galera, the dataset is **synchronized** between one or more servers:
data-centric



You can write to any node in your cluster No need to worry about eventual out-of-sync



Write events/transactions are sent in parallel



Cluster Membership

- determined **by the cluster**
- *wsrep_cluster_address* is just a pointer
- any node is permitted to join that
  - knows the cluster name
  - can find a single active cluster node

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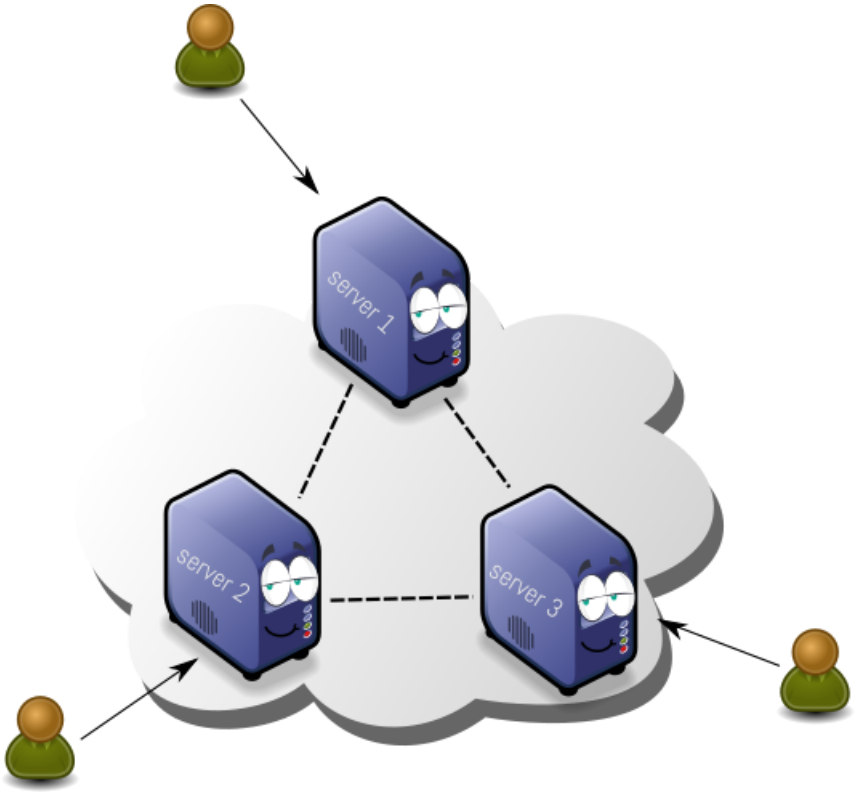
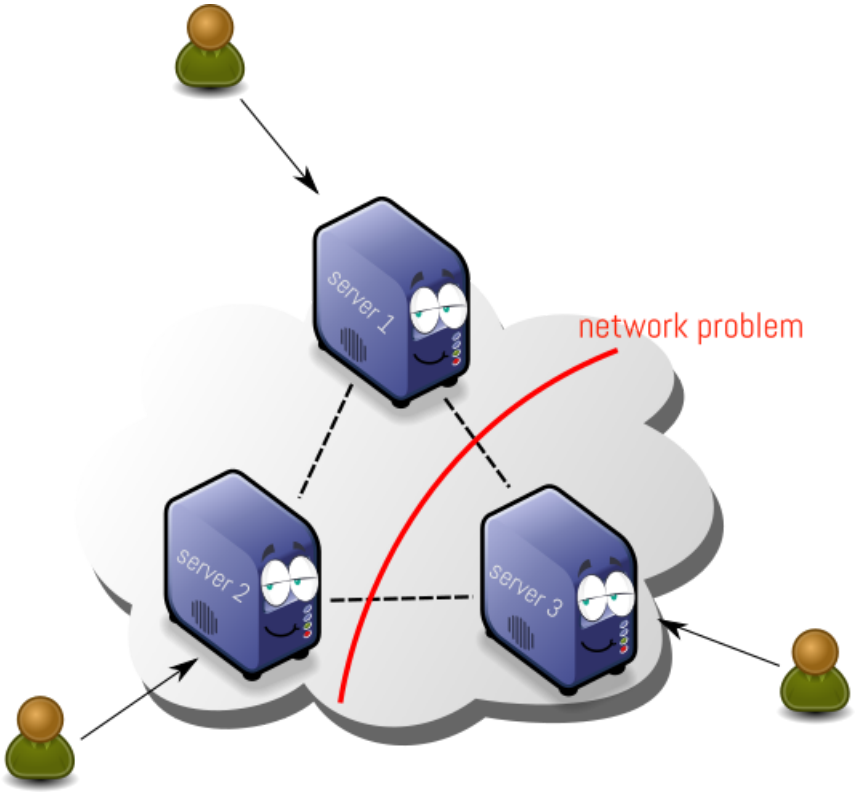
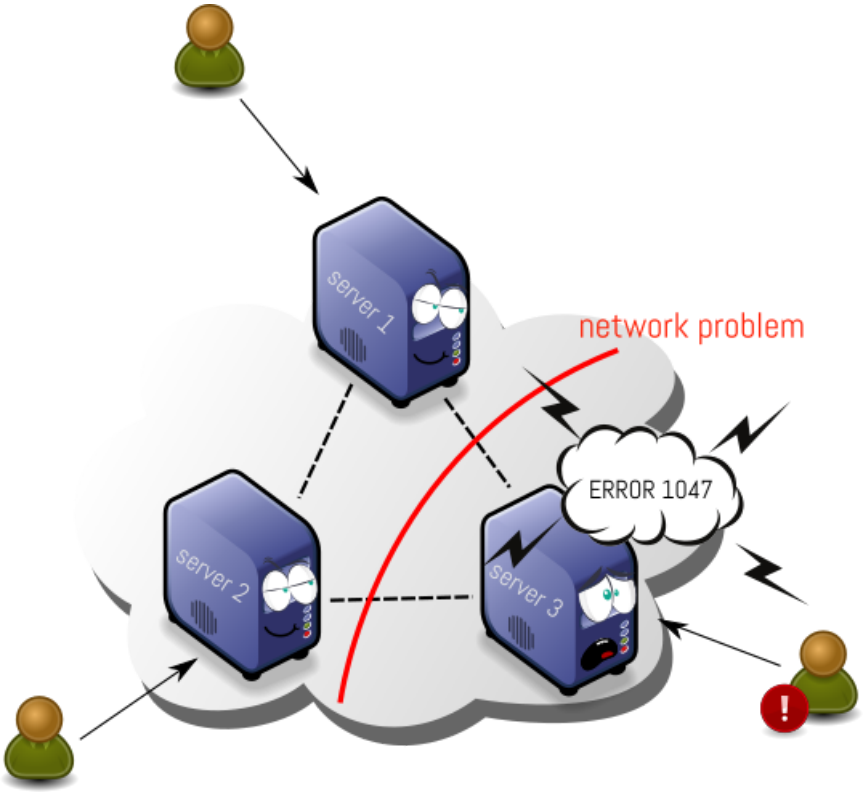
```
wsrep_cluster_address = gcomm://192.168.1.1,192.168.1.2,192.168.1.3
```

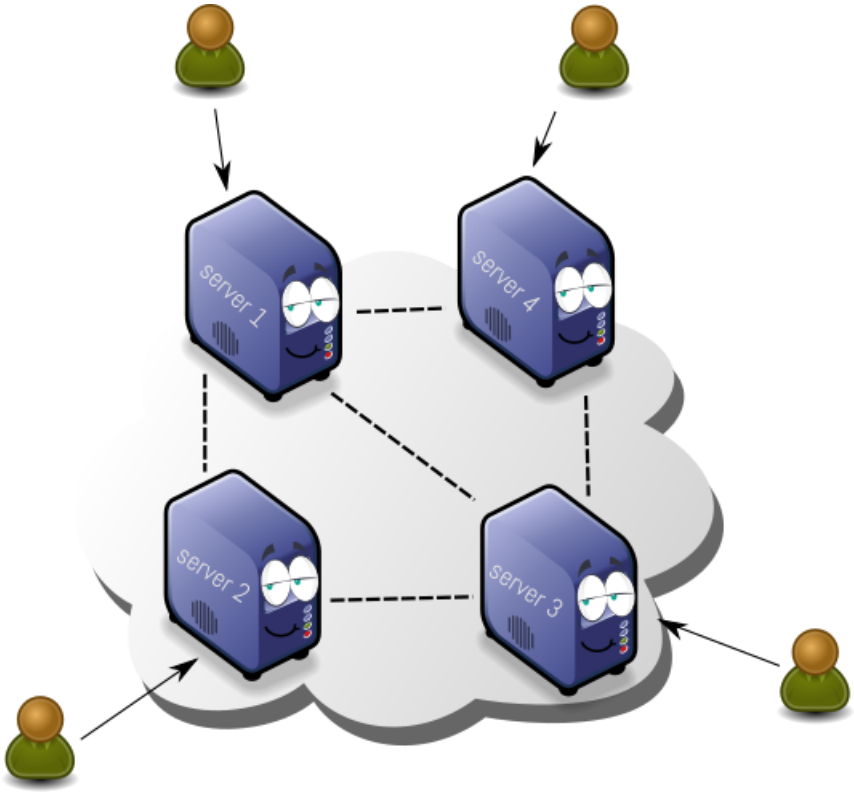
The cluster manages **quorum**

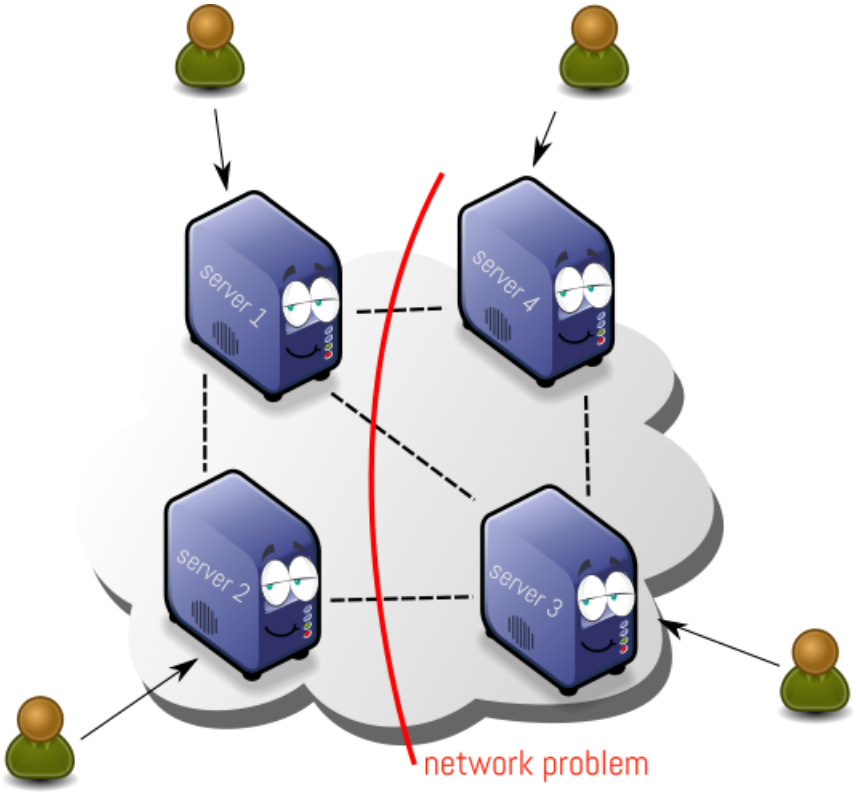
and has split-brain protection.

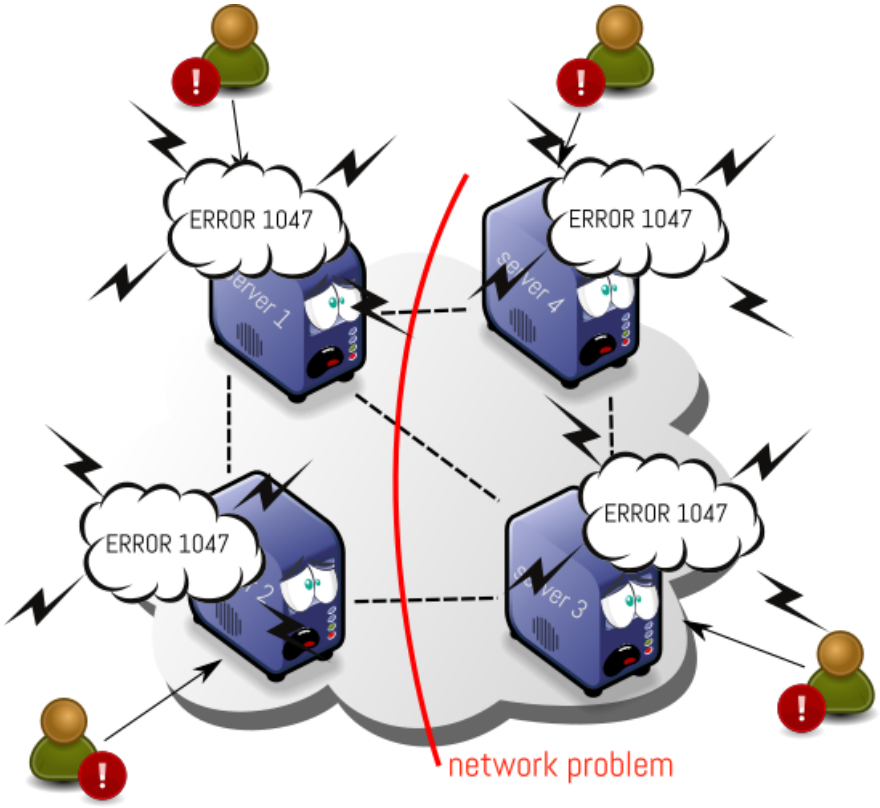

server 1
server 2
server 3


server 1
network problem
server 2
server 3


server 1
network problem
ERROR 1047
server 2
server 3
!


server 1
server 4
server 2
server 3


server 1
server 4
server 2
server 3
network problem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Replication

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- Serialized by Group Communication

GTID

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  - though they appear the same

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- GTIDs ensure cluster members are consistent with each other
  - nodes joining a cluster have their GTIDs checked
- GTIDs can be used to compare downed nodes to each other

GTID

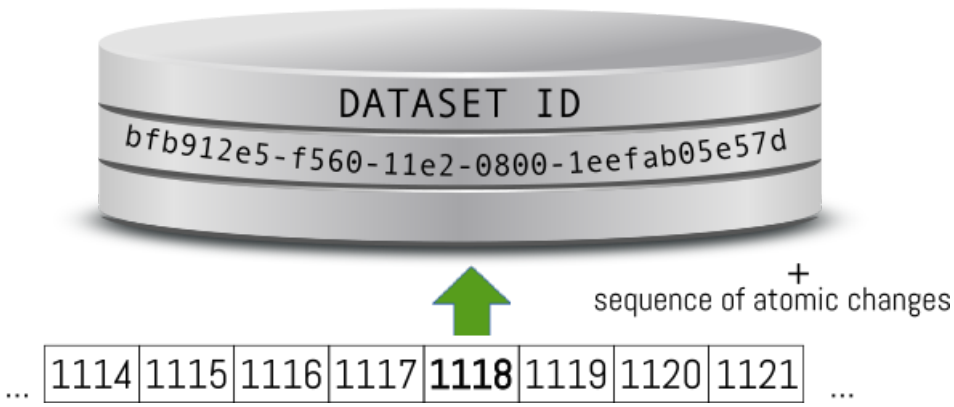
The highest GTID is the most recently written

Generally the best practice it to bootstrap the node with the most recent data

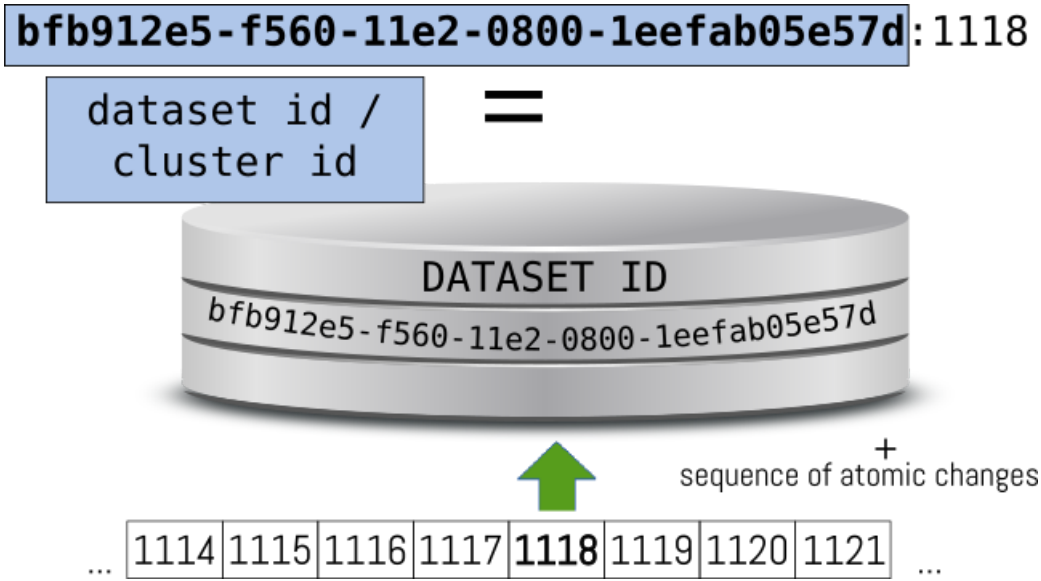
GTID

bfb912e5-f560-11e2-0800-1eefab05e57d:1118

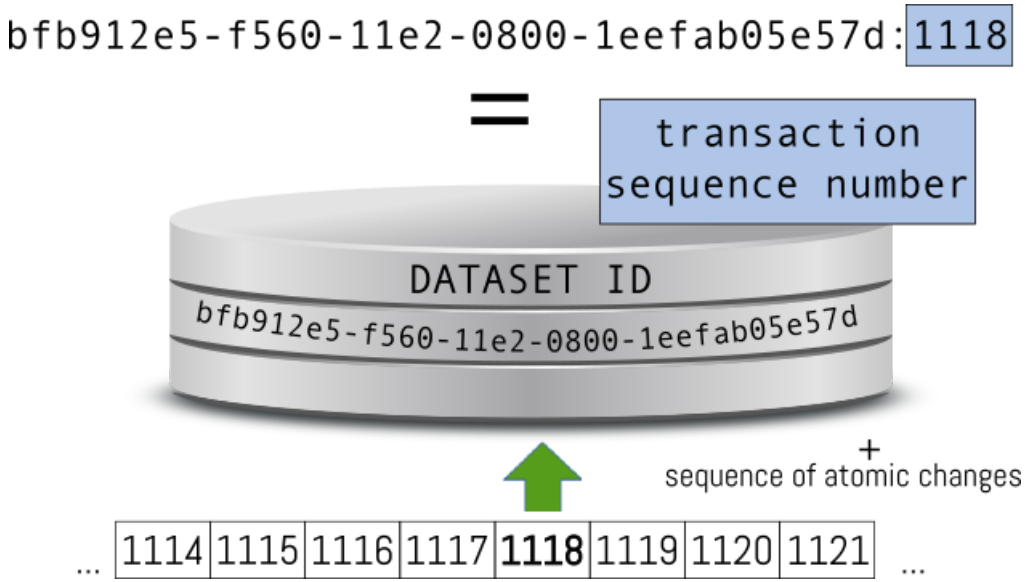
=



GTID


bfb912e5-f560-11e2-0800-1eefab05e57d:1118
dataset id / cluster id
=
DATASET ID
bfb912e5-f560-11e2-0800-1eefab05e57d
+
sequence of atomic changes
... 1114 1115 1116 1117 1118 1119 1120 1121 ...

GTID


bfb912e5-f560-11e2-0800-1eefab05e57d:1118
=
transaction sequence number
DATASET ID
bfb912e5-f560-11e2-0800-1eefab05e57d
+
sequence of atomic changes
... 1114 1115 1116 1117 1118 1119 1120 1121 ...

Global Transaction IDs

- initial dataset
  - bfb912e5-f560-11e2-0800-1eefab05e57d:**0**

Global Transaction IDs

- initial dataset
  - bfb912e5-f560-11e2-0800-1eefab05e57d:**0**
- first change/transaction/writeset
  - bfb912e5-f560-11e2-0800-1eefab05e57d:**1**

Global Transaction IDs

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  - bfb912e5-f560-11e2-0800-1eefab05e57d:**0**
- first change/transaction/writeset
  - bfb912e5-f560-11e2-0800-1eefab05e57d:**1**
- undefined GTID
  - 00000000-0000-0000-0000-000000000000:**-1**

Global Transaction IDs : Galera vs MySQL 5.6

Galera GTID :

```
bfb912e5-f560-11e2-0800-1eefab05e57d:1118
```

MySQL 5.6 GTID :


```
3e11fa47-71ca-11e2-9e33-c80aa9429562:23
```

Global Transaction IDs : Galera vs MySQL 5.6

Galera GTID :

`bfb912e5-f560-11e2-0800-1eefab05e57d:1118`

dataset / cluster ID

MySQL 5.6 GTID :

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server ID

Global Transaction IDs : Galera vs MySQL 5.6

Galera GTID :

`bfb912e5-f560-11e2-0800-1eefab05e57d`:`1118`

dataset / cluster ID

data change inside the cluster

MySQL 5.6 GTID :

`3e11fa47-71ca-11e2-9e33-c80aa9429562`:`23`

server ID

trx processed by the server

Global Transaction IDs : Galera vs MySQL 5.6

In MySQL 5.6

```
9a511b7b-7059-11e2-9a24-08002762b8af:32
9a511b7b-7059-11e2-9a24-08002762b8af:33
9a511b7b-7059-11e2-9a24-08002762b8af:34
[ new master promoted ]
3e11fa47-71ca-11e2-9e33-c80aa9429562:1
3e11fa47-71ca-11e2-9e33-c80aa9429562:2
3e11fa47-71ca-11e2-9e33-c80aa9429562:3
```

Global Transaction IDs : Galera vs MySQL 5.6

In Galera

```
bfb912e5-f560-11e2-0800-1eefab05e57da:1118
bfb912e5-f560-11e2-0800-1eefab05e57da:1119
bfb912e5-f560-11e2-0800-1eefab05e57da:1120
```

Global Transaction IDs : Galera vs MySQL 5.6

In Galera

```
bfb912e5-f560-11e2-0800-1eefab05e57da:1118
bfb912e5-f560-11e2-0800-1eefab05e57da:1119
bfb912e5-f560-11e2-0800-1eefab05e57da:1120
[ new master promoted ]
```

Global Transaction IDs : Galera vs MySQL 5.6

In Galera

```
bfb912e5-f560-11e2-0800-1eefab05e57da:1118
bfb912e5-f560-11e2-0800-1eefab05e57da:1119
bfb912e5-f560-11e2-0800-1eefab05e57da:1120
[ new master promoted ]
bfb912e5-f560-11e2-0800-1eefab05e57da:1121
bfb912e5-f560-11e2-0800-1eefab05e57da:1122
bfb912e5-f560-11e2-0800-1eefab05e57da:1123
```

GTID Assignment

UUID

The **UUID** section, 128-bit, is generated during bootstrapping to identify the cluster.

Generated by mixing the timer value and pseudo-random numbers (depending primarily from the timer and PID), but, currently, there is no use of NIC's MAC-address although in theory it may be done that way.

More info: https://gist.github.com/lefred/88a2cec88d03854d9934

GTID Assignment (3)

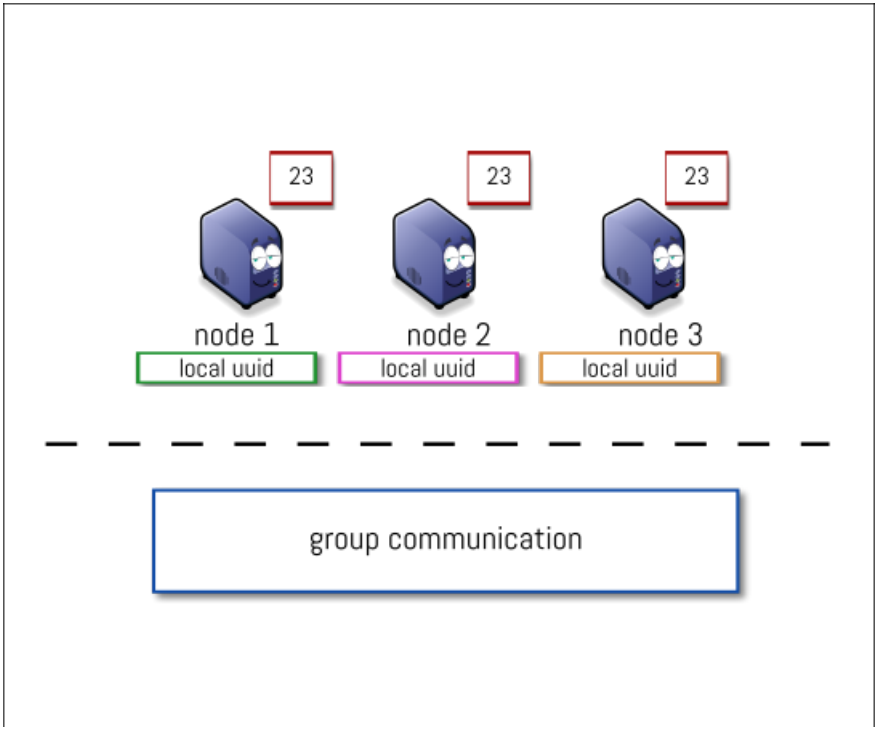
SEQNO

The **seqno**, 64-bit, is incremented only when the transaction passes certification and is ready for commit.

For the curious, the algorithm used to derive sequence number is Totem Single-ring Ordering protocol.

Before that, there is already communication between the nodes, *group communication* is used to define a group-channel id which is a locally maintained counter by each node in sync with the group.

Serialization of writesets



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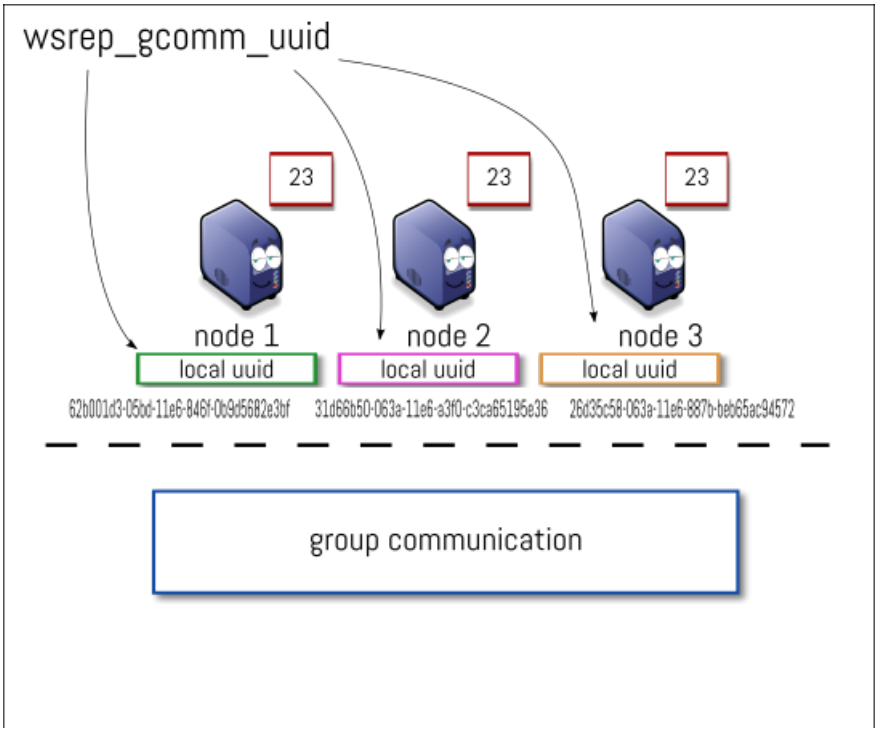

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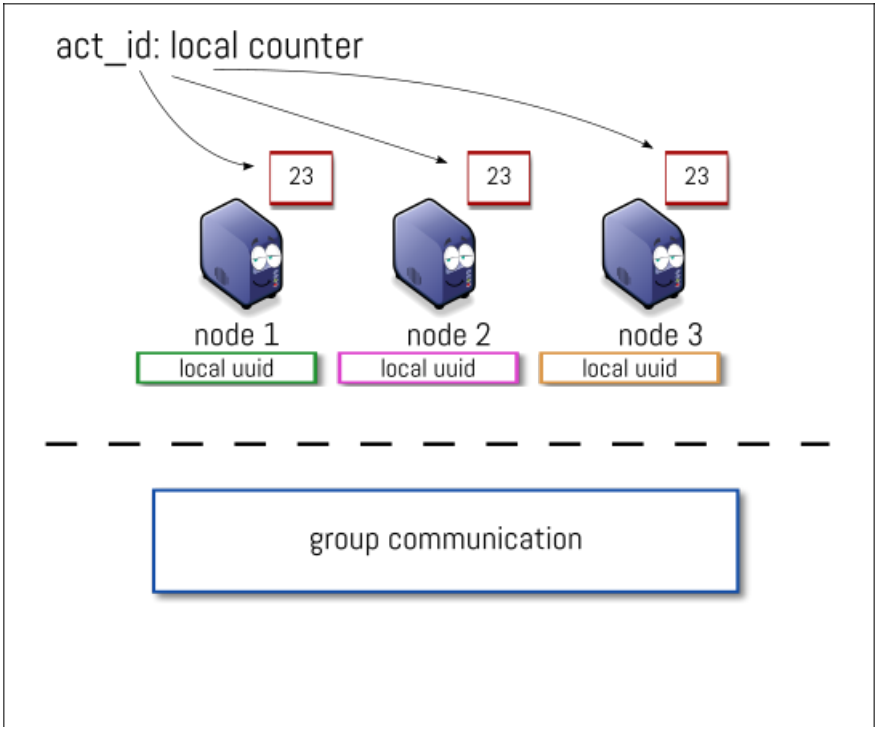

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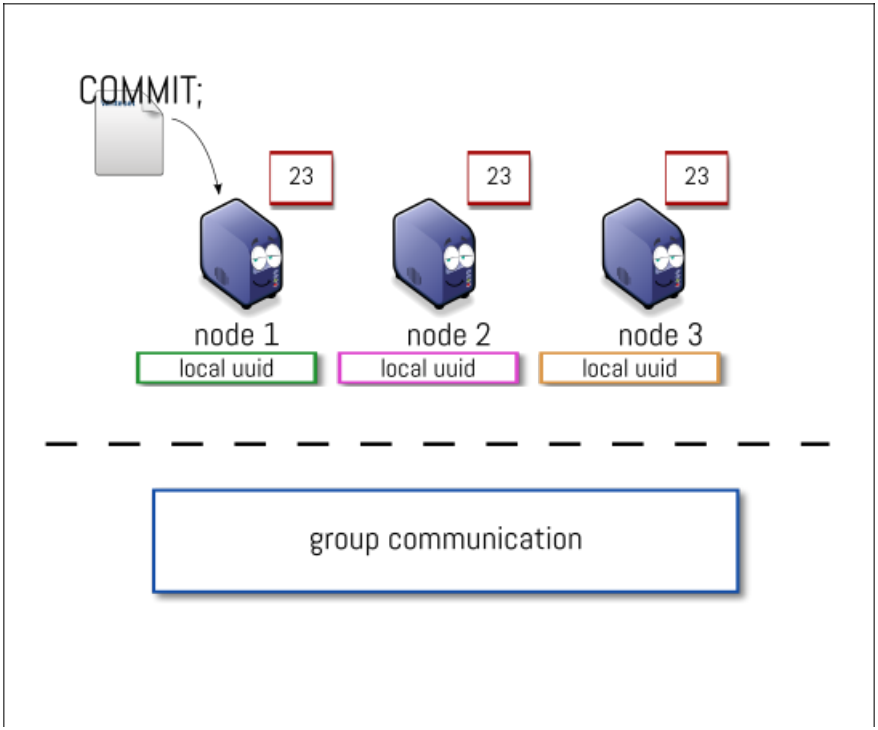

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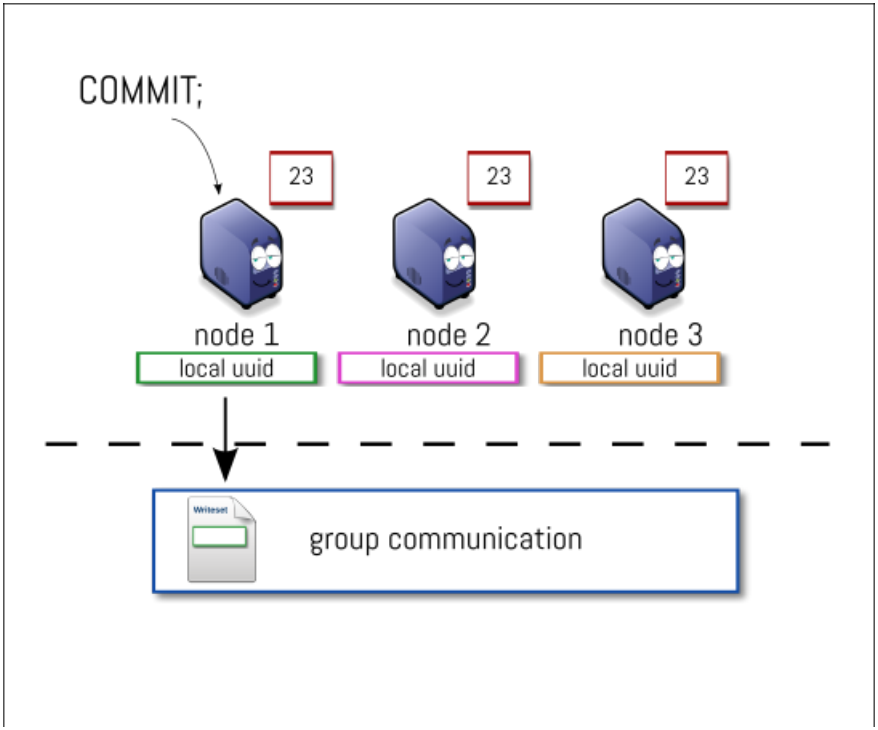

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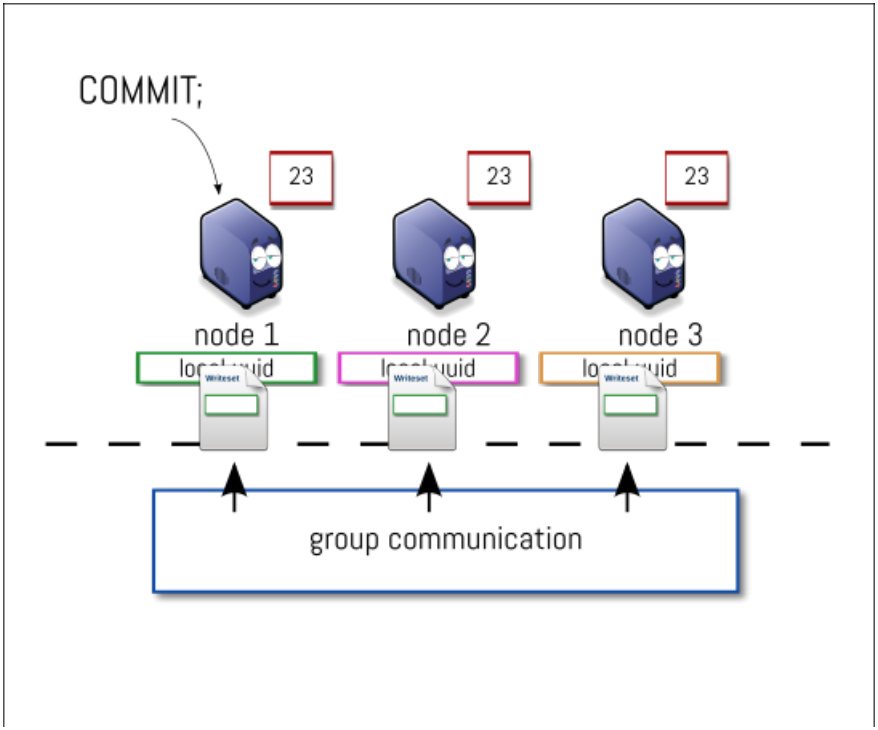
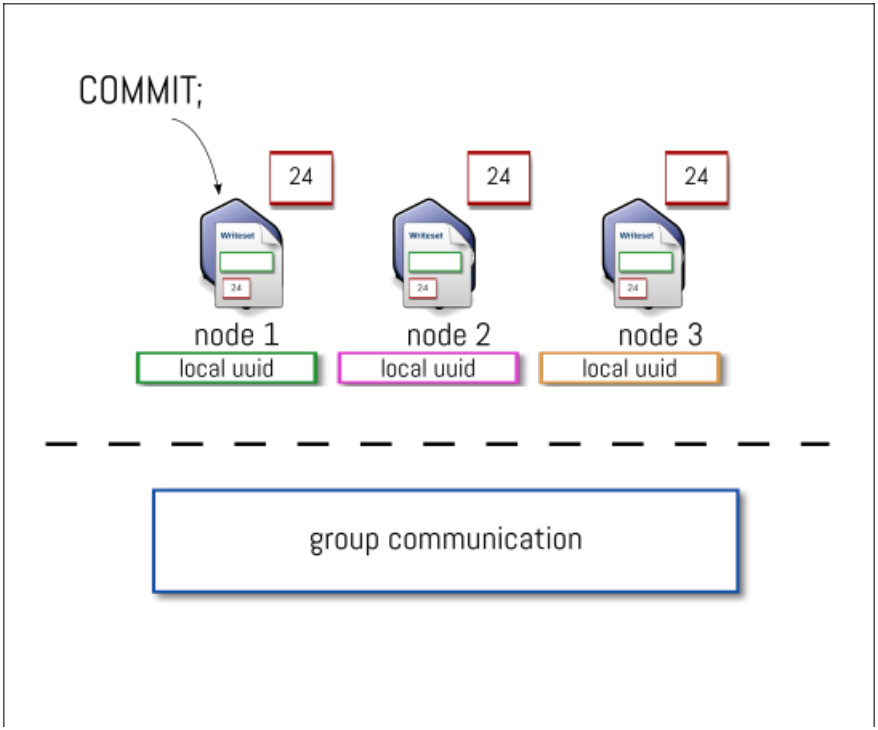
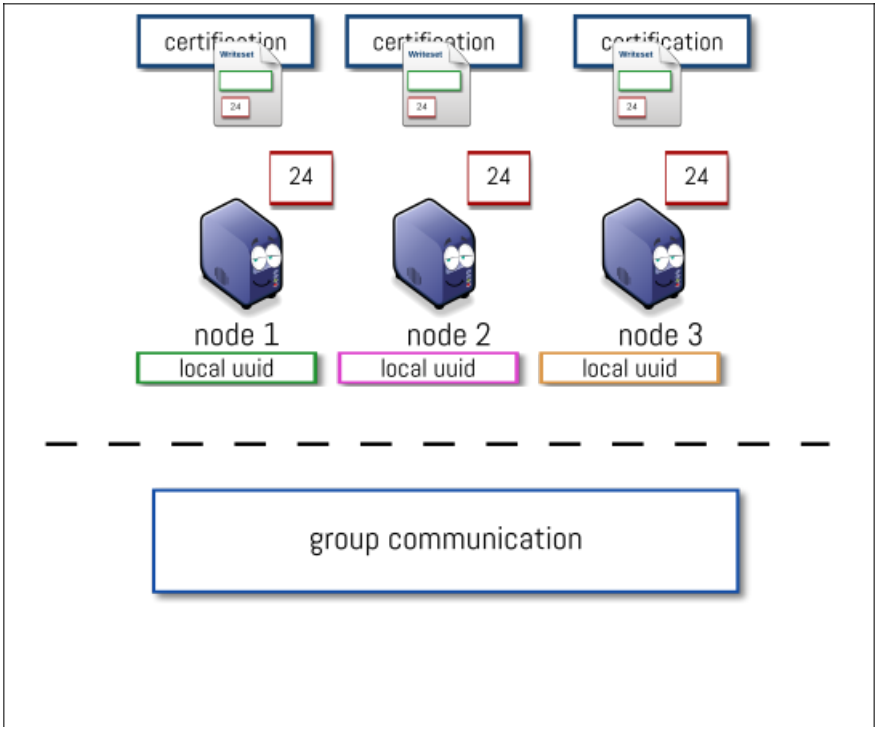


Serialization of writesets



Serialization of writesets



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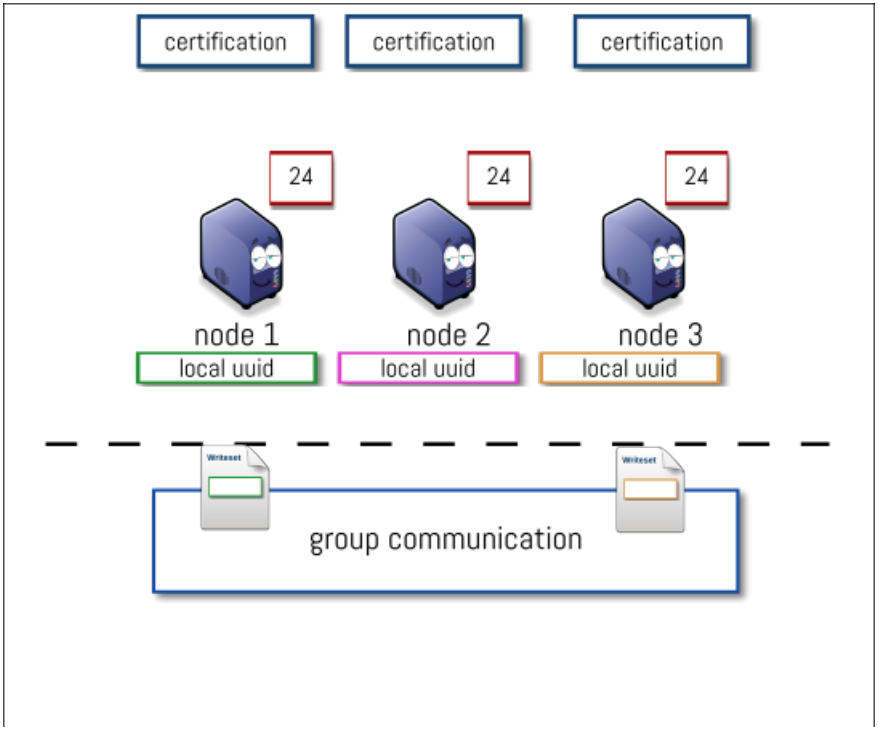

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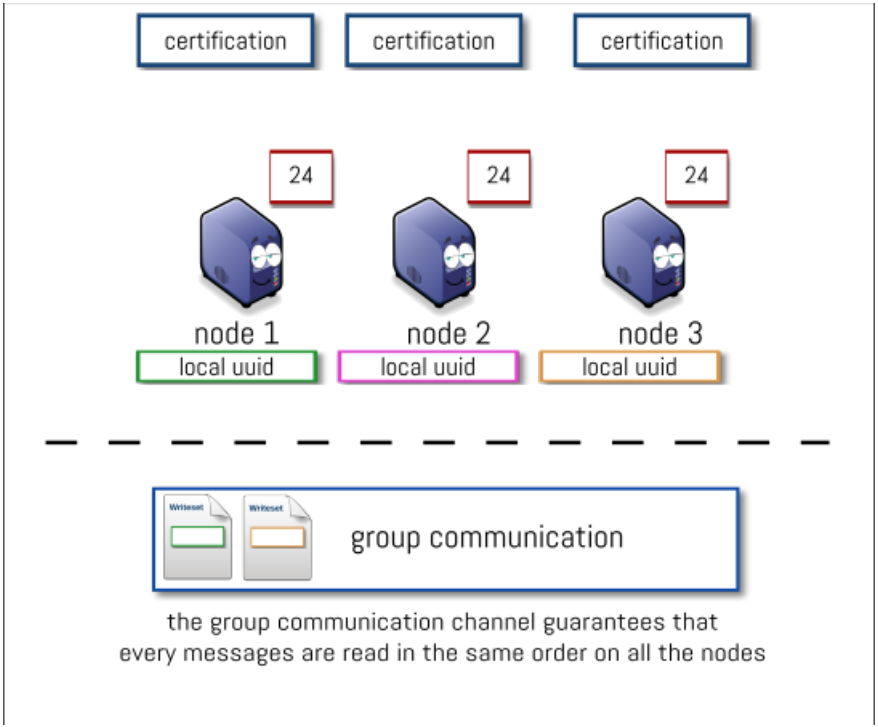

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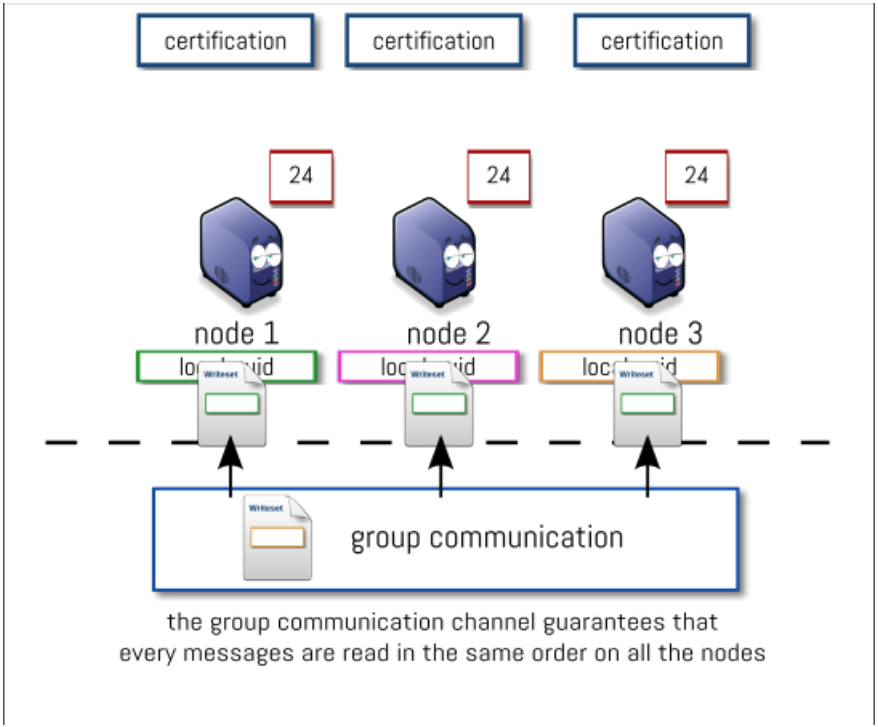

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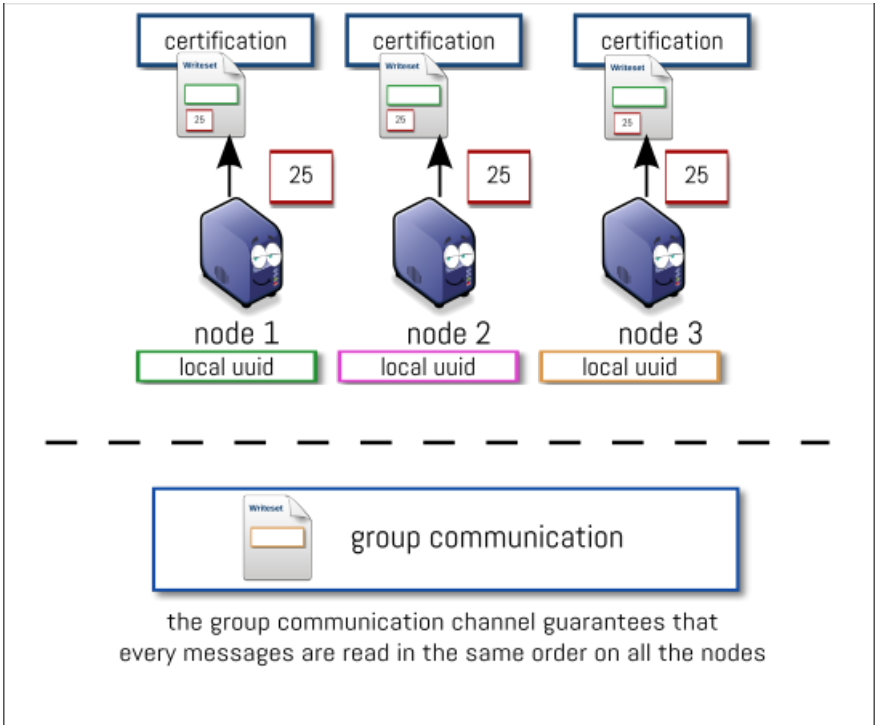

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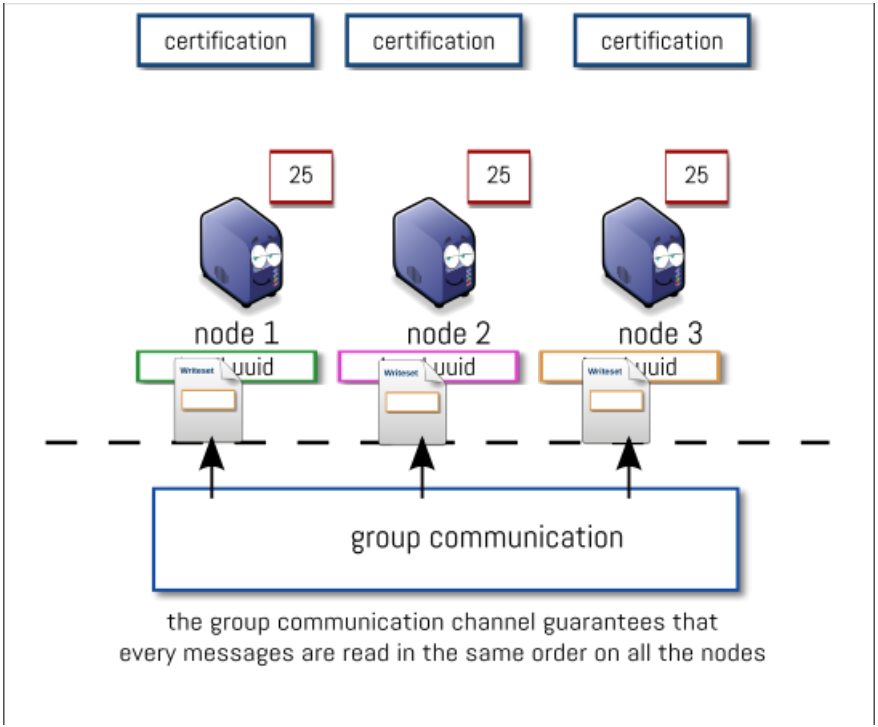

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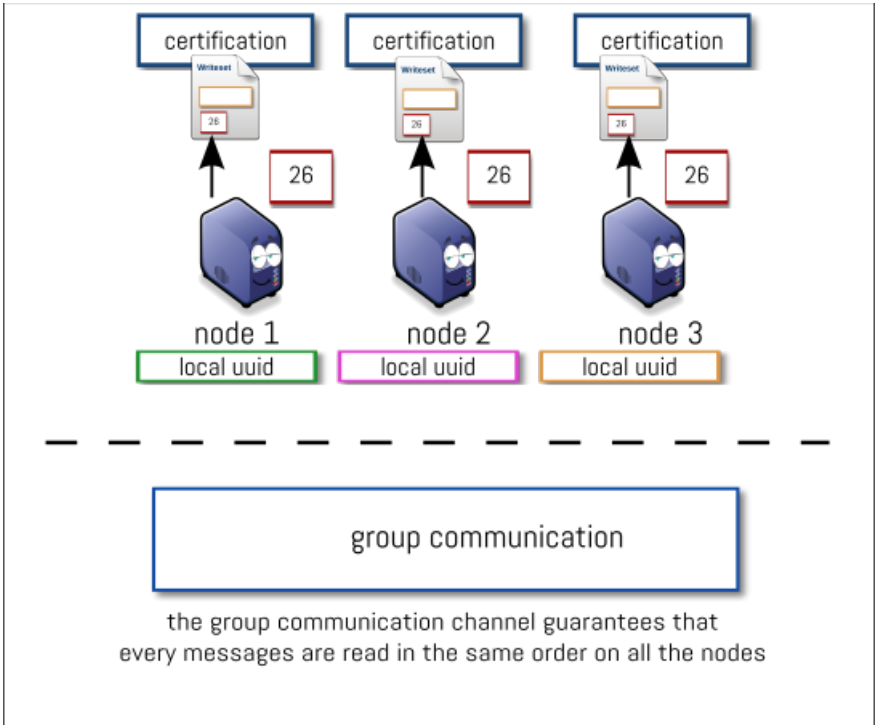

Roles

We have 4 distinct roles in Galera:

- 2 for replication
- 2 for state transfer

Replication Roles

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- '**slave/joiner** node'
  - The node that received the given transaction via Galera replication.
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- Writeset: Galera's term for a transaction. One or more RBR row changes

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State Transfer Roles

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  - **Joiner** = Mew node
  - **Donor** = Node giving a copy of the datadir
- State Snapshot transfer
  - Full backup of Donor to Joiner
- Incremental Snapshot transfer
  - Only changes since node left cluster

Writeset

- RBR payload (black box to Galera)

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- Replication keys (generated by master/donor node)

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Writeset

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- Replication keys (generated by master/donor node)
  - Primary keys
  - Unique keys
  - Foreign Keys
  - Table names
  - Schema names
- Keys are what make certification possible

Replication ?

It consists in 4 operations:

- Apply
- Replication
- Certification
- Commit

The order differs with the node's role

Replication Order on Master/Donor

1. Apply
2. Replication
3. Certification
4. Commit

Replication Order on Slave/Joiner

1. Replication (from master/donor)
2. Certification
3. Apply
4. Commit

Certification

- Can this writeset be applied?

Certification

- Can this writeset be applied?
  - Based on unapplied earlier transactions on master/donor

Certification

- Can this writeset be applied?
  - Based on unapplied earlier transactions on master/donor
  - Such conflicts must come from other nodes

Certification

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- Happens on every node

Certification

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  - Based on unapplied earlier transactions on master/donor
  - Such conflicts must come from other nodes
- Happens on every node
- Should be deterministic on every node

Certification

- Can this writeset be applied?
  - Based on unapplied earlier transactions on master/donor
  - Such conflicts must come from other nodes
- Happens on every node
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- Results are not reported to the cluster

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  - Based on unapplied earlier transactions on master/donor
  - Such conflicts must come from other nodes
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- Results are not reported to the cluster
  - Pass: enter apply queue (commit success on master/donor)

Certification

- Can this writeset be applied?
  - Based on unapplied earlier transactions on master/donor
  - Such conflicts must come from other nodes
- Happens on every node
- Should be deterministic on every node
- Results are not reported to the cluster
  - Pass: enter apply queue (commit success on master/donor)
  - Fail: drop transaction (or return deadlock on master/donor)

Certification

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  - Based on unapplied earlier transactions on master/donor
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- Results are not reported to the cluster
  - Pass: enter apply queue (commit success on master/donor)
  - Fail: drop transaction (or return deadlock on master/donor)
- Serialized by group communication sequence (and GTID will be synchronized following the same sequence)

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  - Based on unapplied earlier transactions on master/donor
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- Happens on every node
- Should be deterministic on every node
- Results are not reported to the cluster
  - Pass: enter apply queue (commit success on master/donor)
  - Fail: drop transaction (or return deadlock on master/donor)
- Serialized by group communication sequence (and GTID will be synchronized following the same sequence)
- Cost based on # of keys or # of rows

Apply

- Apply is done on slave nodes after certification

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- Can be parallelized

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  - if wsrep_slave_threads > 1

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  - if there are no other writesets with conflicting keys also being applied
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Apply

- Apply is done on slave nodes after certification
- Can be parallelized
  - if wsrep_slave_threads > 1
  - if there are no other writesets with conflicting keys also being applied
- Cost: size of transaction
- Generates brute force aborts on local node for conflicts

Commit

- Final local InnoDB commit

Commit

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  - i.e., innodb_flush_log_at_trx_commit

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- GTID gets generated

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  - i.e., innodb_flush_log_at_trx_commit
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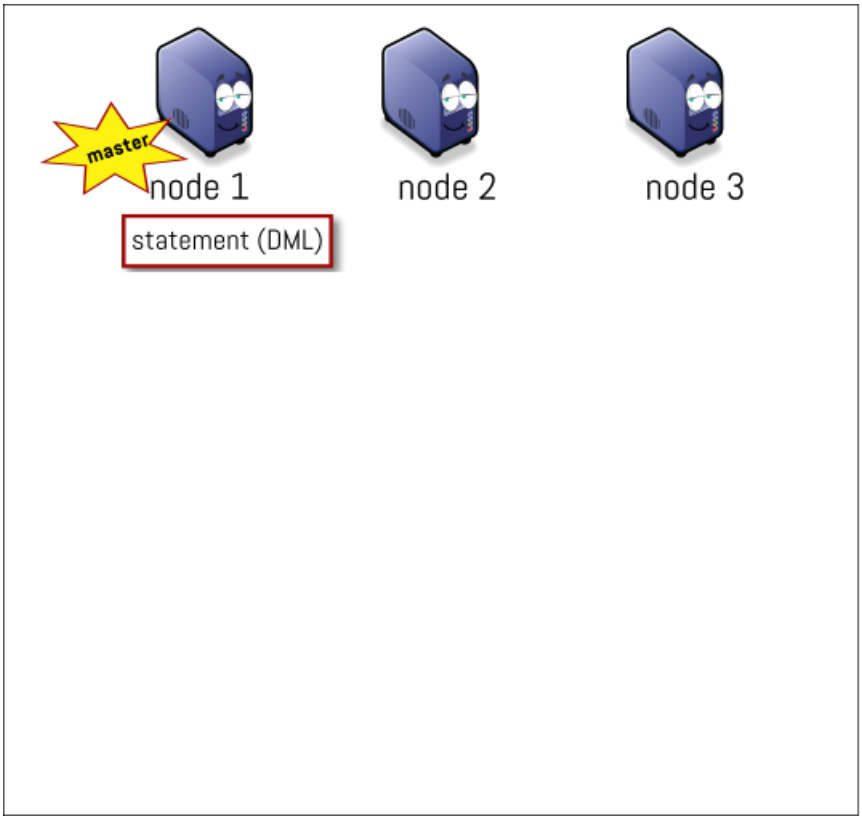
- Done by applier threads on slaves/joiners
- Done by client thread on master/donor

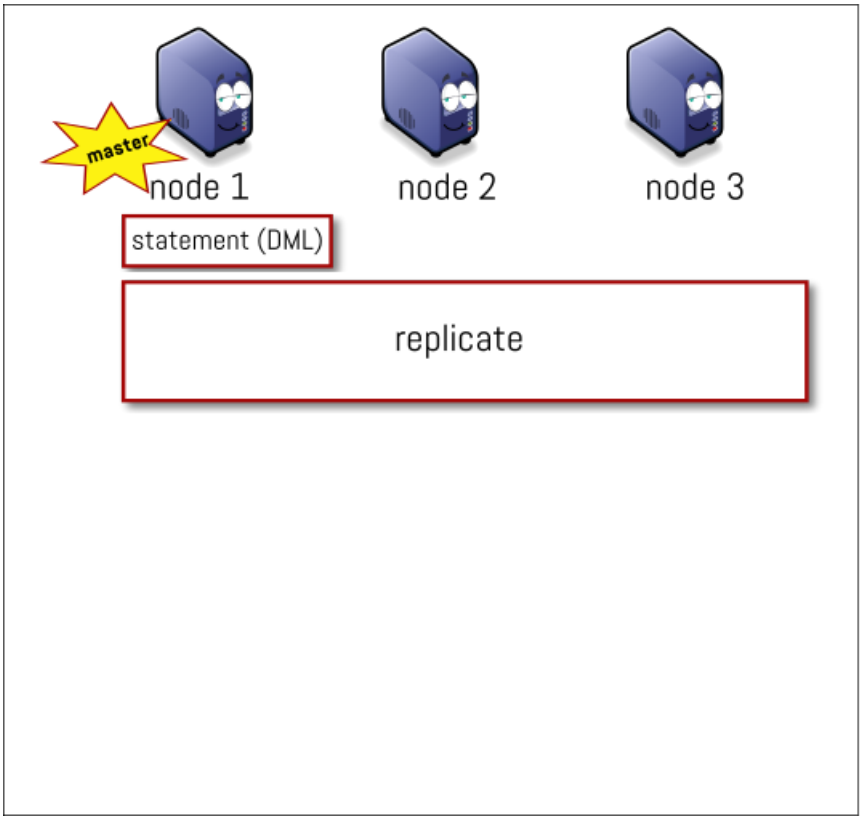
Commit

- Final local InnoDB commit
  - i.e., innodb_flush_log_at_trx_commit
- GTID gets generated
- Done by applier threads on slaves/joiners
- Done by client thread on master/donor
- innodb_flush_log_at_trx_commit=1 not required generally for PXC!

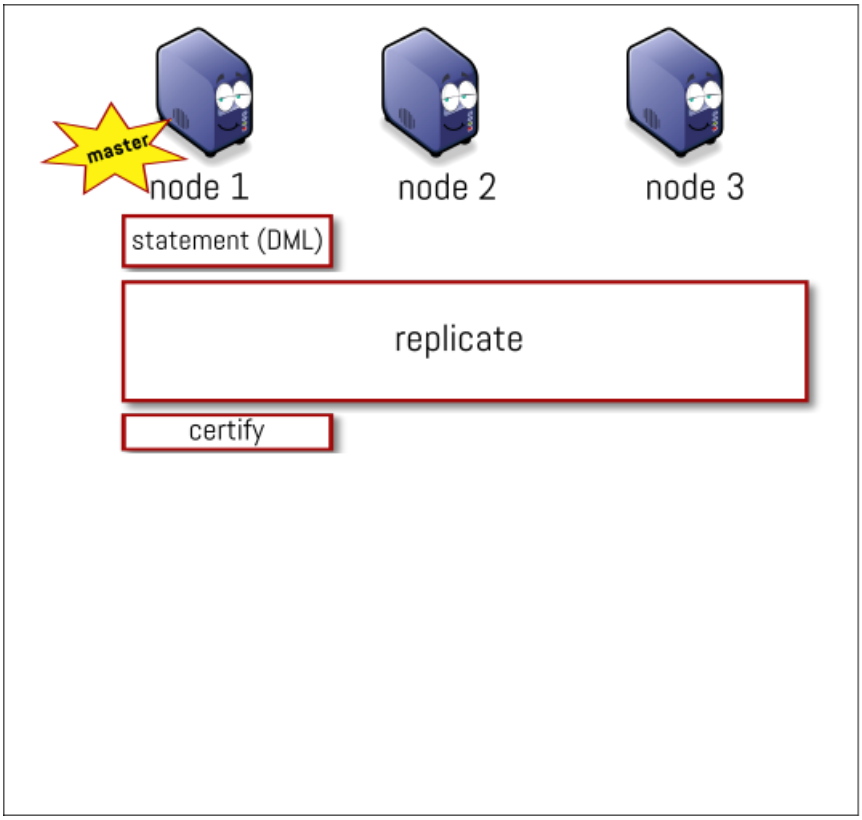
Galera Replication (autocommit)



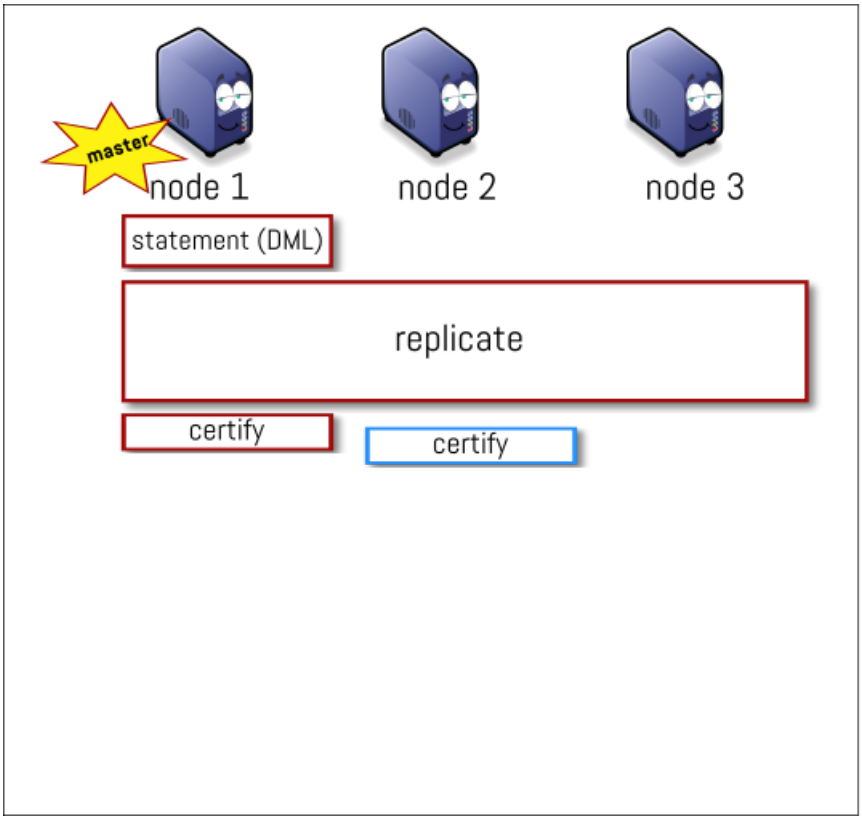
Galera Replication (autocommit)



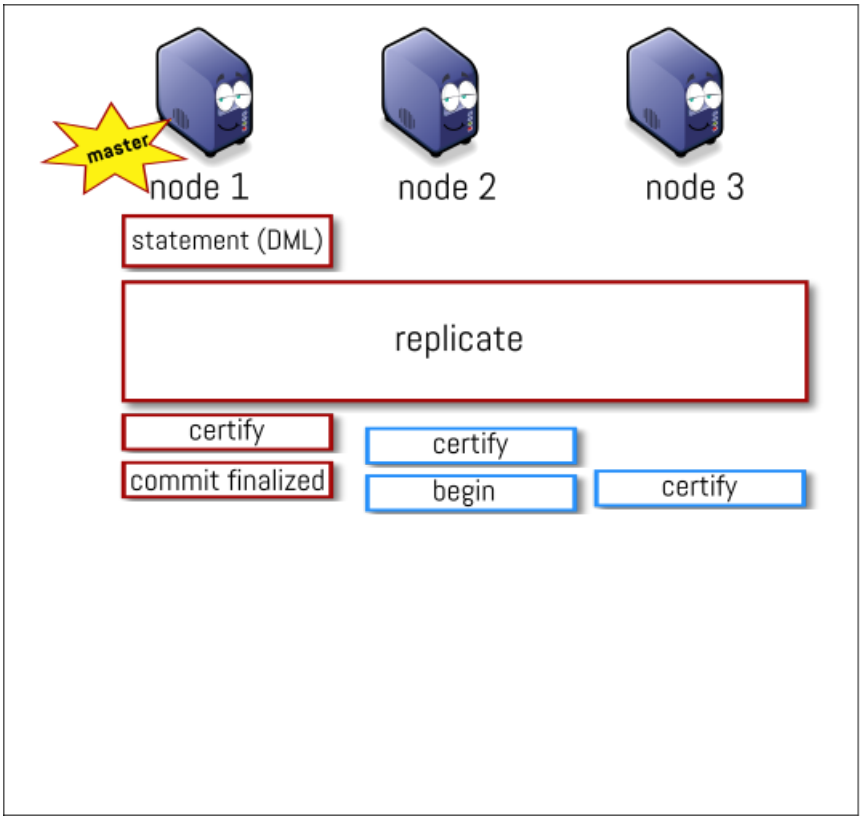
Galera Replication (autocommit)



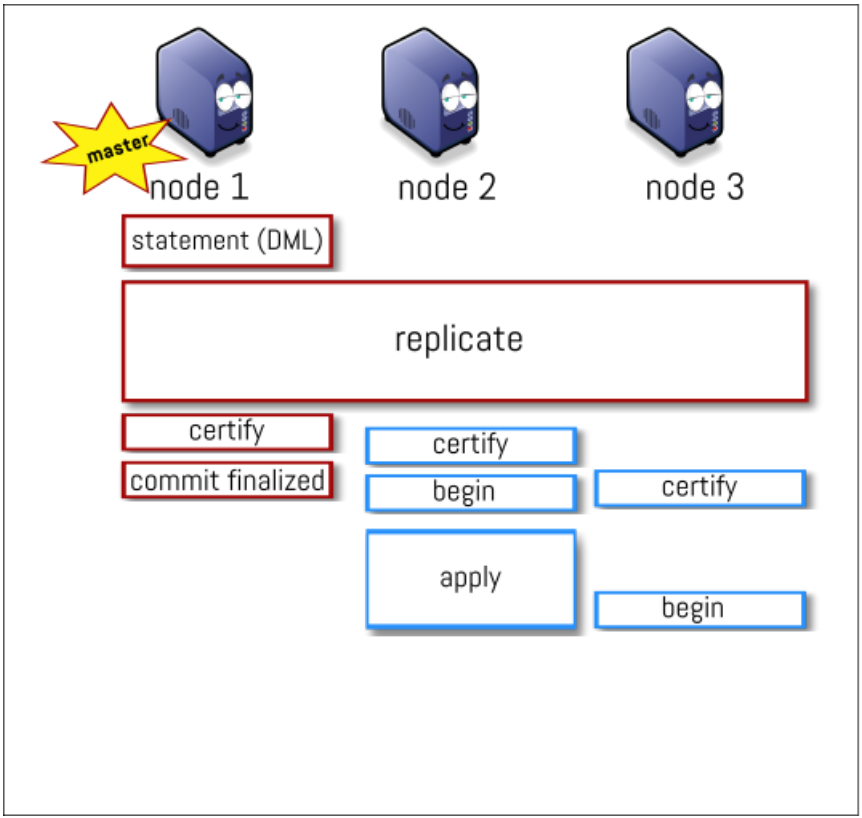
Galera Replication (autocommit)



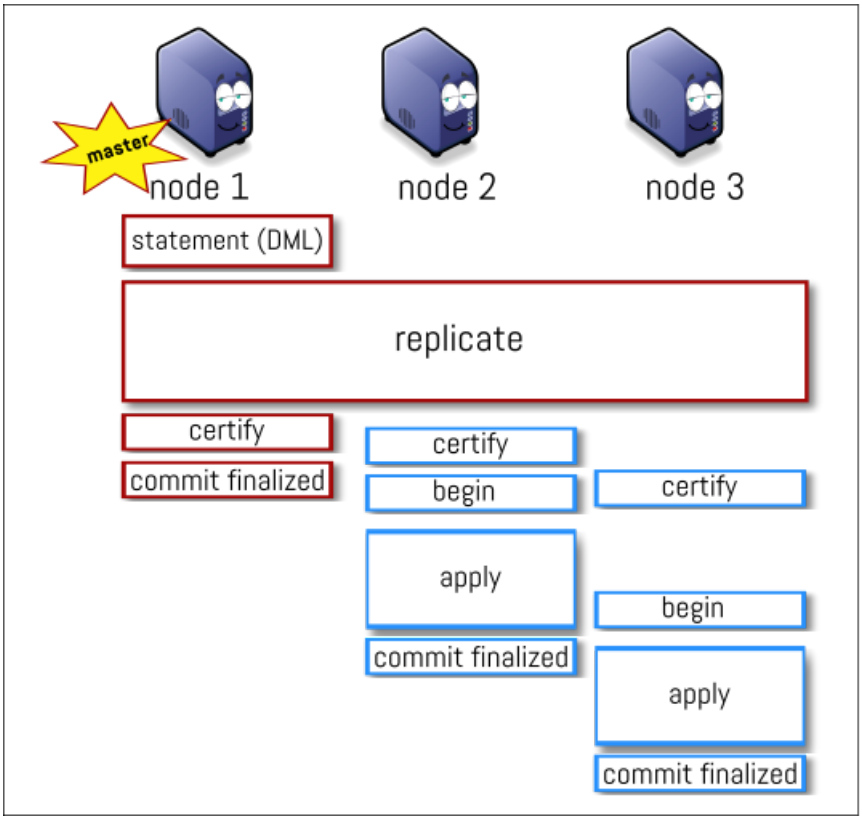
Galera Replication (autocommit)



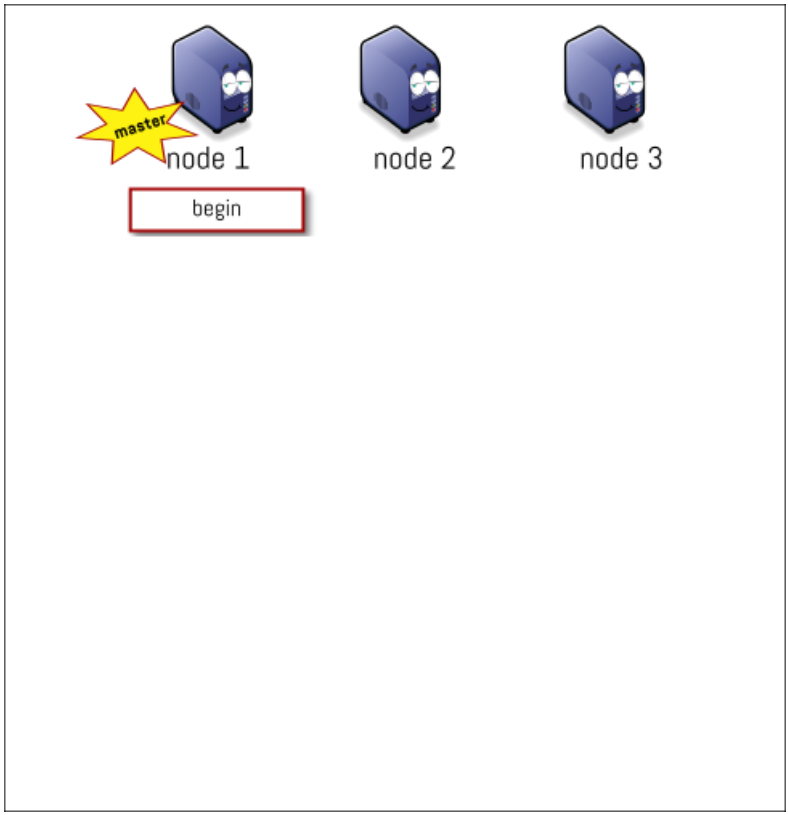
Galera Replication (autocommit)



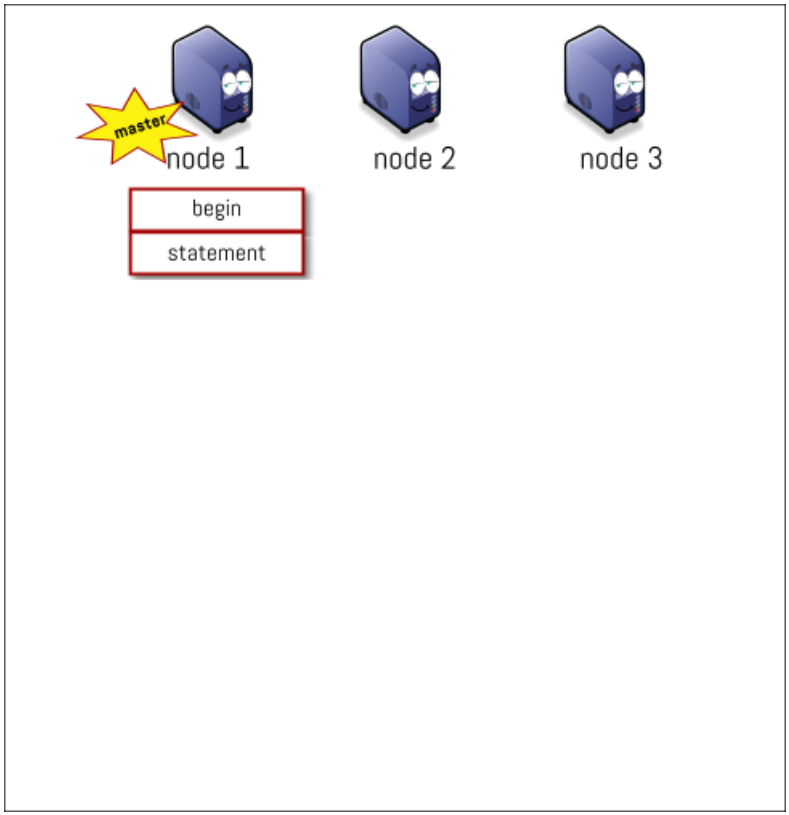
Galera Replication (autocommit)



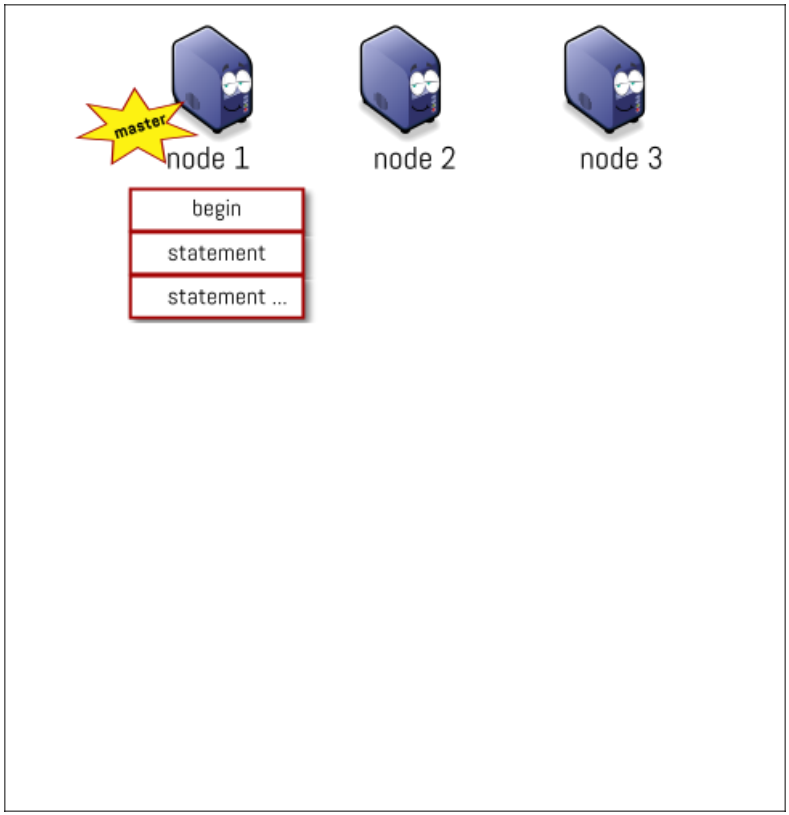
Galera Replication (full transaction)



Galera Replication (full transaction)



Galera Replication (full transaction)



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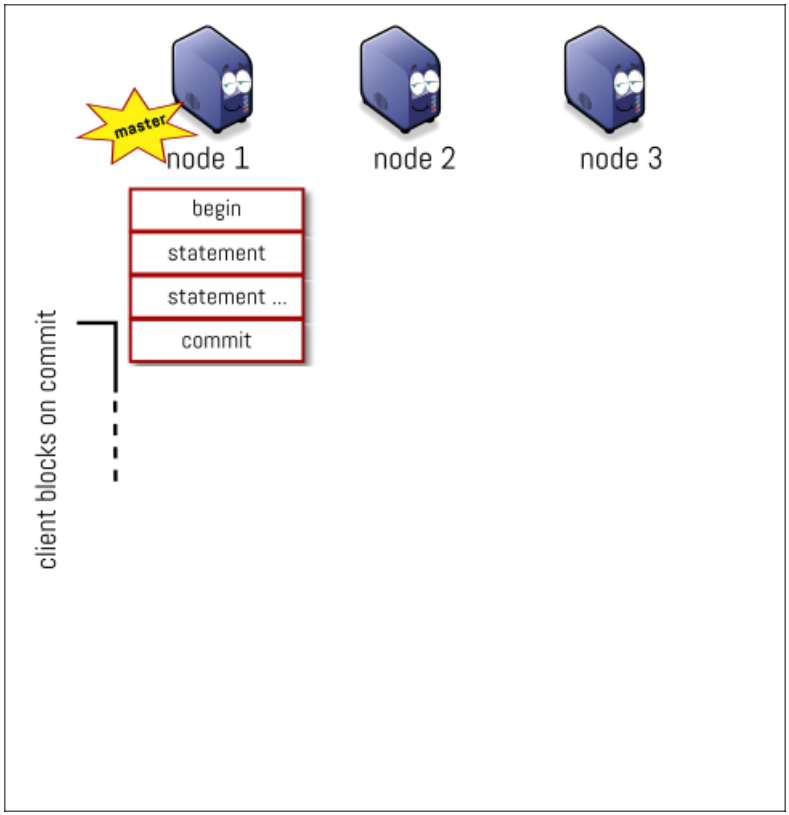
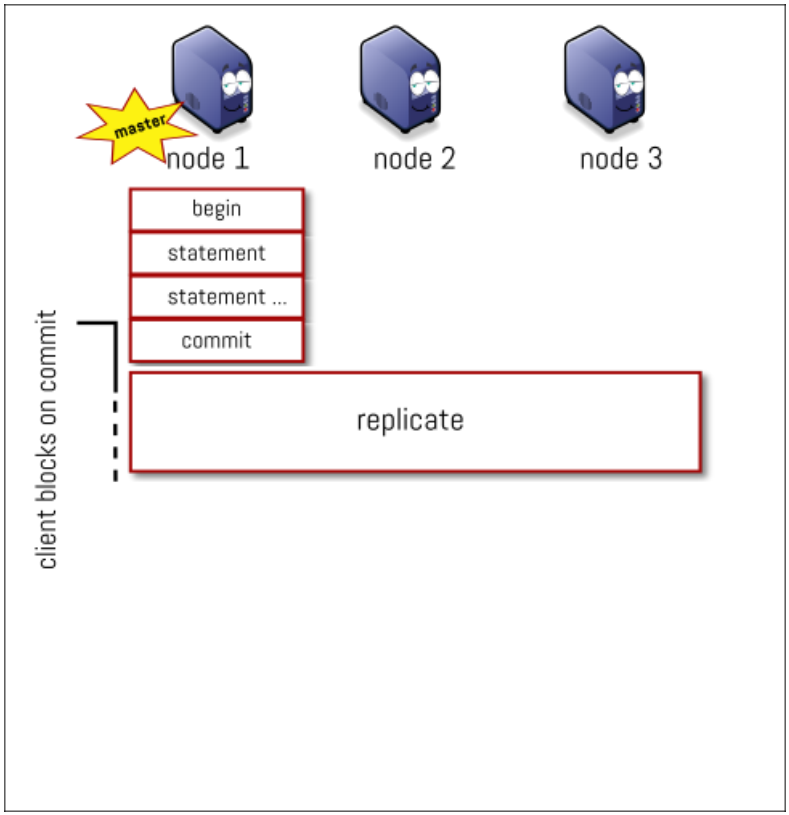
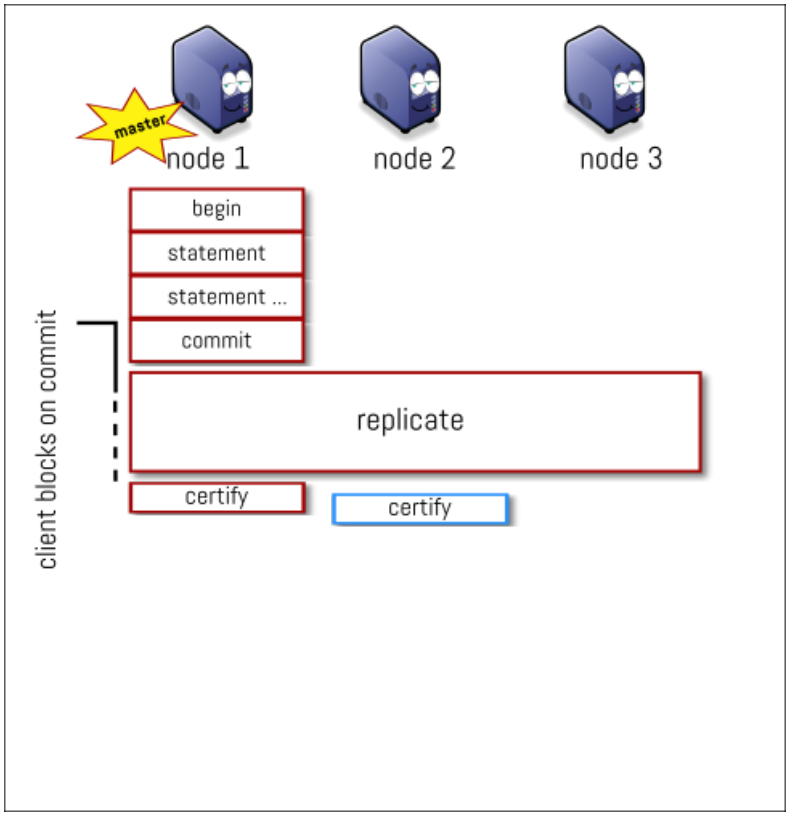


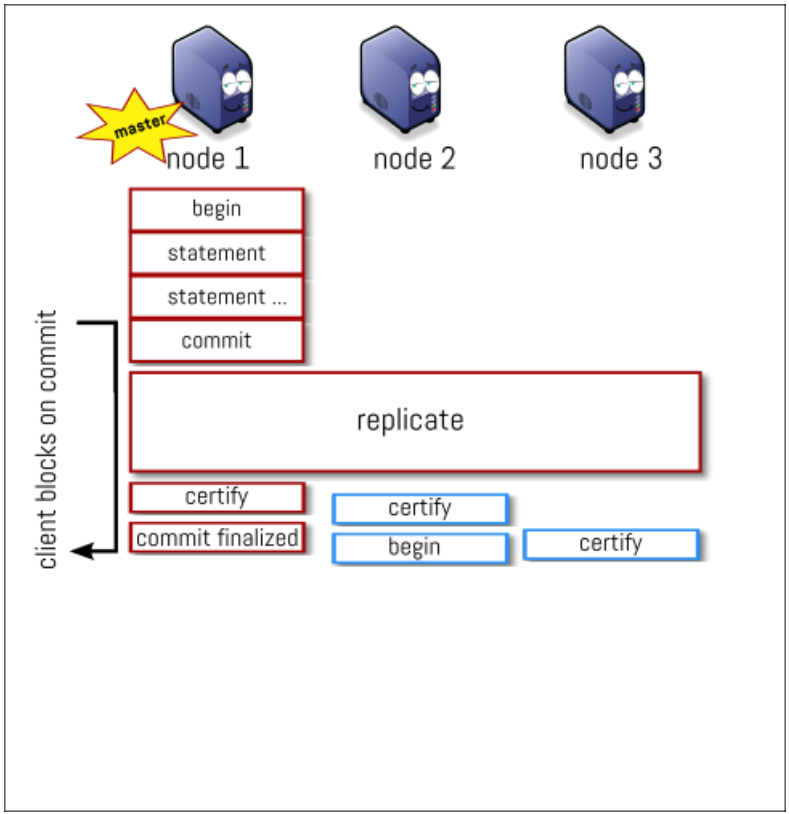
Galera Replication (full transaction)



Galera Replication (full transaction)



Galera Replication (full transaction)



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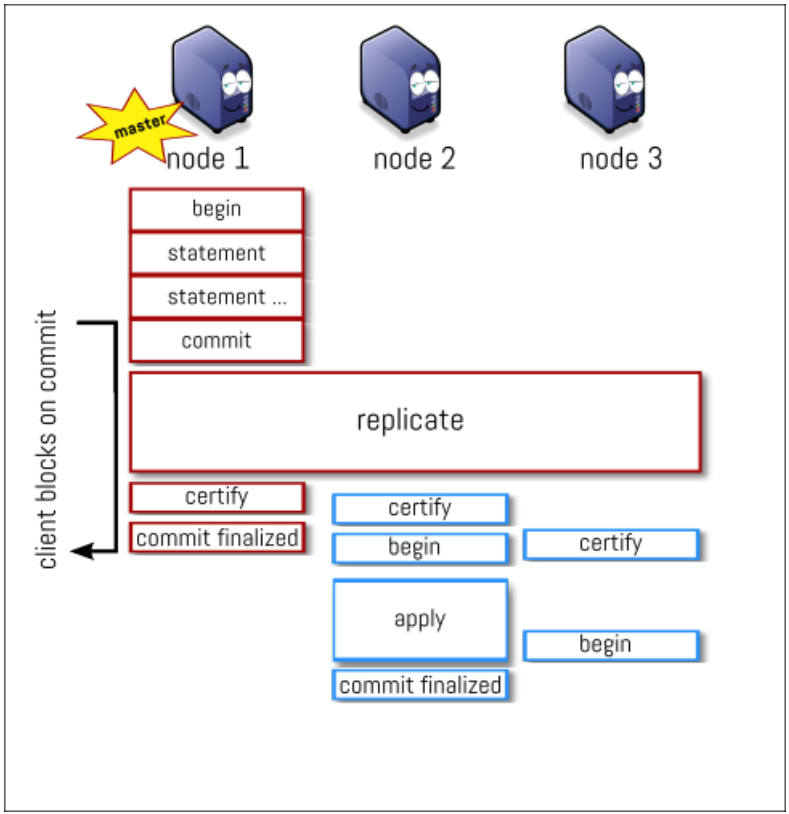
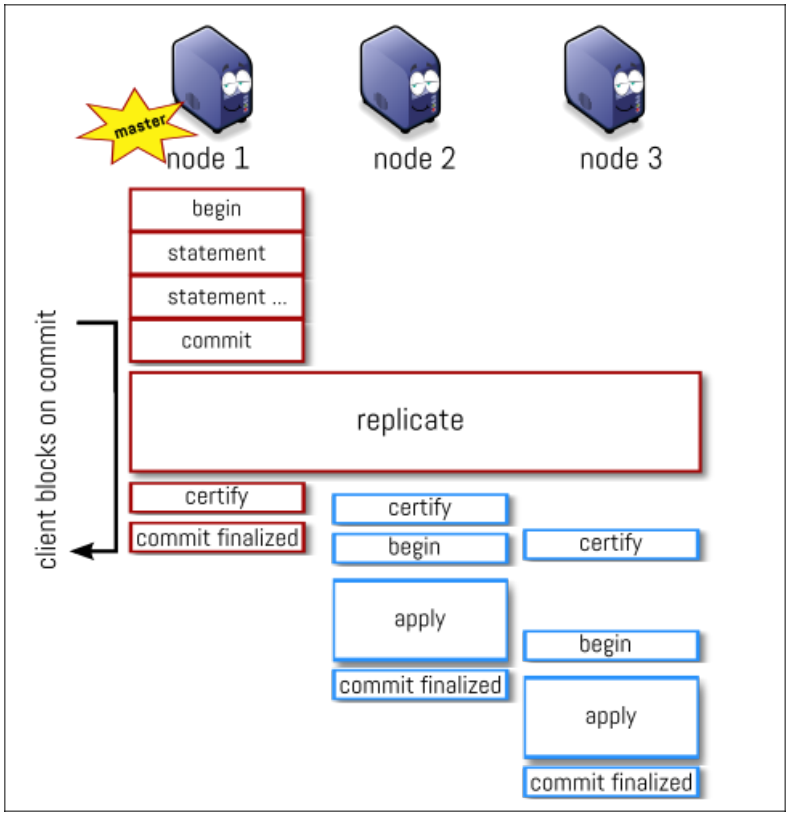
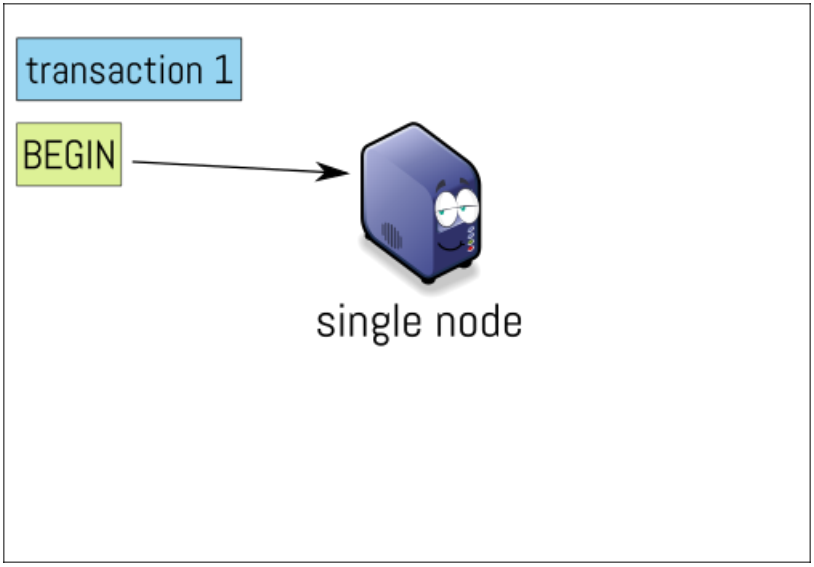


Galera Replication (full transaction)



Optimistic Locking

Traditional locking



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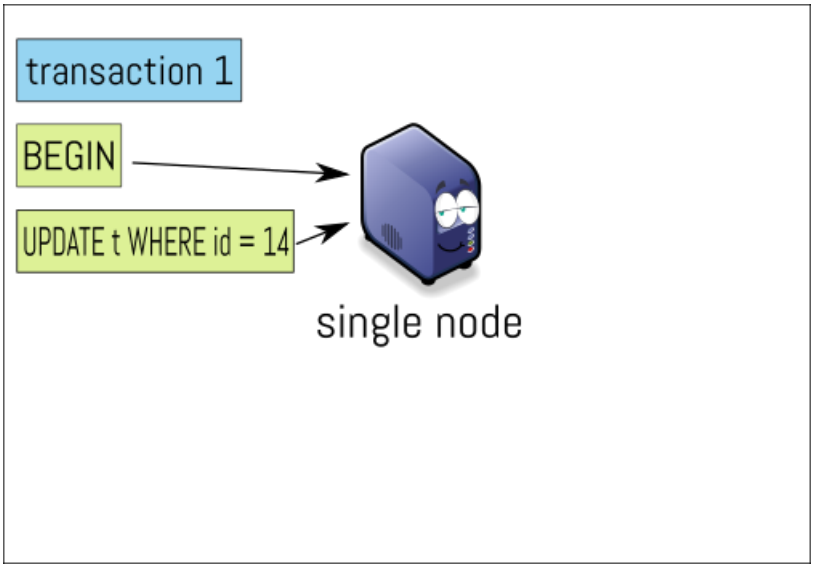
Traditional locking



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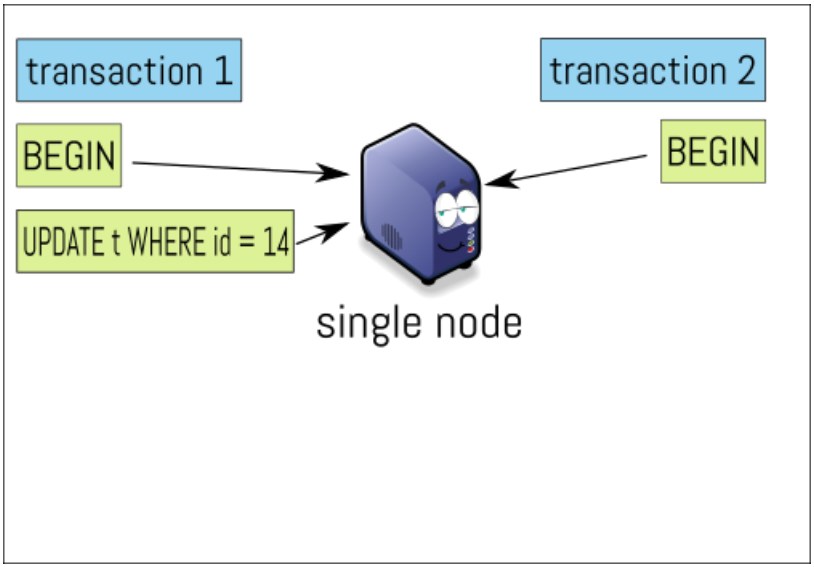
Traditional locking



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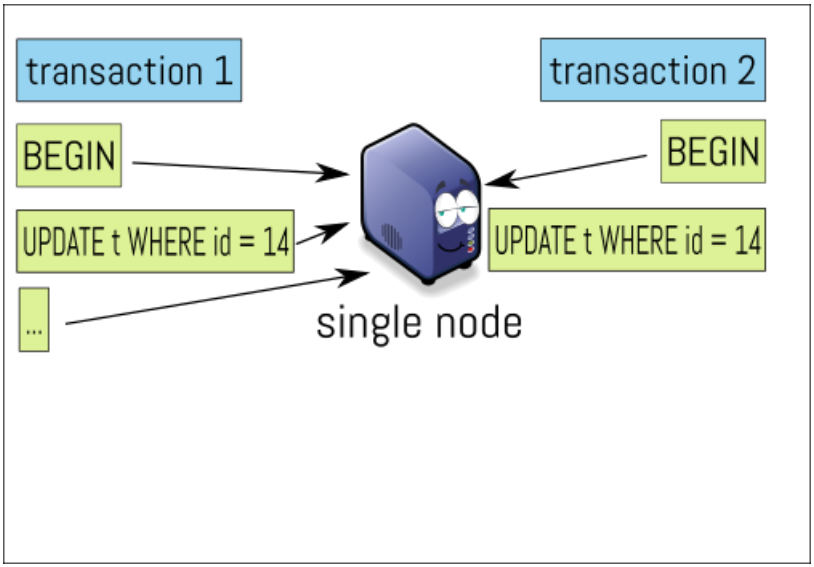

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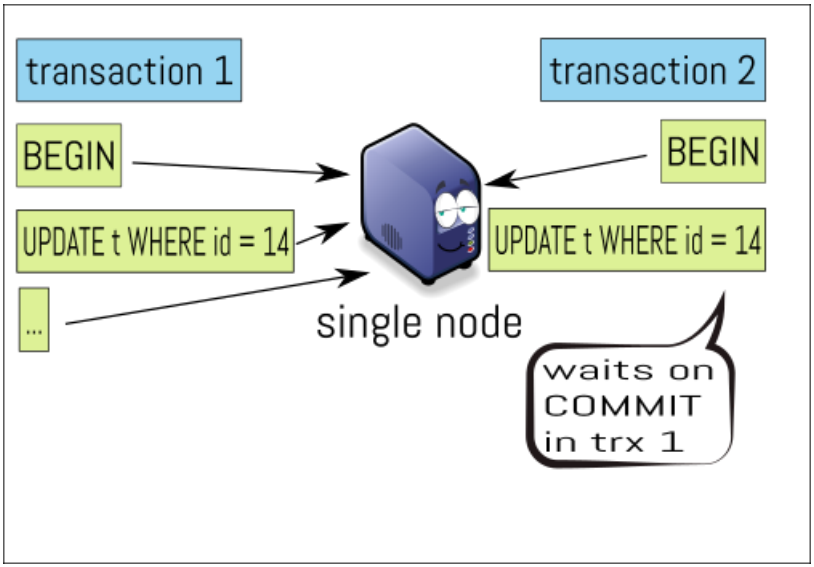

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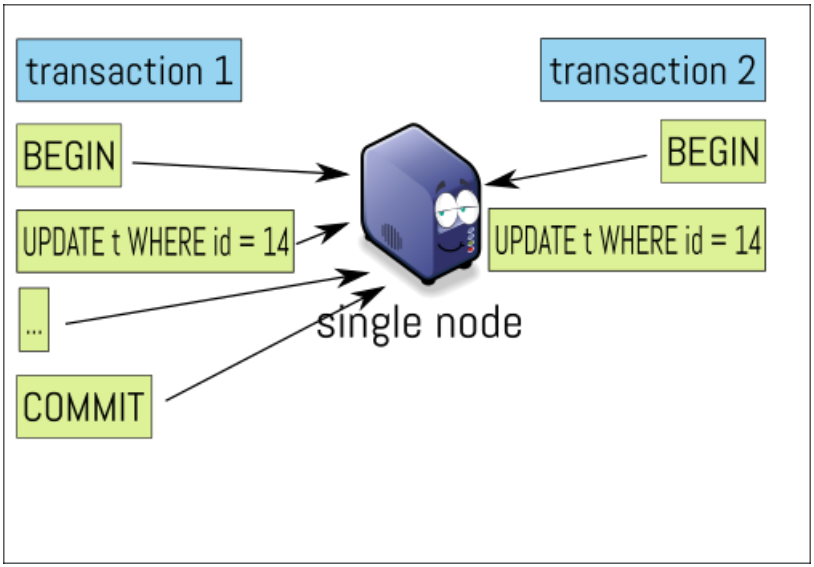
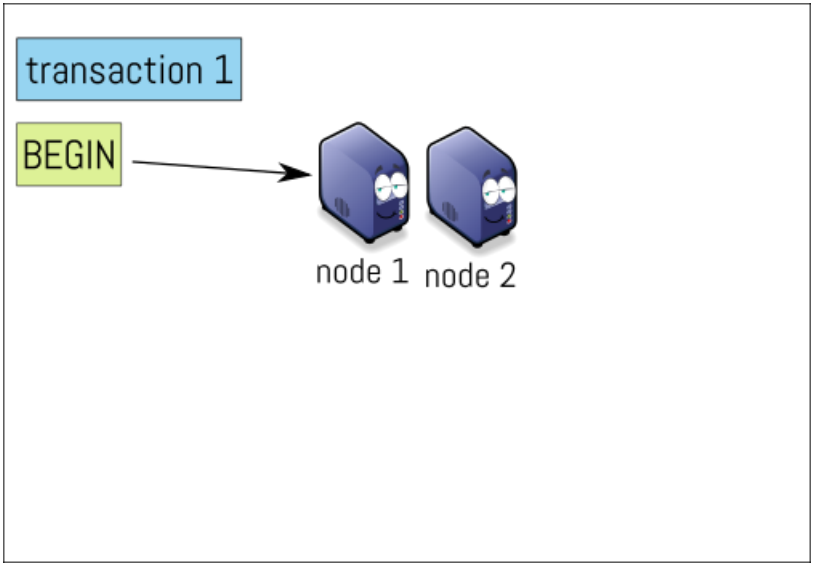
Traditional locking



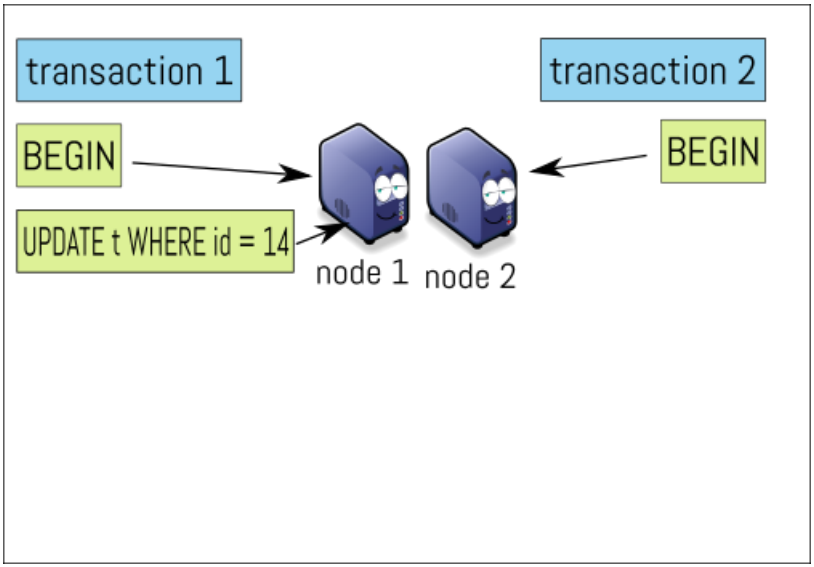
Optimistic Locking

Optimistic Locking



Optimistic Locking

Optimistic Locking



Optimistic Locking

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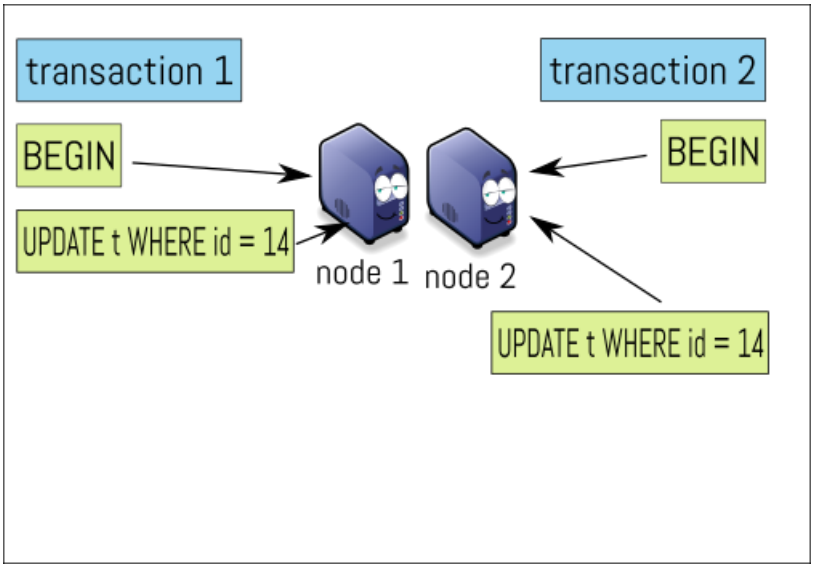
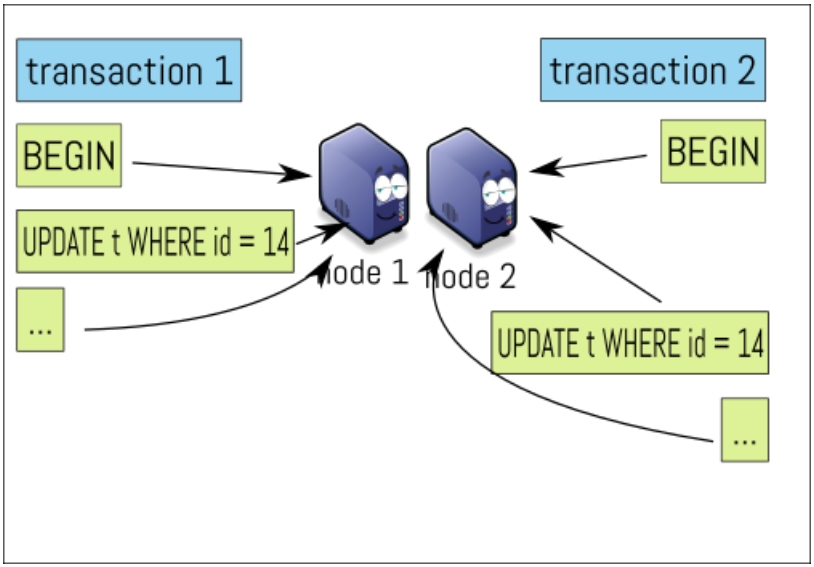


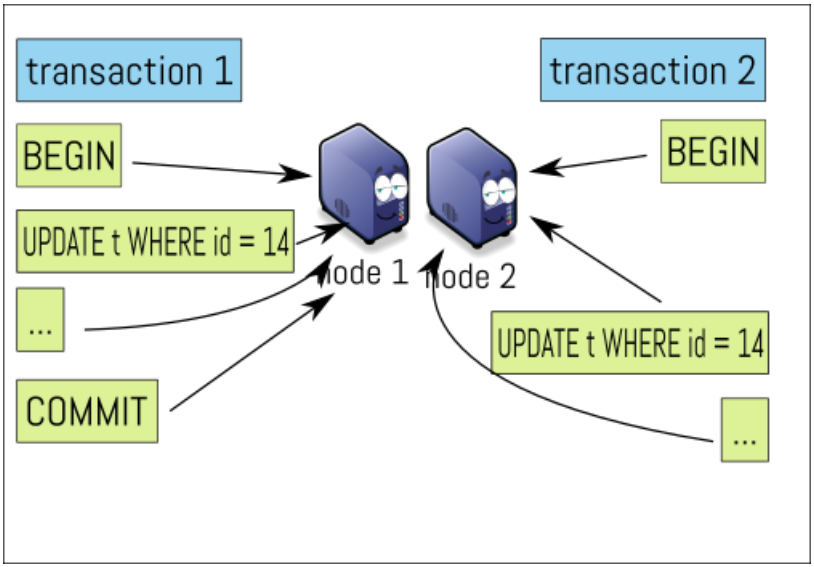
Optimistic Locking

Optimistic Locking



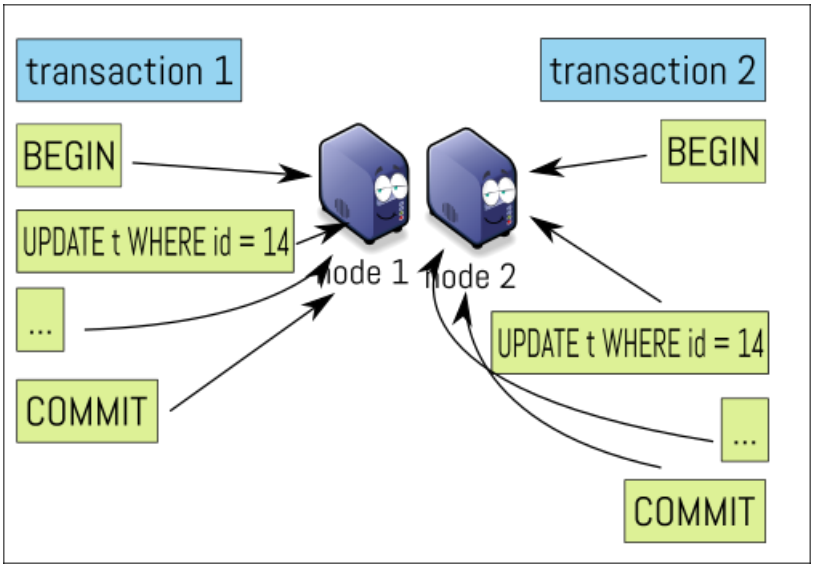
Optimistic Locking

Optimistic Locking



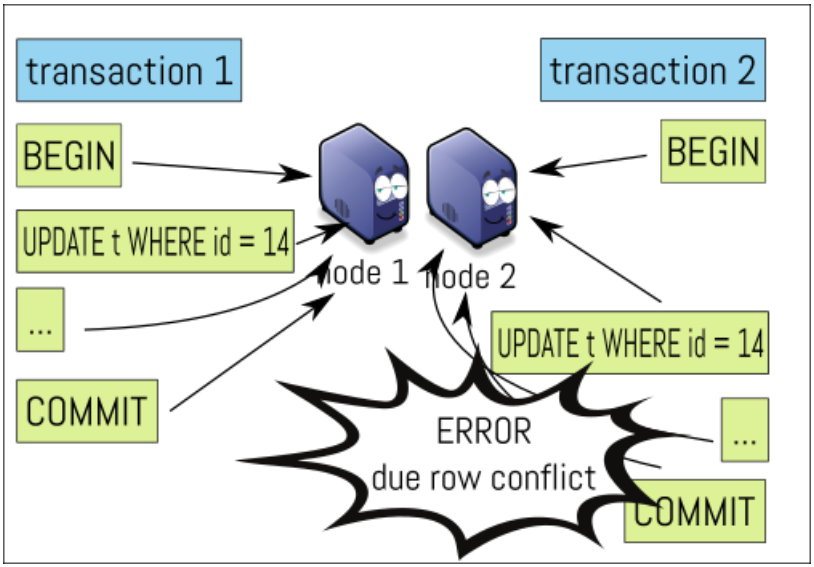
Optimistic Locking

Optimistic Locking

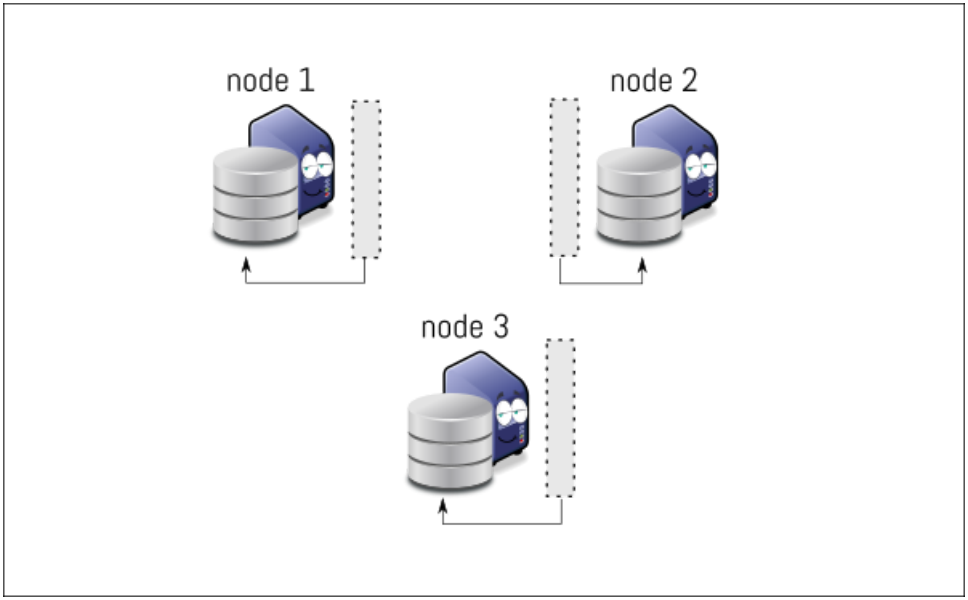


Optimistic Locking

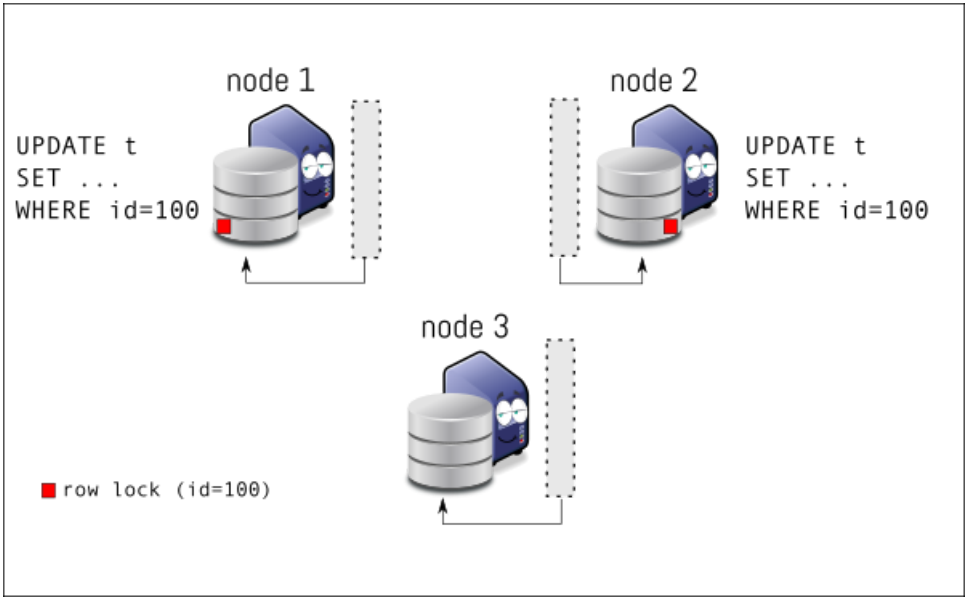
Optimistic Locking



Certification Failure

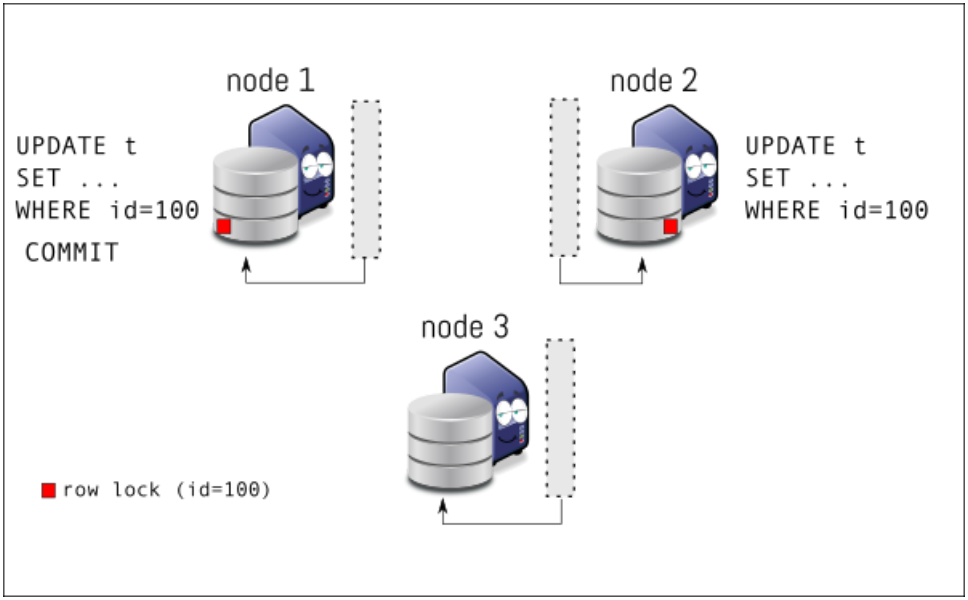


Certification Failure



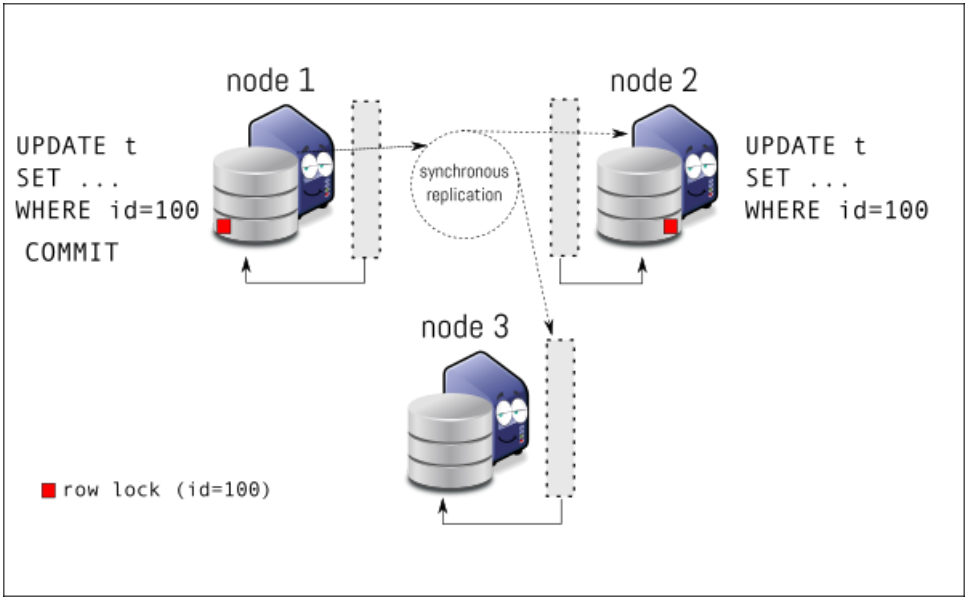
- Trx1 is open on **Node1**
- Trx2 is open on **Node2**

Certification Failure



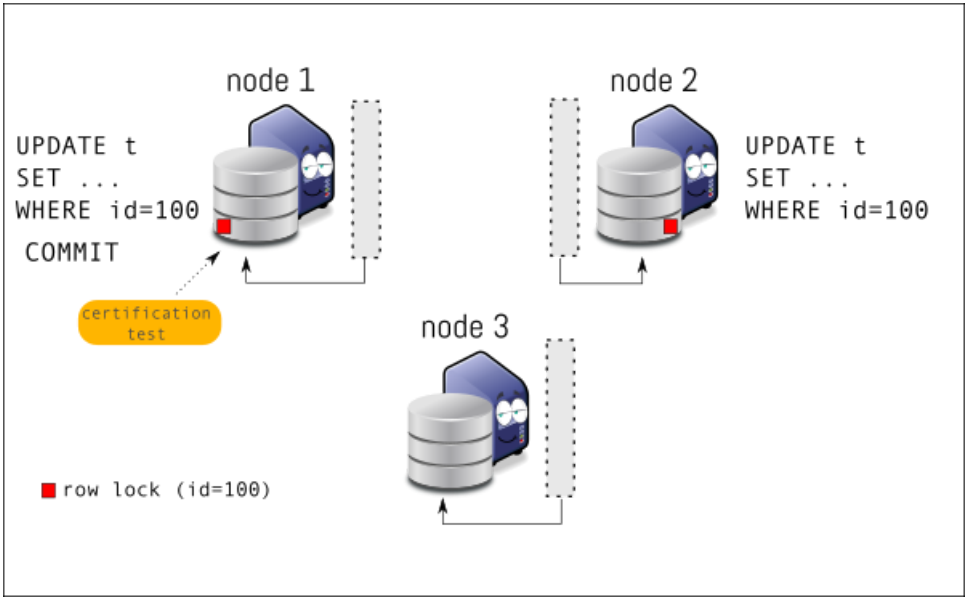
- Node1 gets COMMIT

Certification Failure



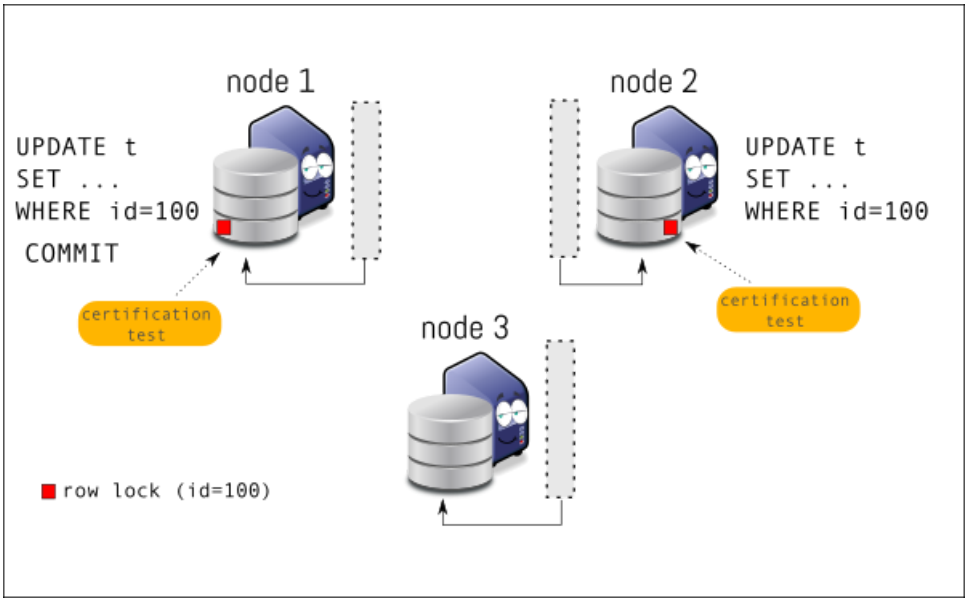
- Synchronous replication

Certification Failure



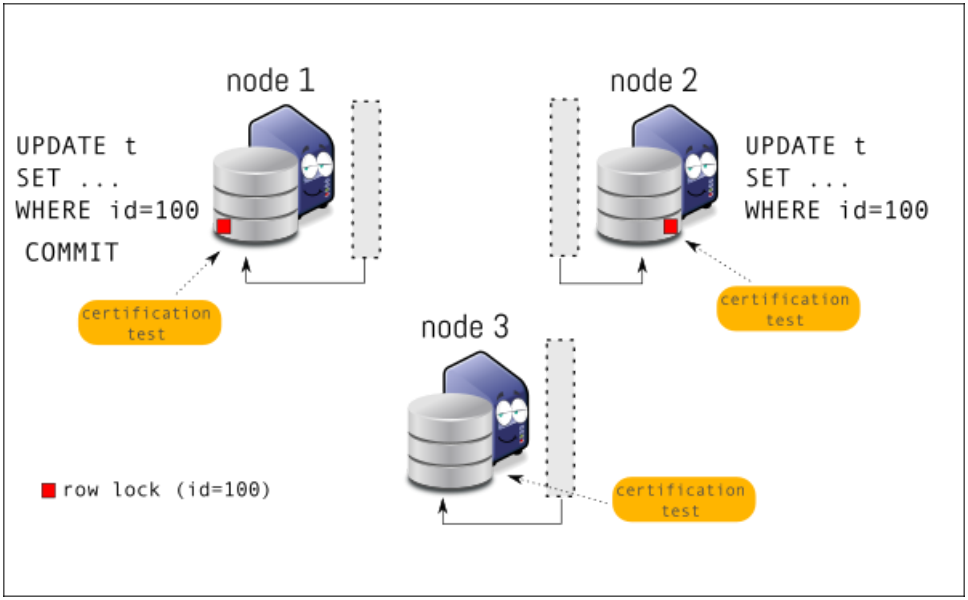
- Certification tests
  - run in isolation on each node

Certification Failure



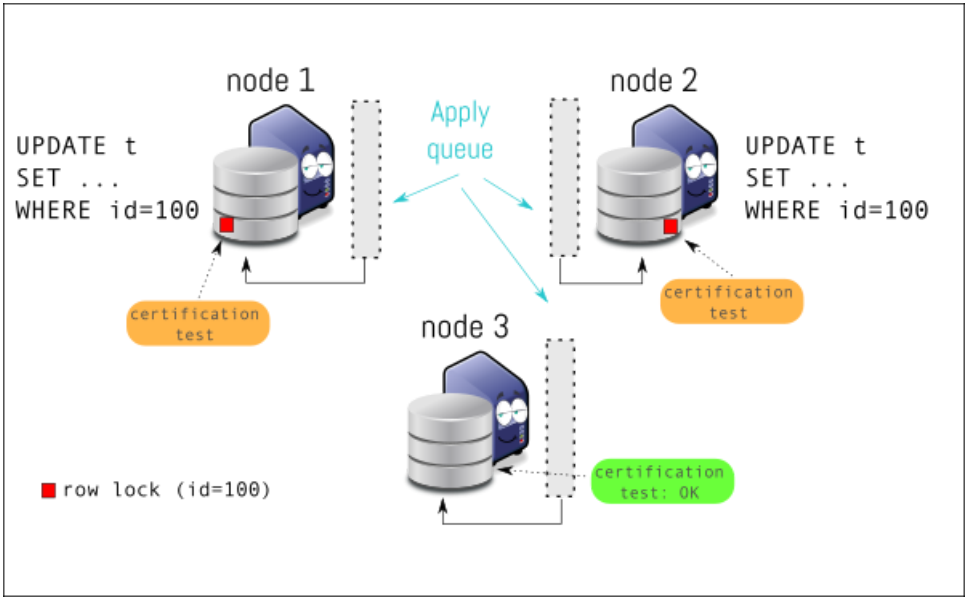
- Certification tests:
  - asynchronous

Certification Failure



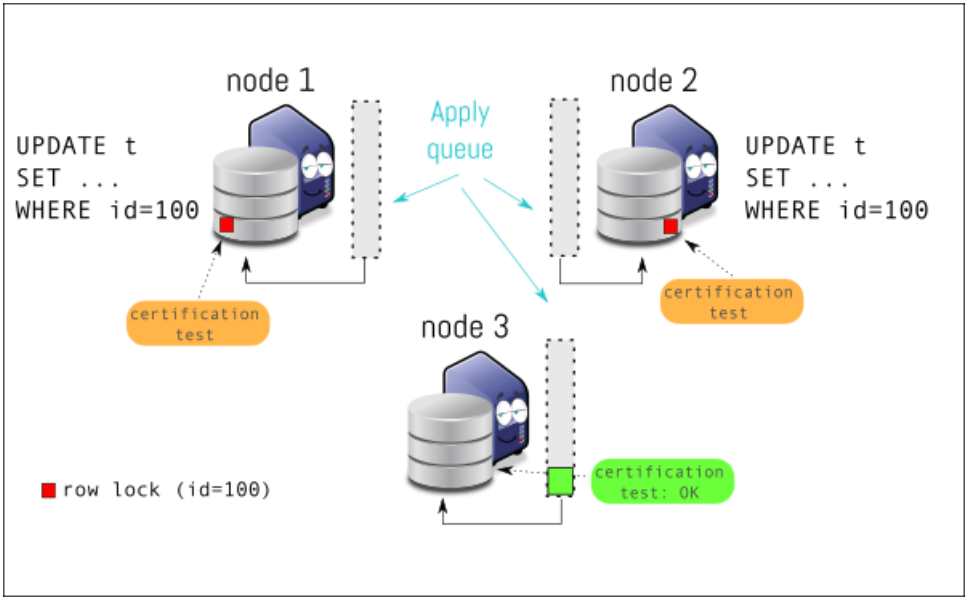
- Synchronous replication
  - deterministic

Certification Failure



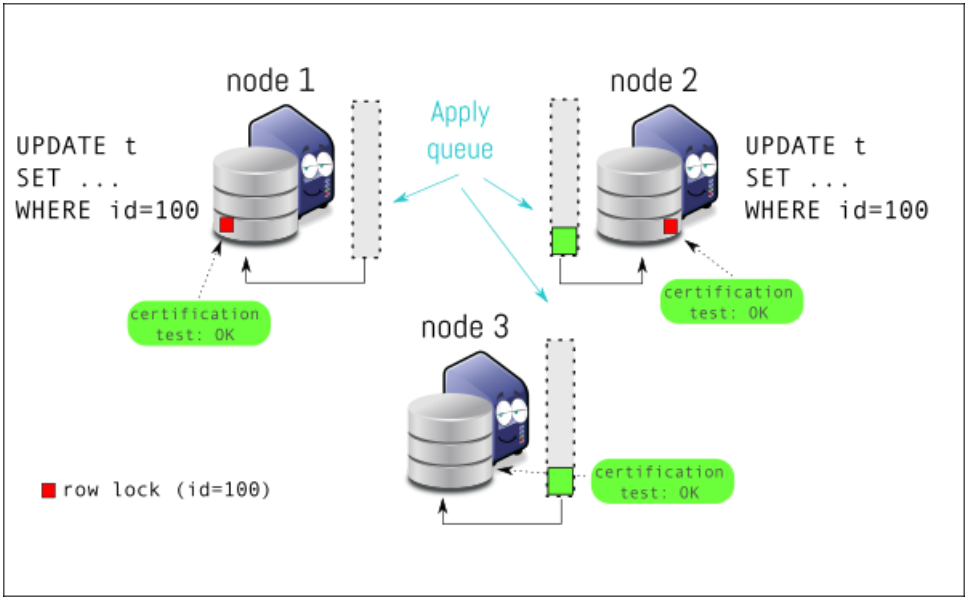
- Certification succeeds

Certification Failure

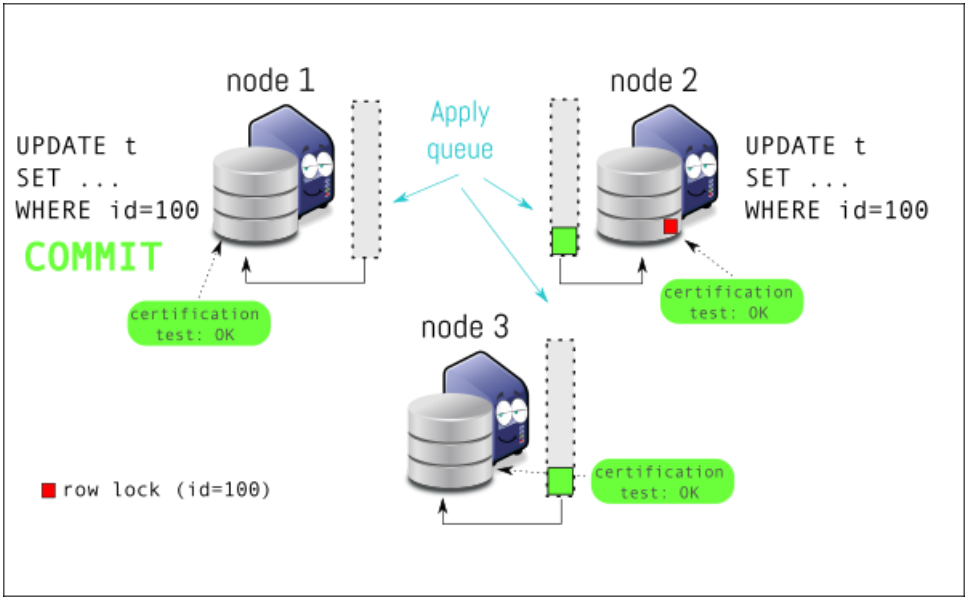


- Certified transaction goes to the apply queue

Certification Failure

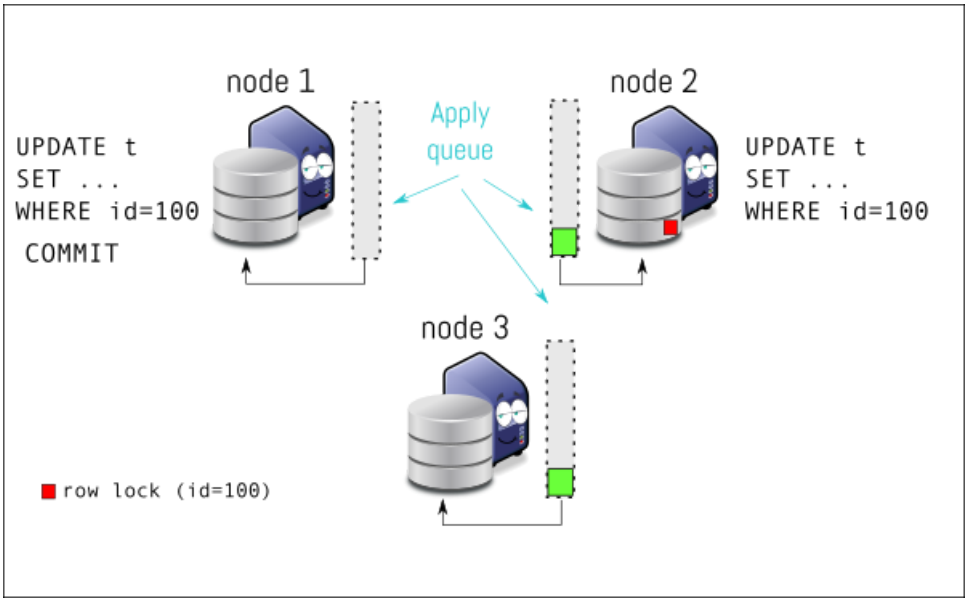


Certification Failure



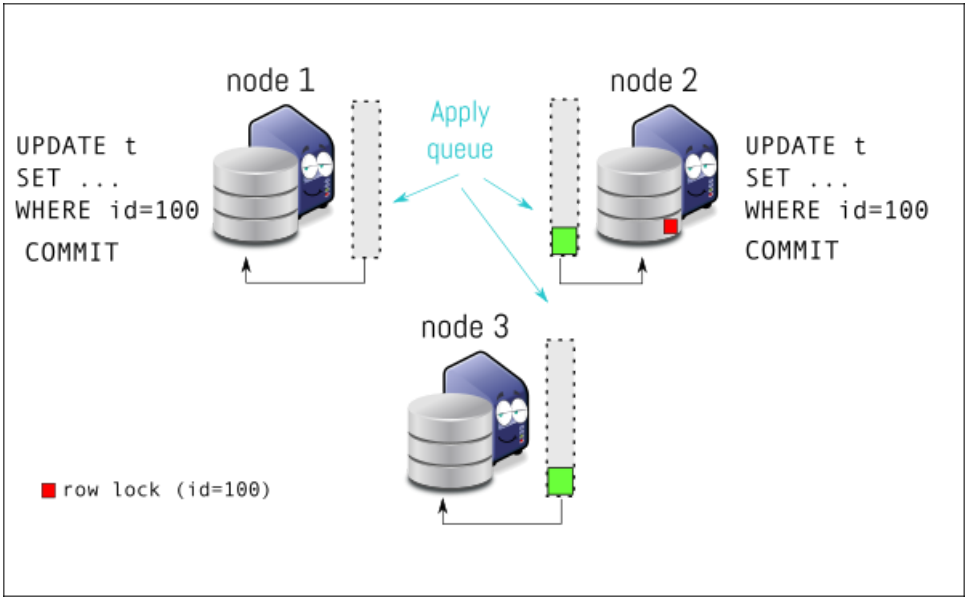
- On **Node1**, a successful cert test, means an actual **commit**

Certification Failure



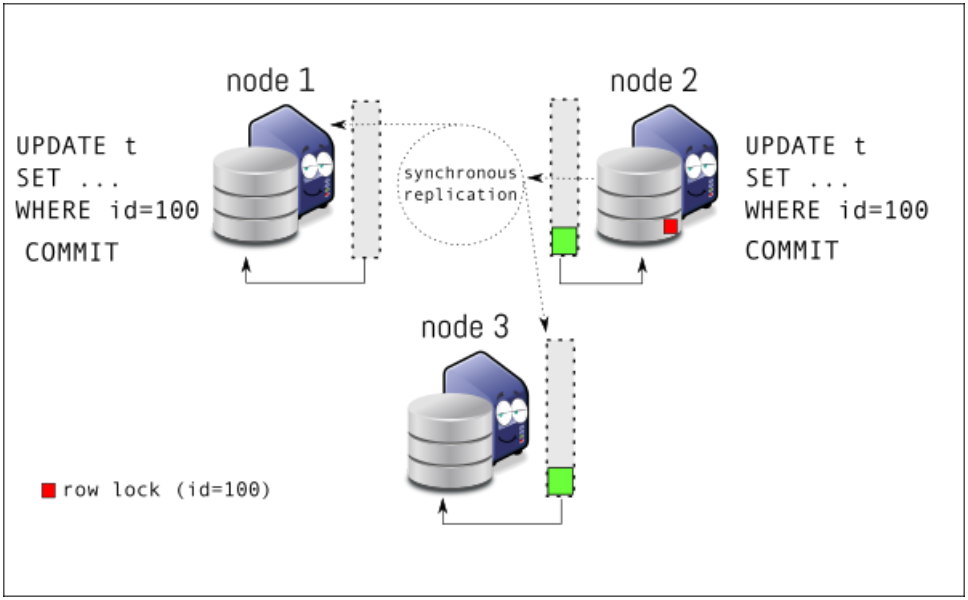
- and transactions in the apply queue (Node2 & Node3) are executed asynchronously

Certification Failure



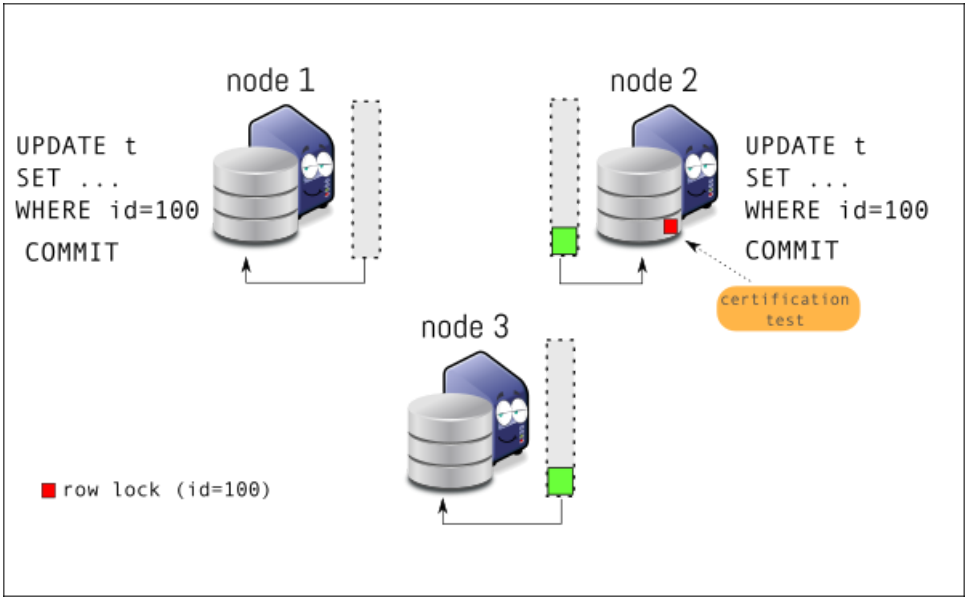
- On **node2** we commit the transaction

Certification Failure

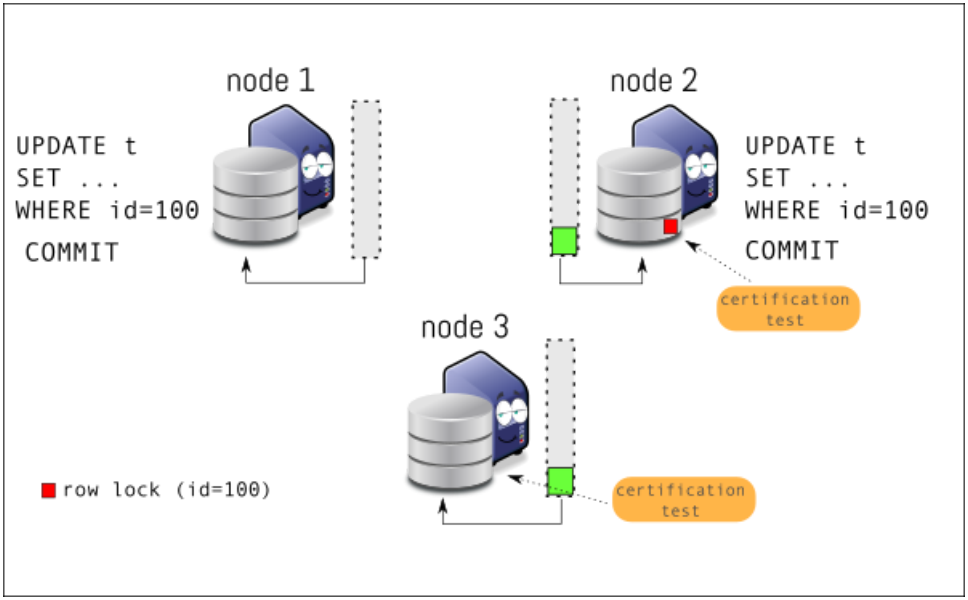


- Synchronous replication

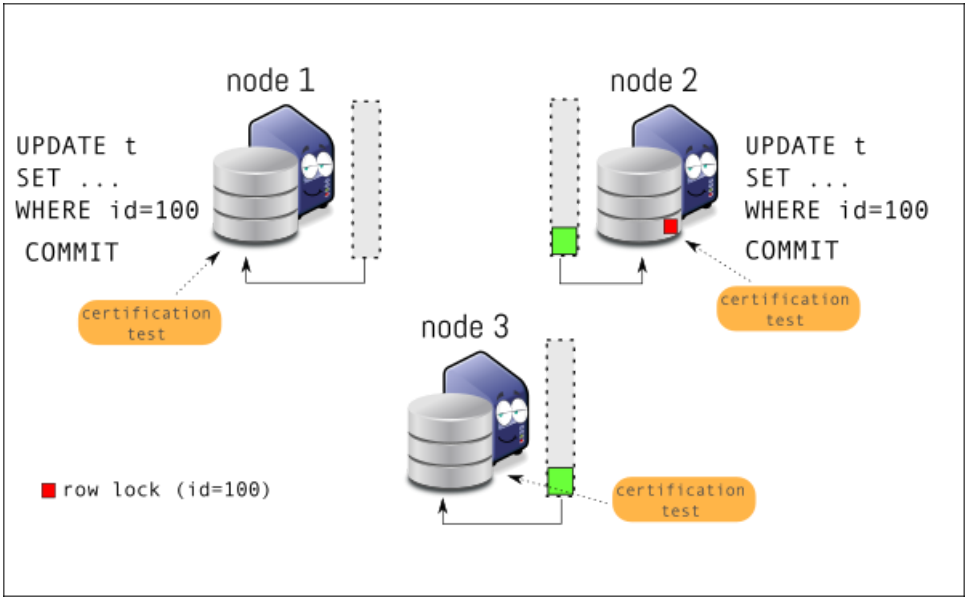
Certification Failure



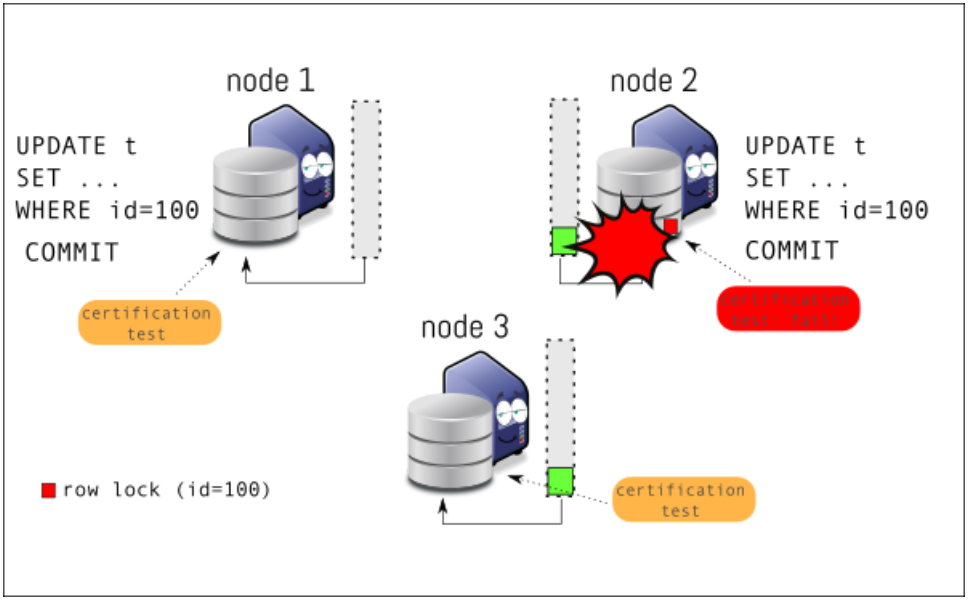
Certification Failure



Certification Failure



Certification Failure



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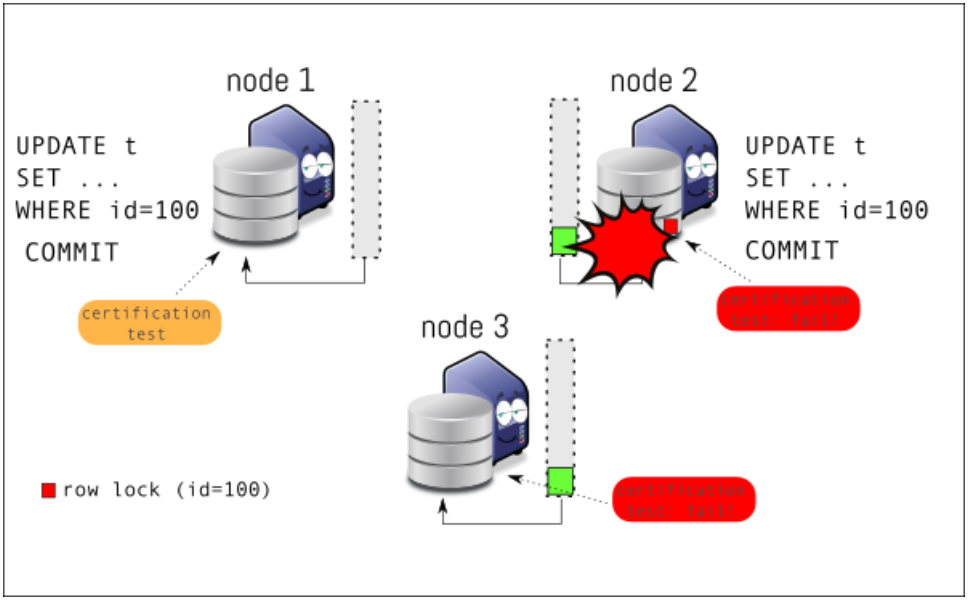

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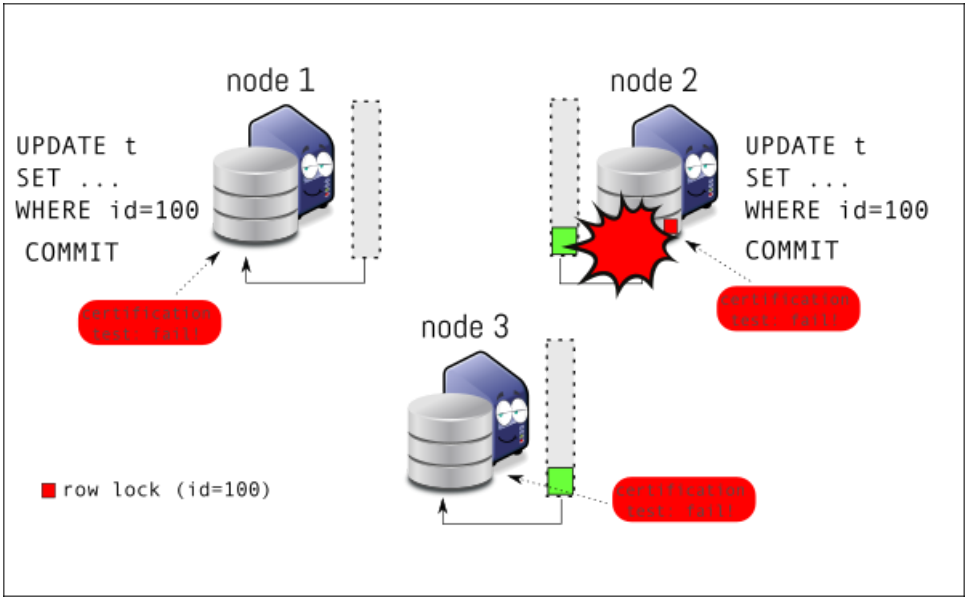
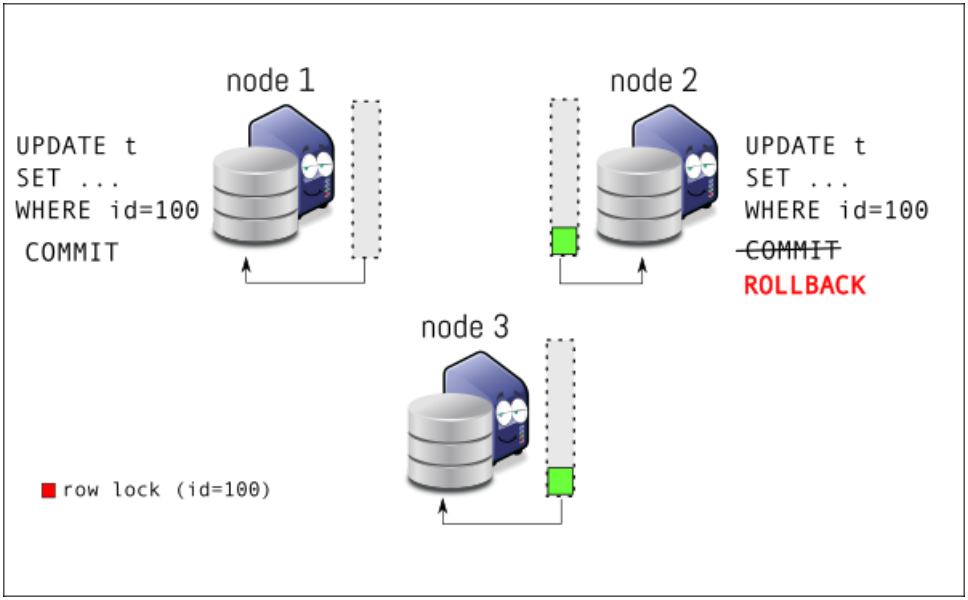
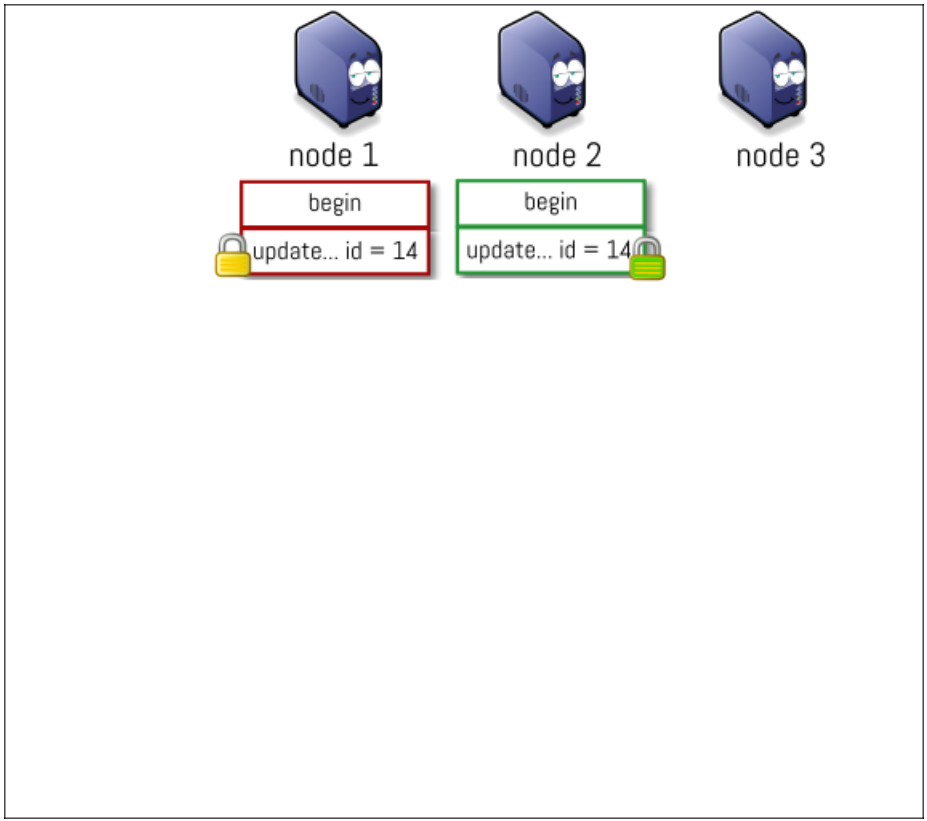


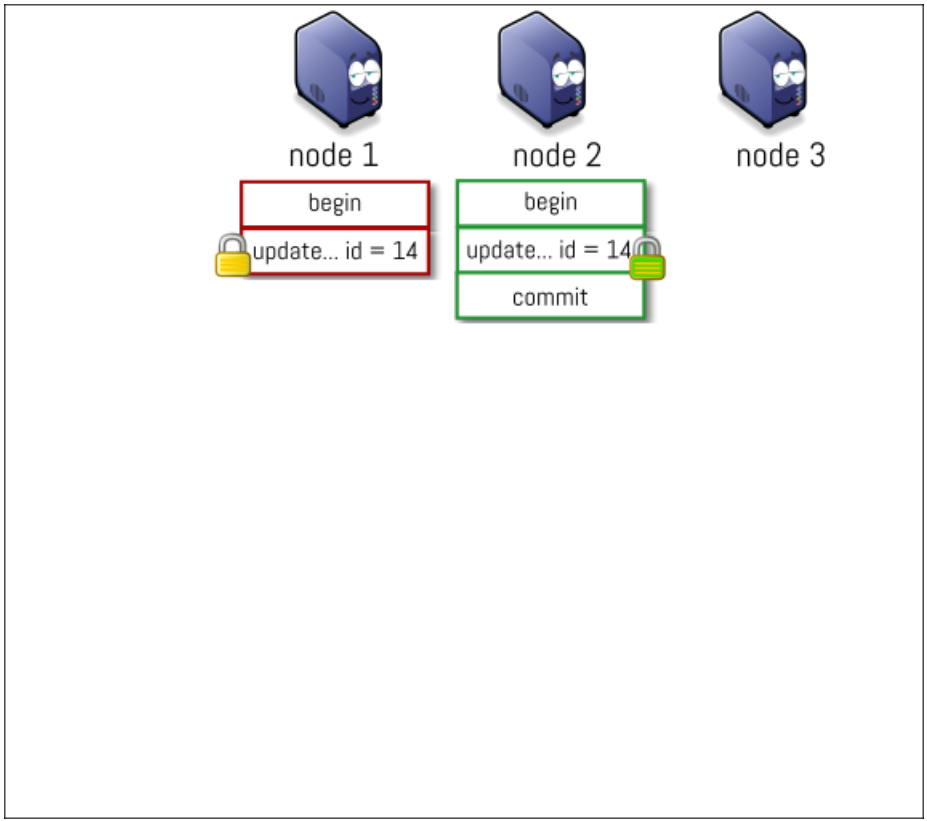
Certification Failure



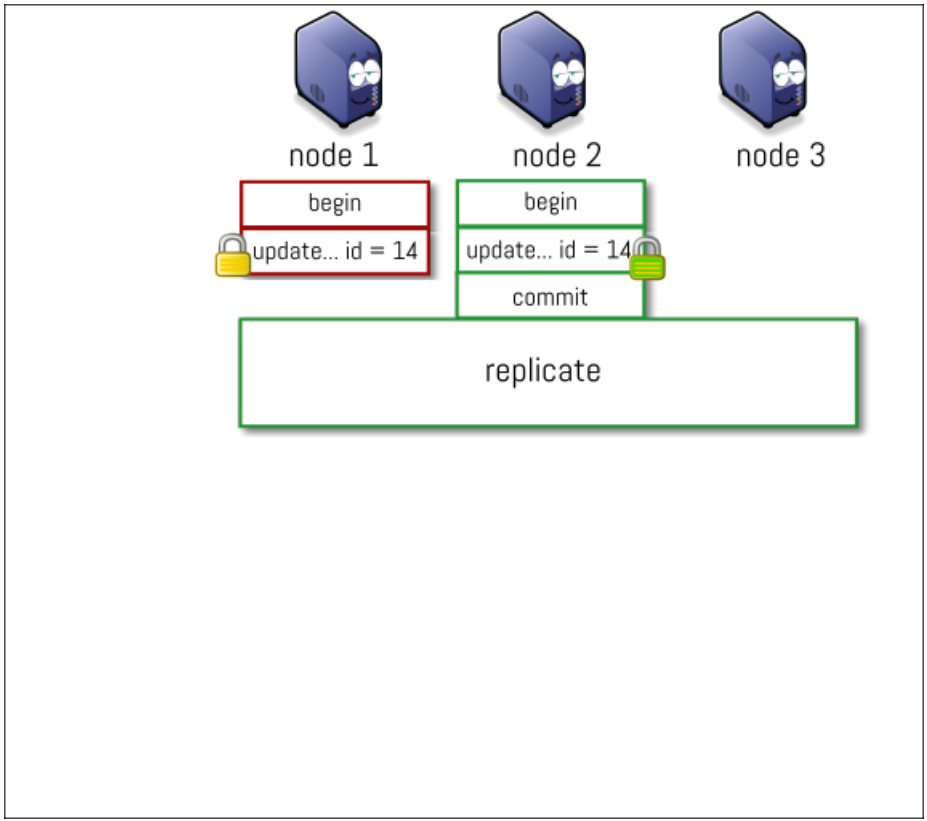
Brute Force Abort (bfa)



Brute Force Abort (bfa)



Brute Force Abort (bfa)



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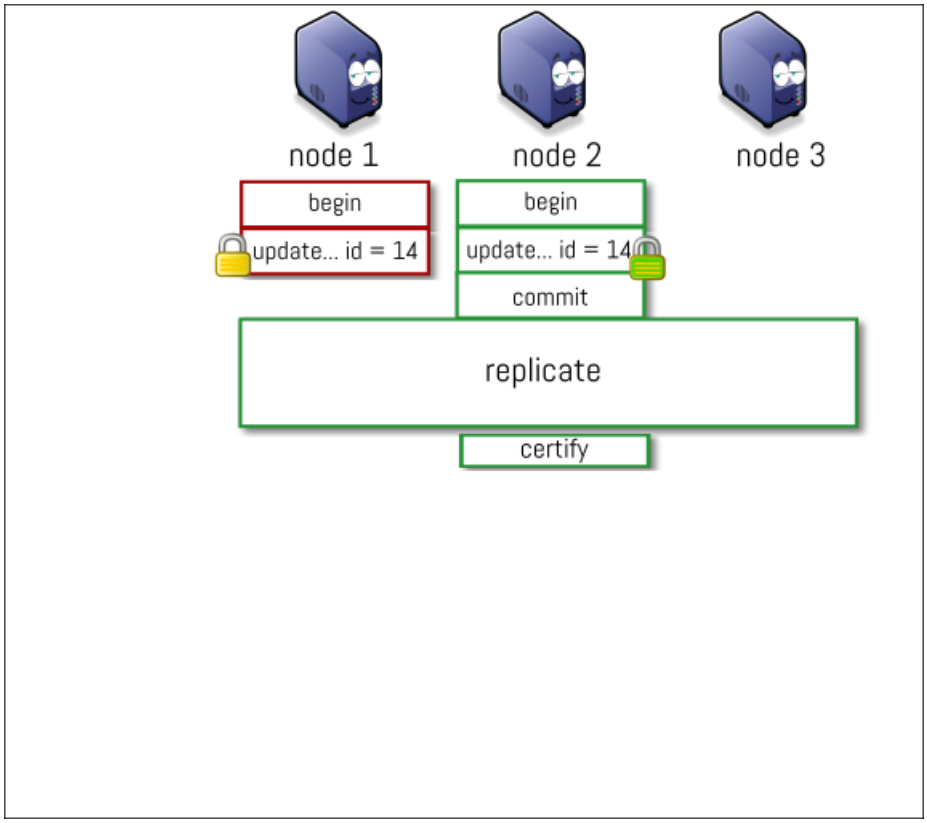

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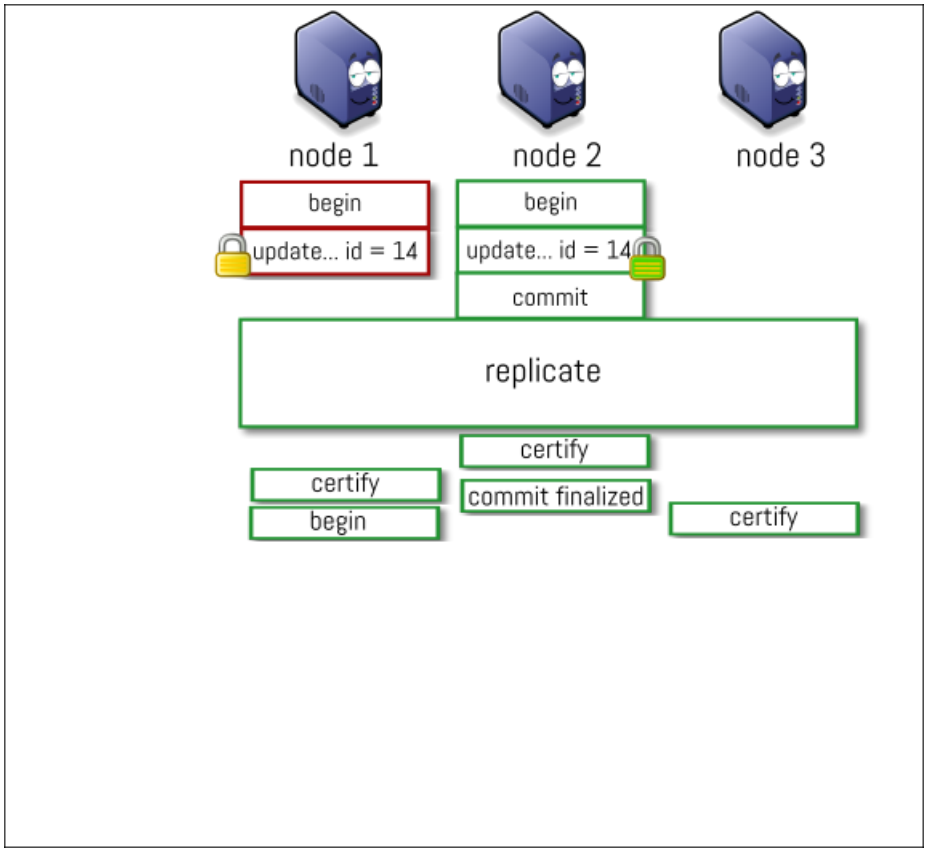
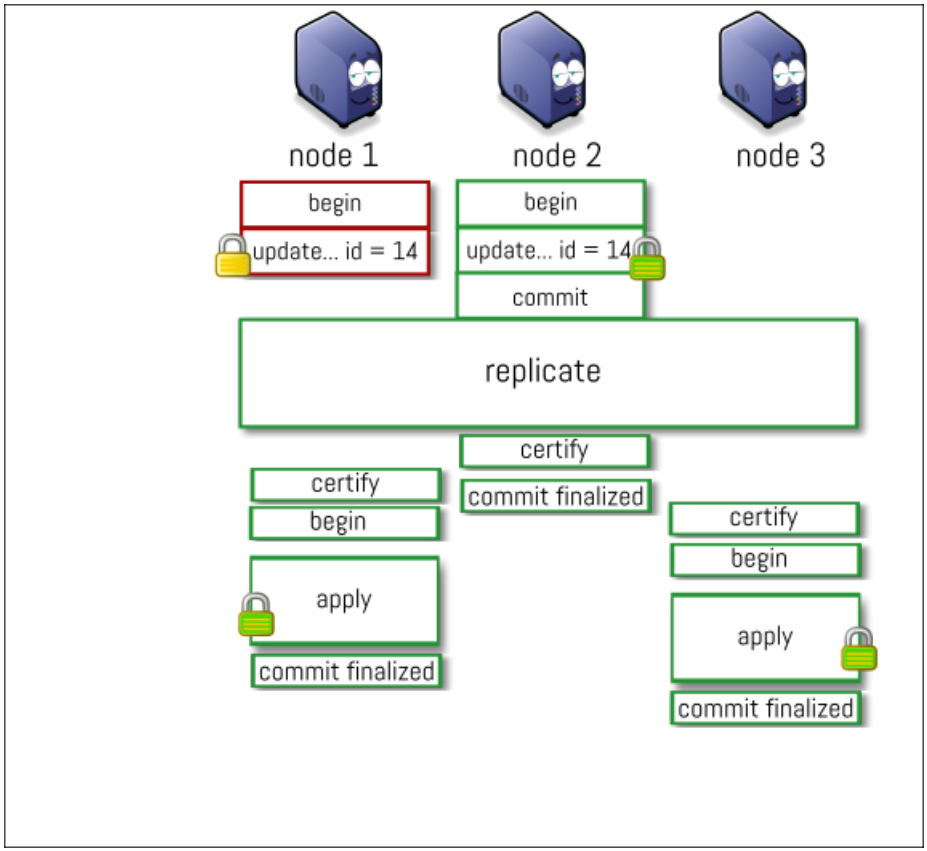


Brute Force Abort (bfa)



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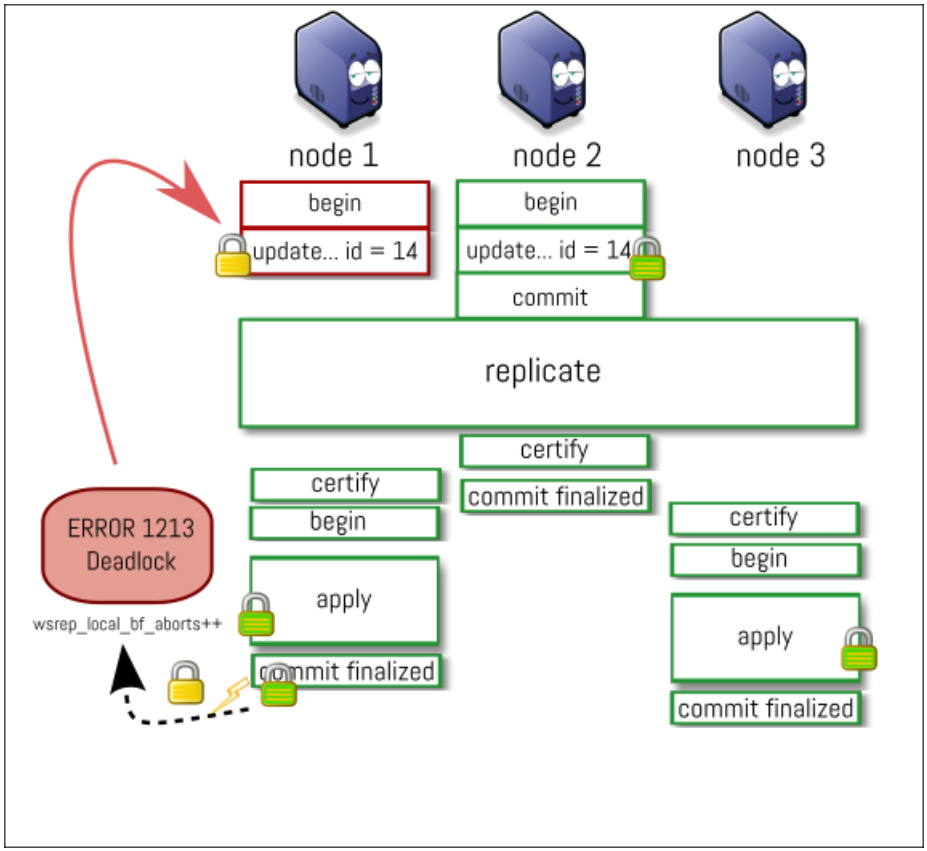
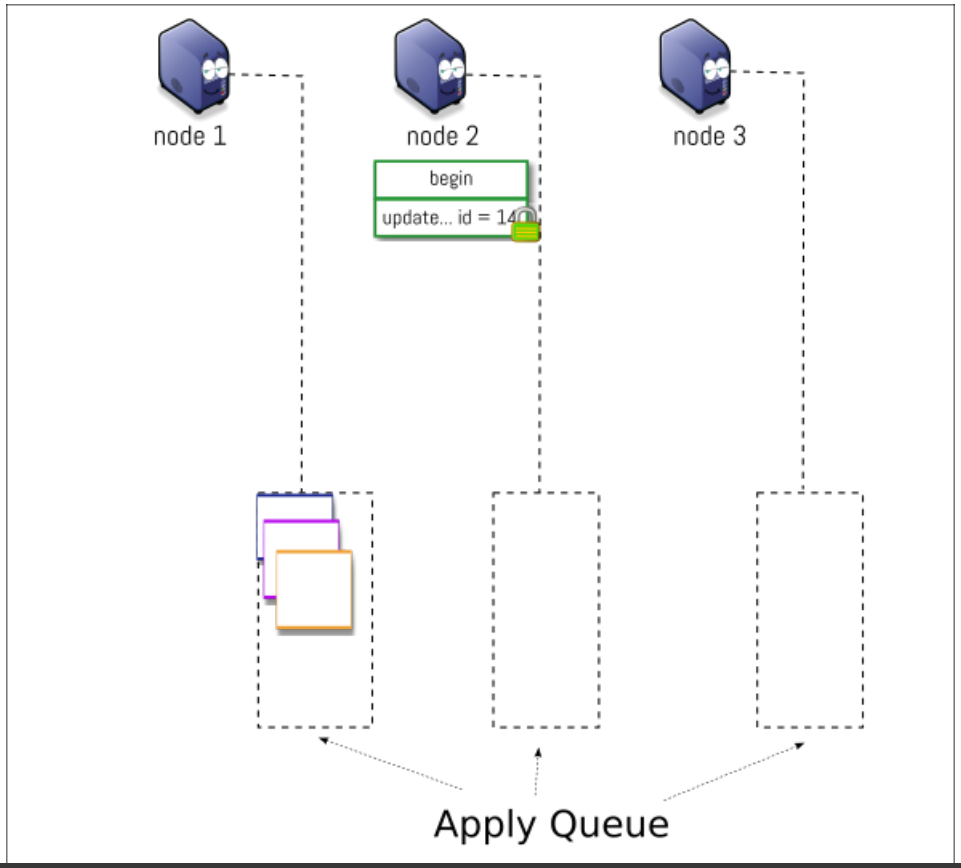


Local Certification Failure (lcf)



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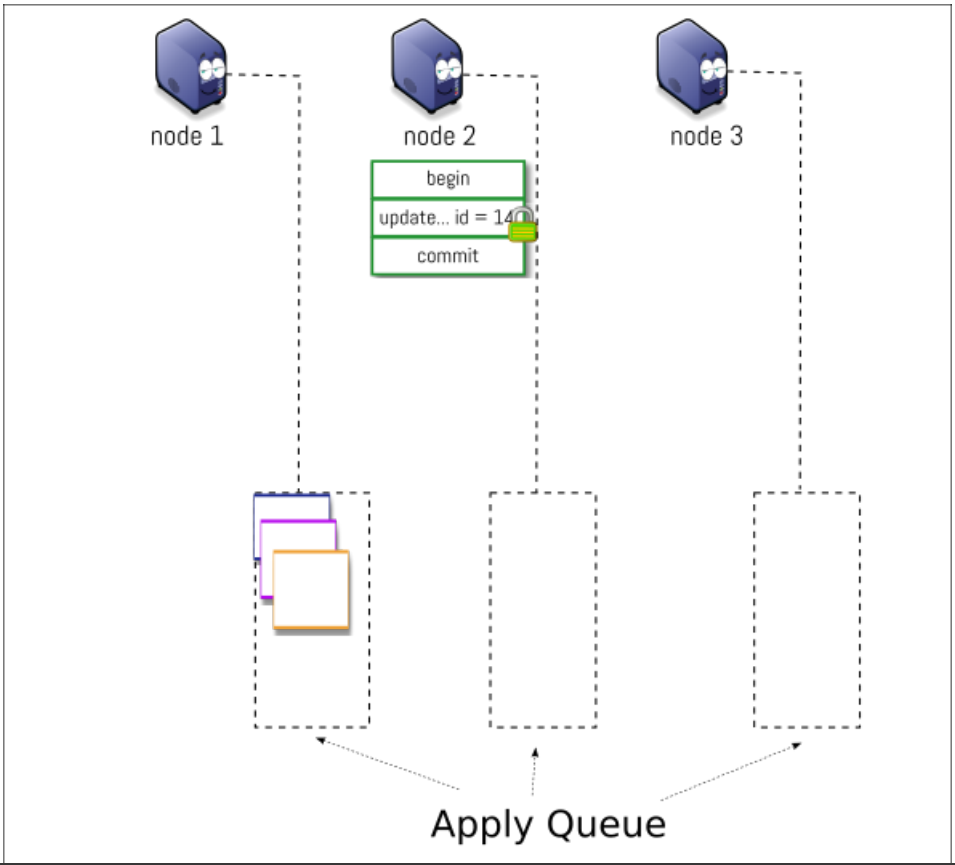

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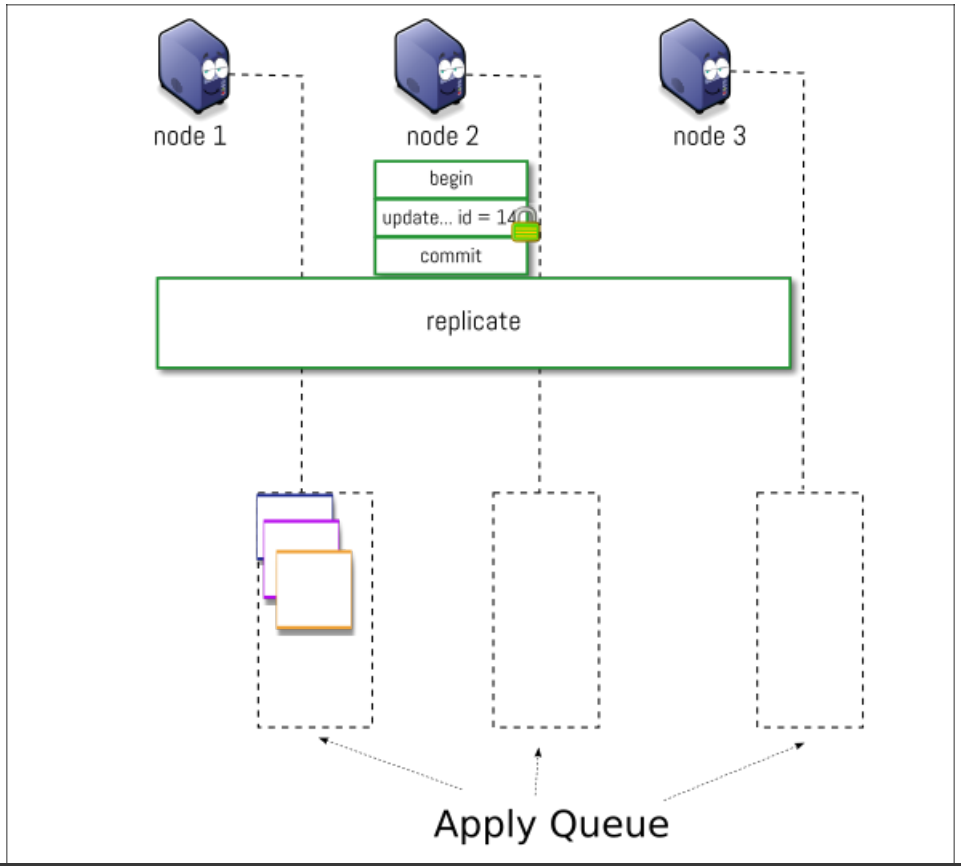

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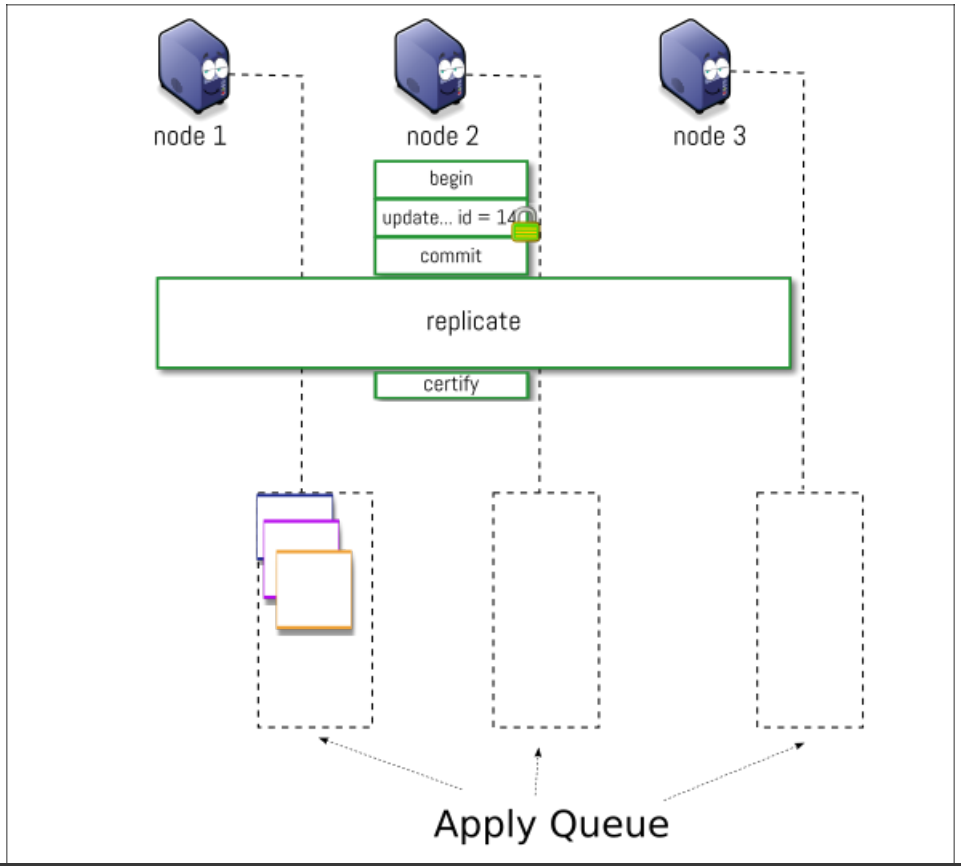

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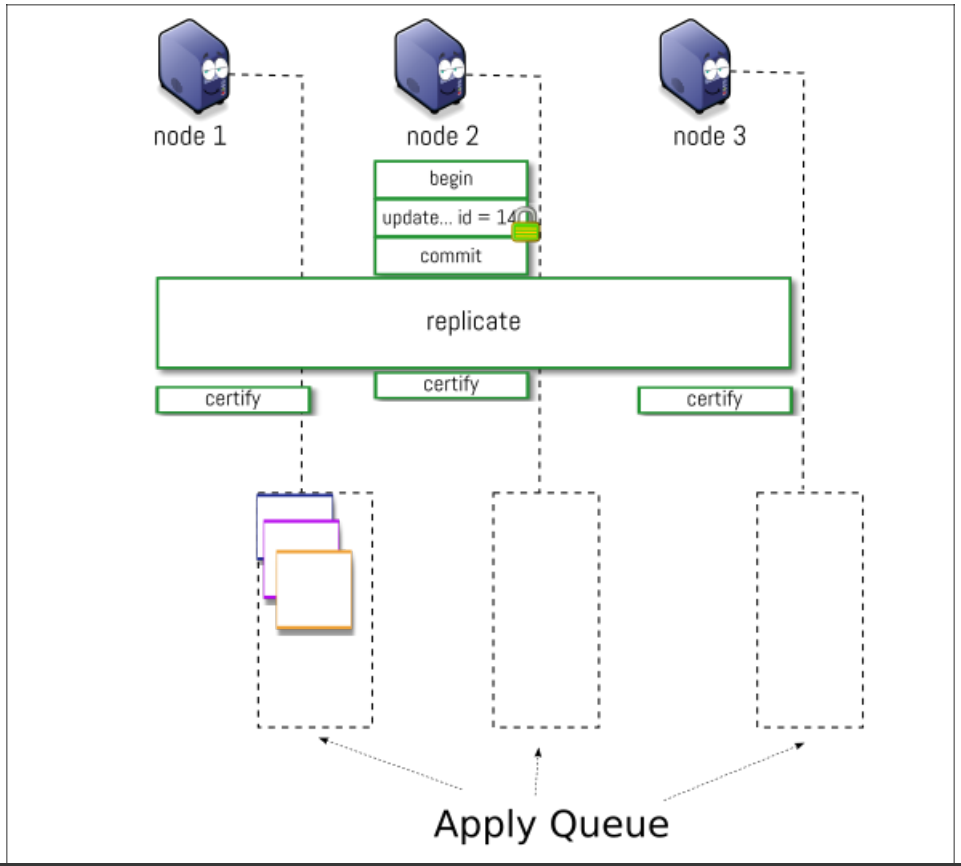

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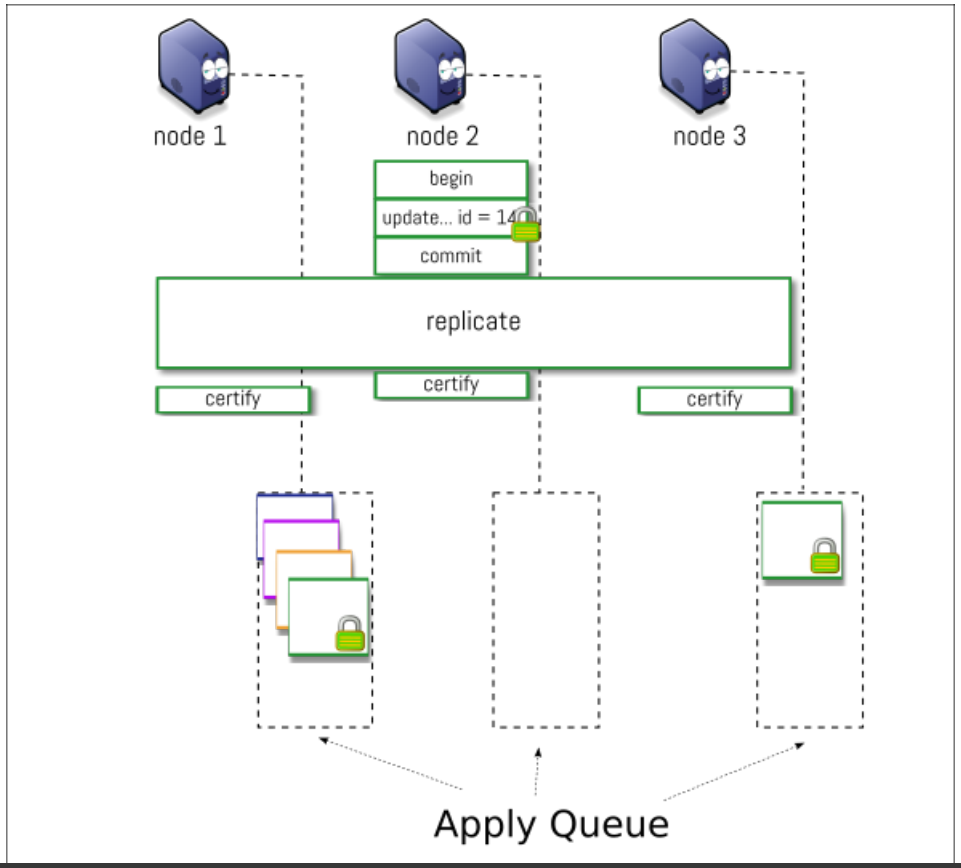

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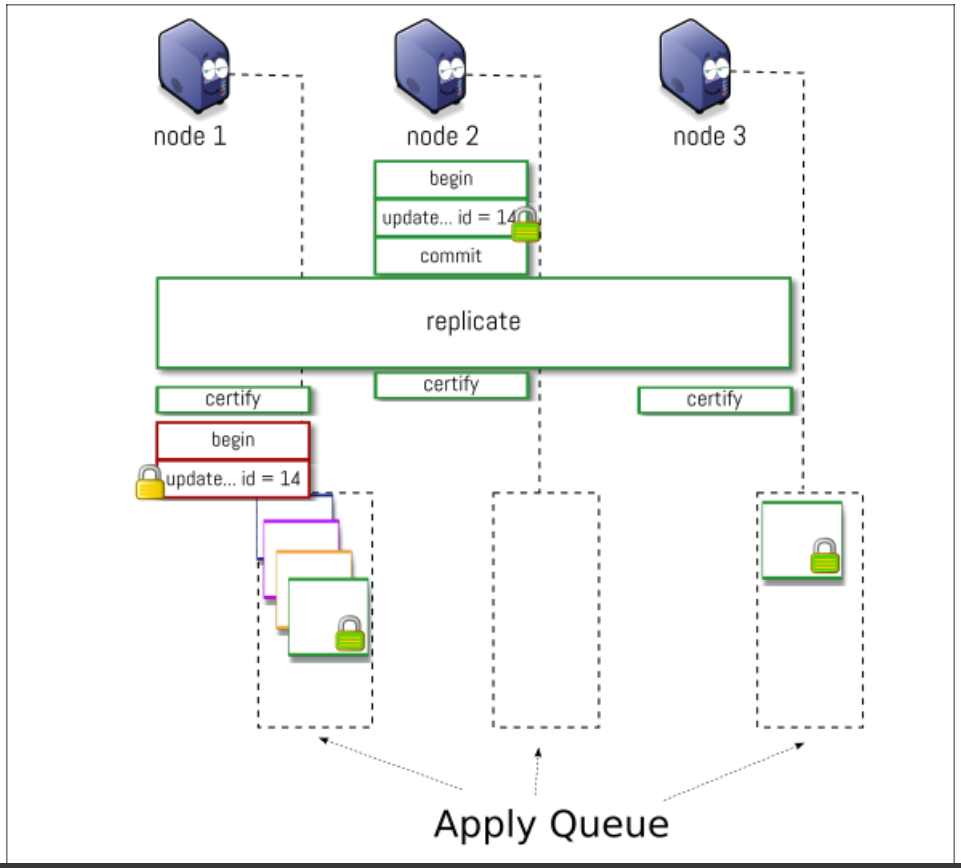

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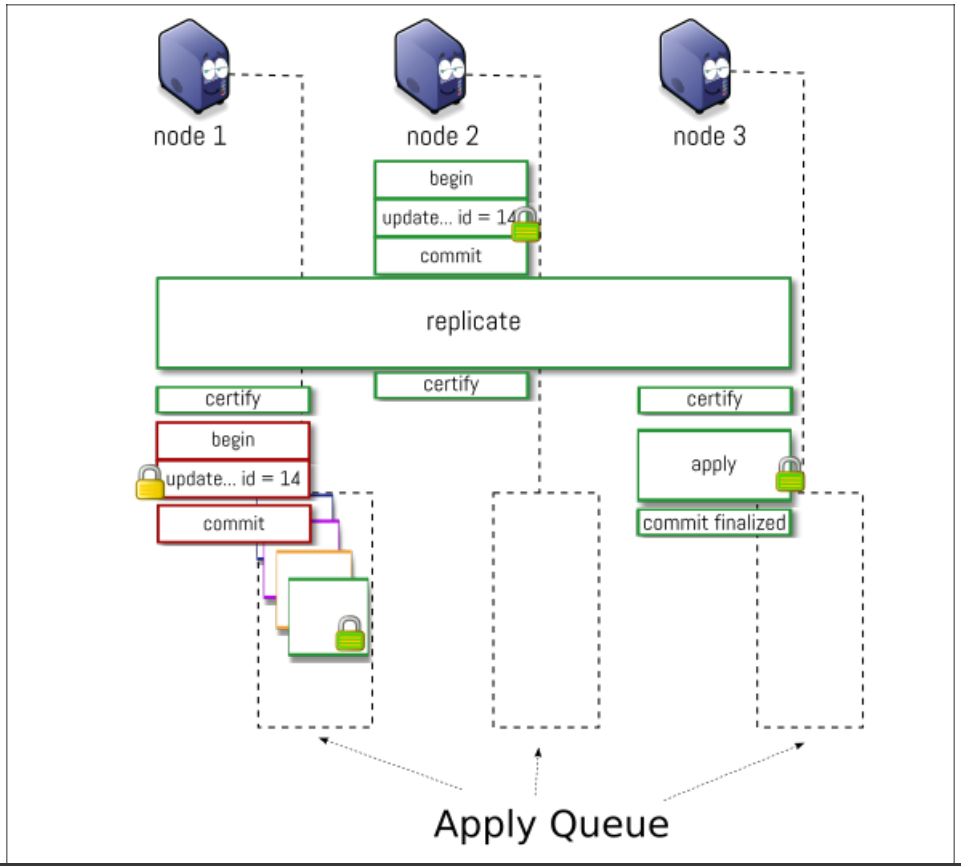

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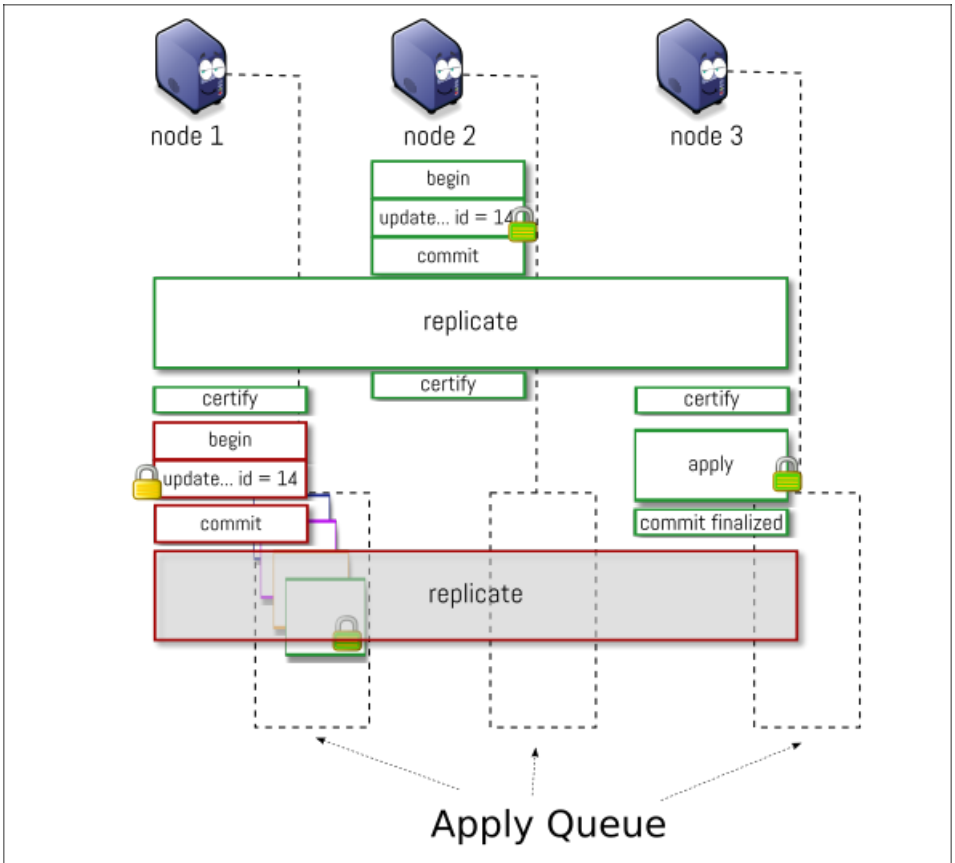

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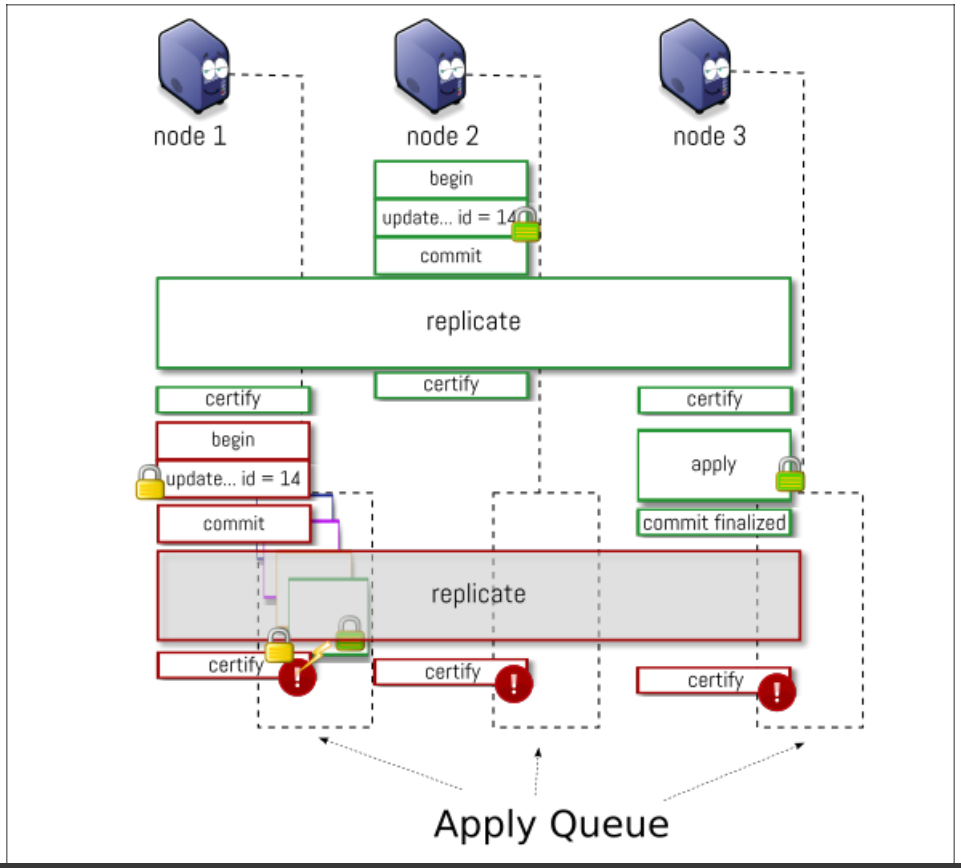
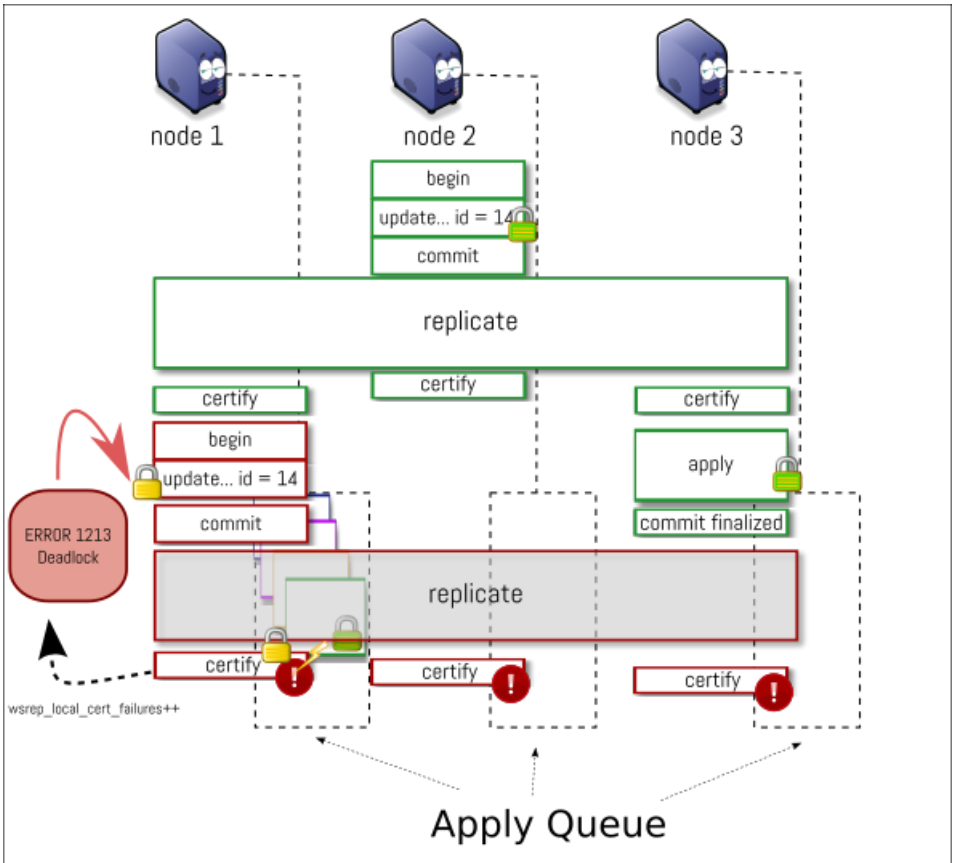


Local Certification Failure (lcf)



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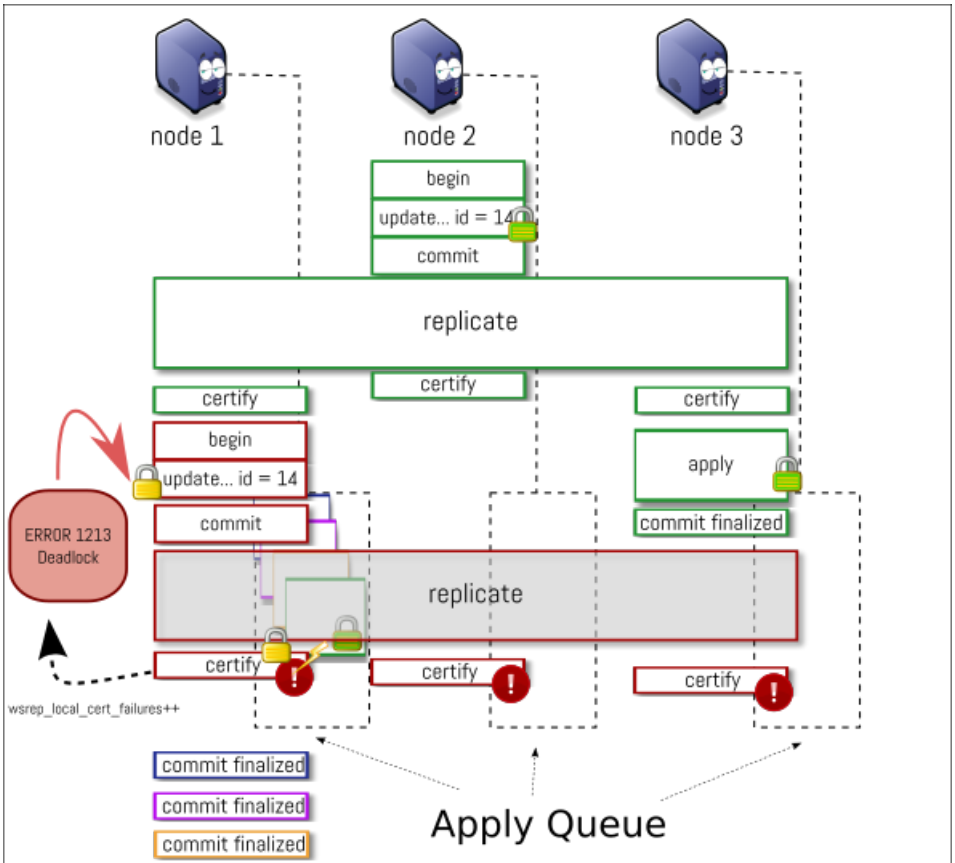
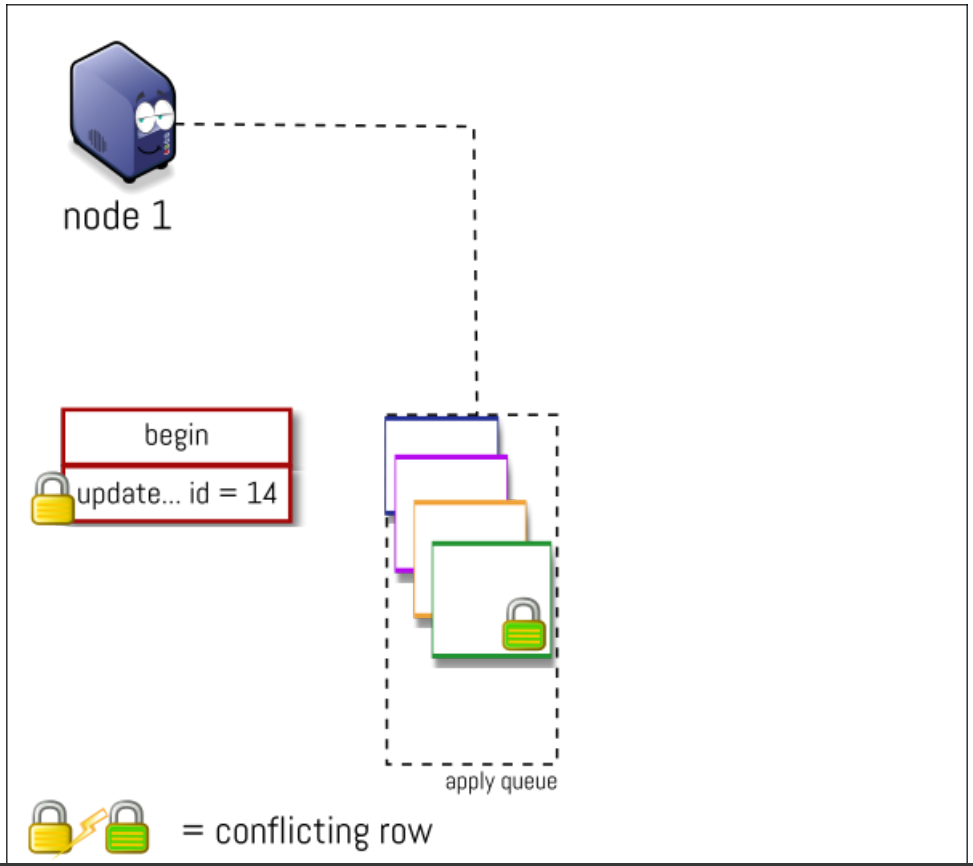
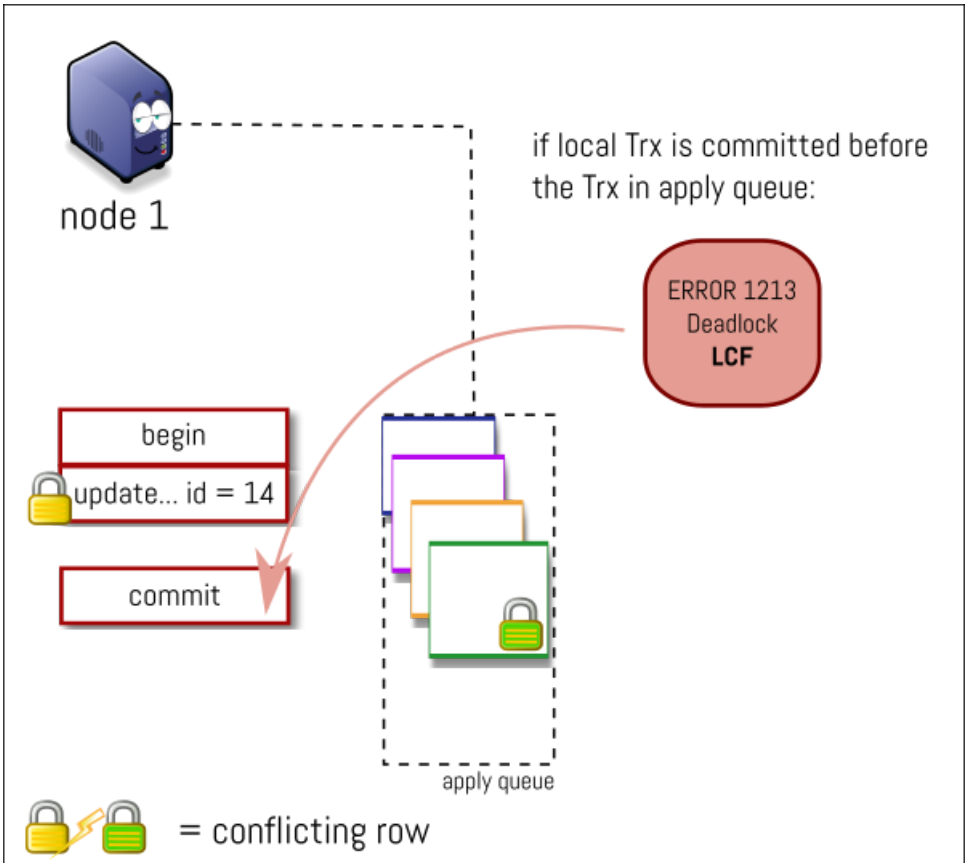


Certification Errors: summary



Certification Errors: summary



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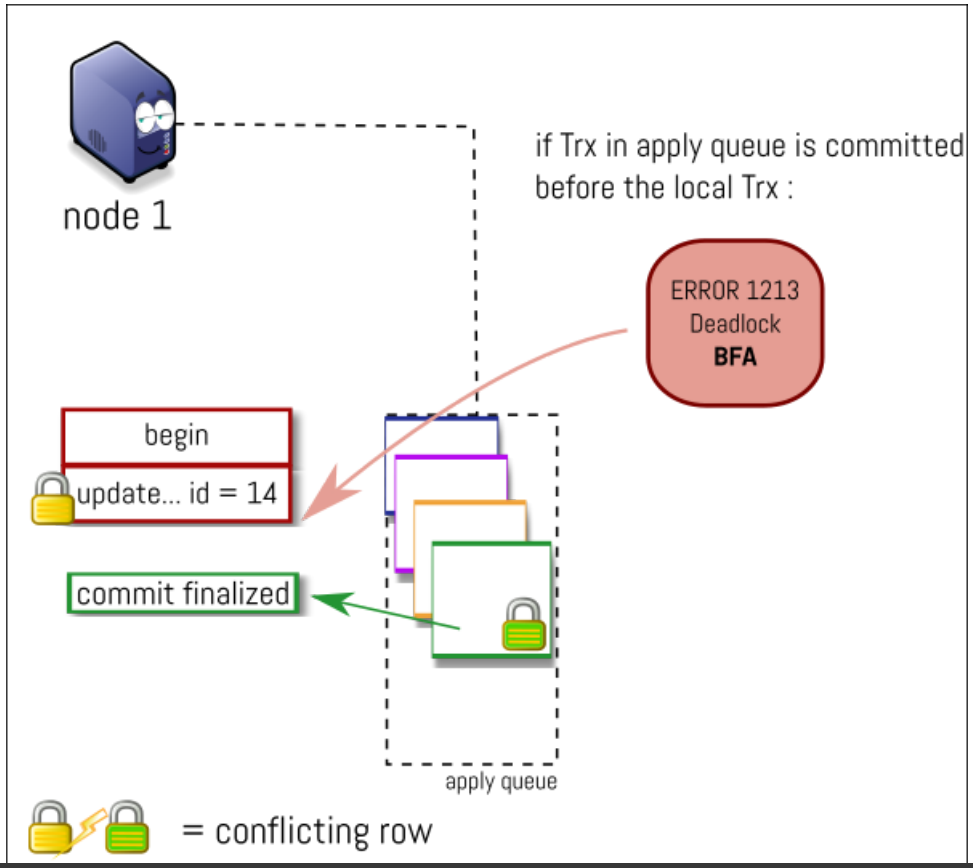

Flow Control

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- CAN **pause the entire cluster** and look like a cluster stall !

Tuning Flow Control

- Too low:

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  - frequent FC from any and all nodes in the cluster

Tuning Flow Control

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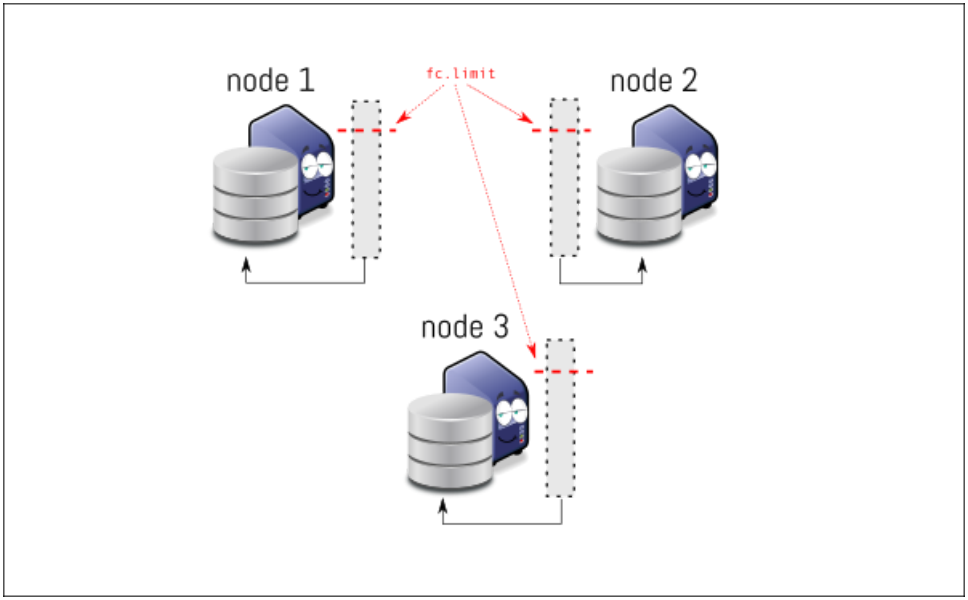
  - increase in commit lag on nodes
- One node with FC issues
  - deal with that node -bad hardware? too slow ?

Flow Control



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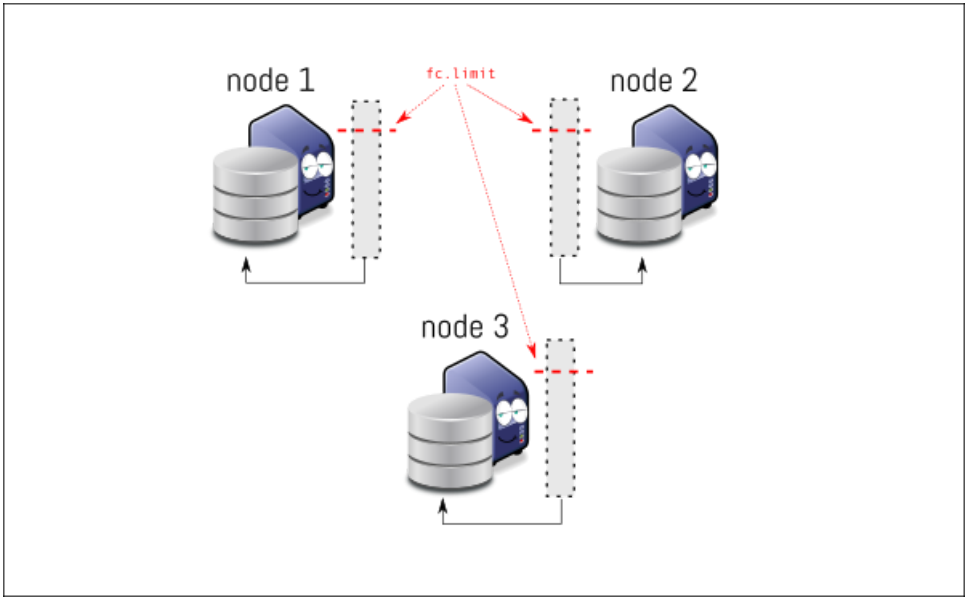
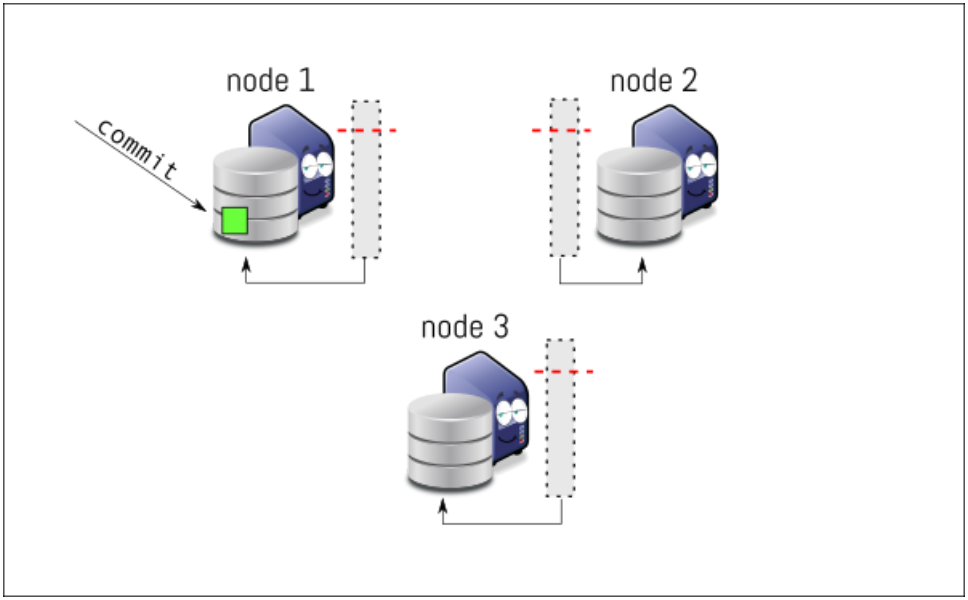
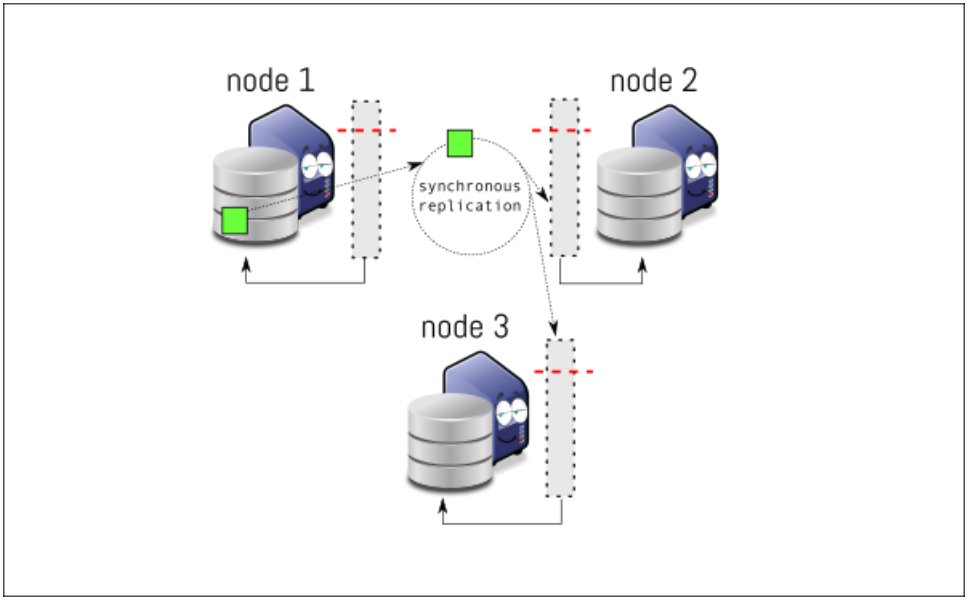


Flow Control



Flow Control



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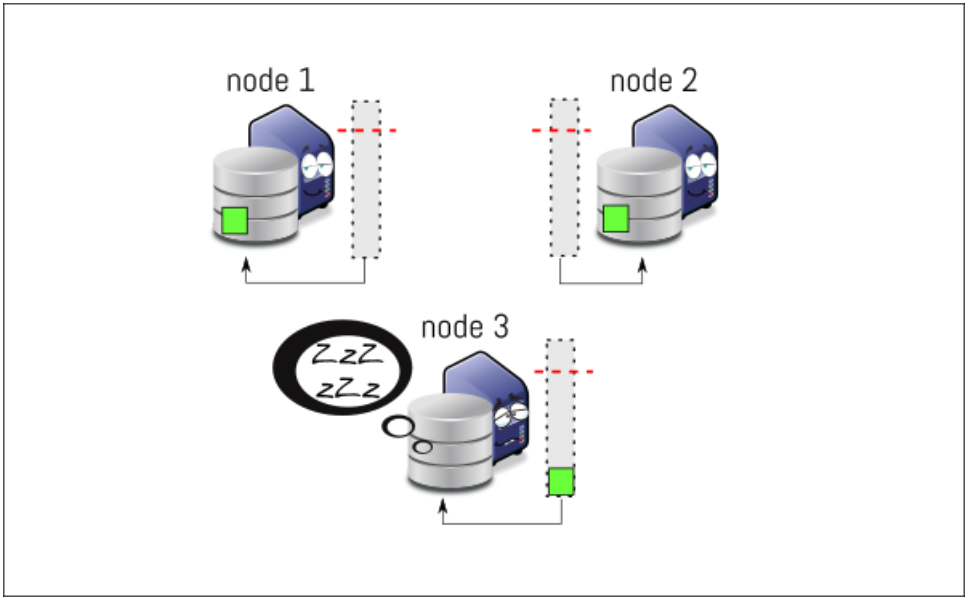

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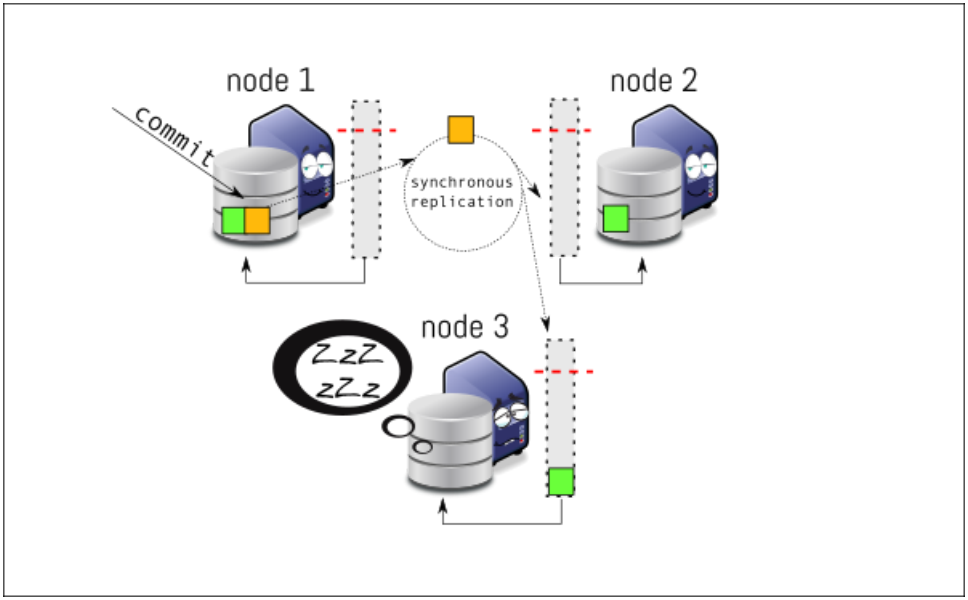

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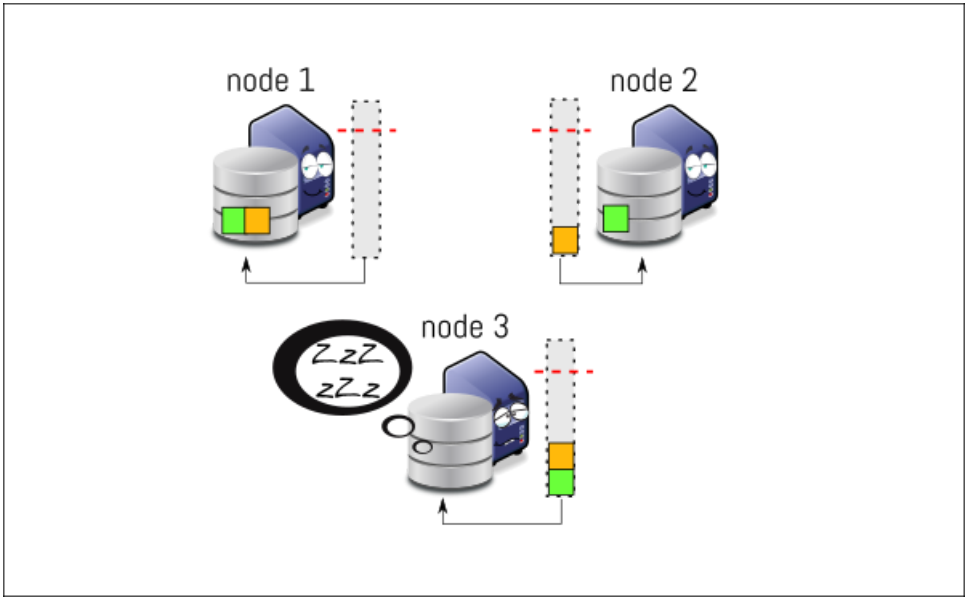

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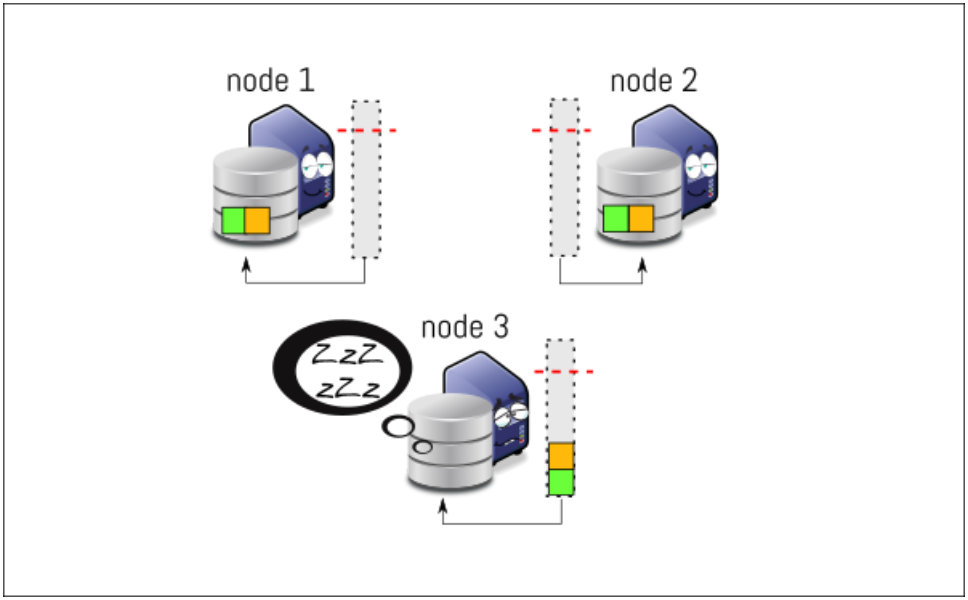

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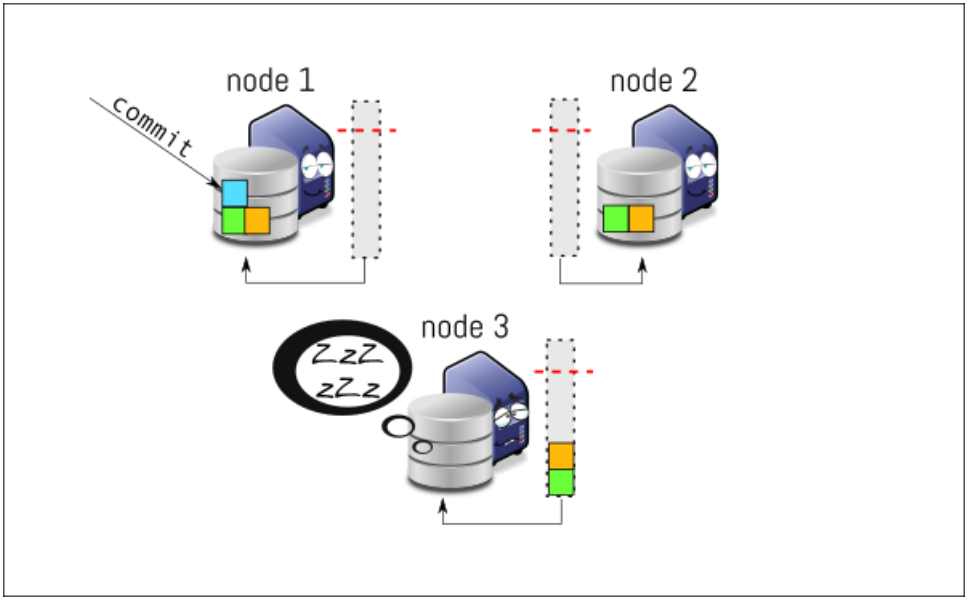

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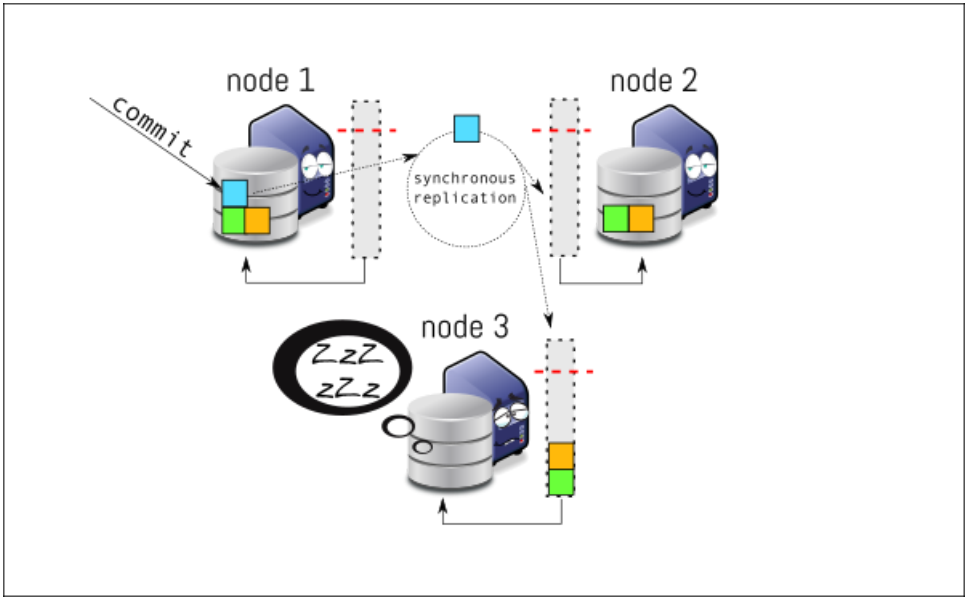

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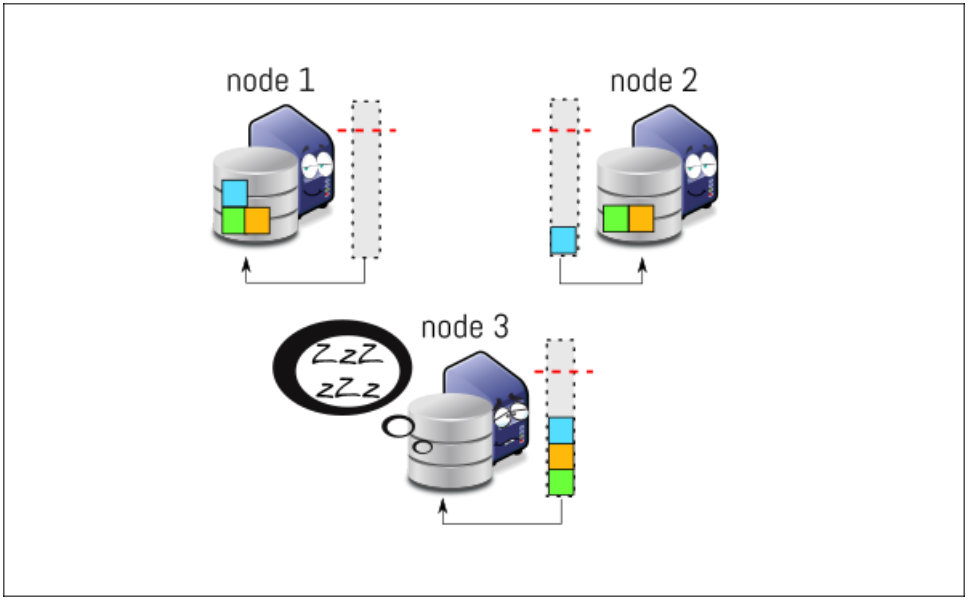

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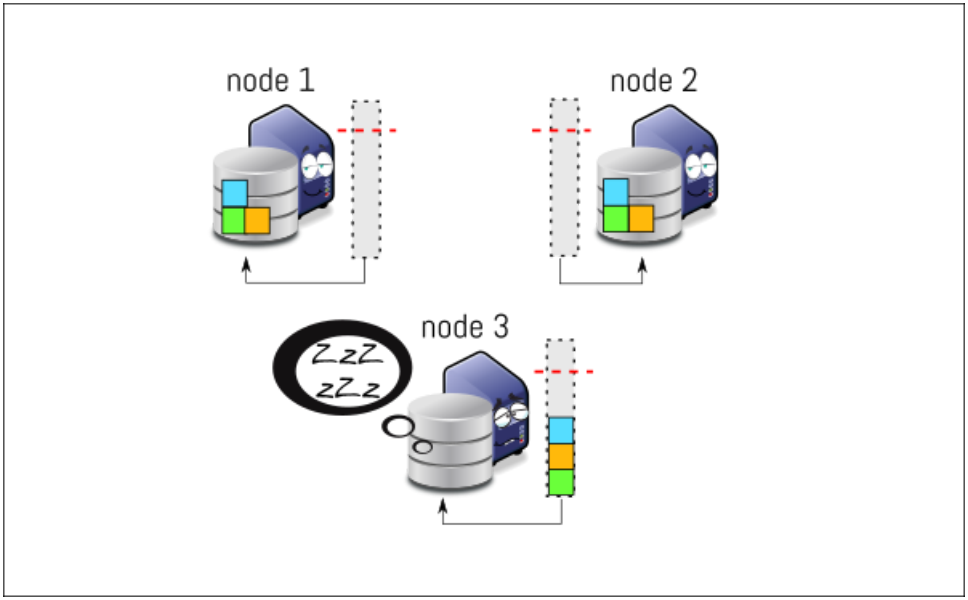

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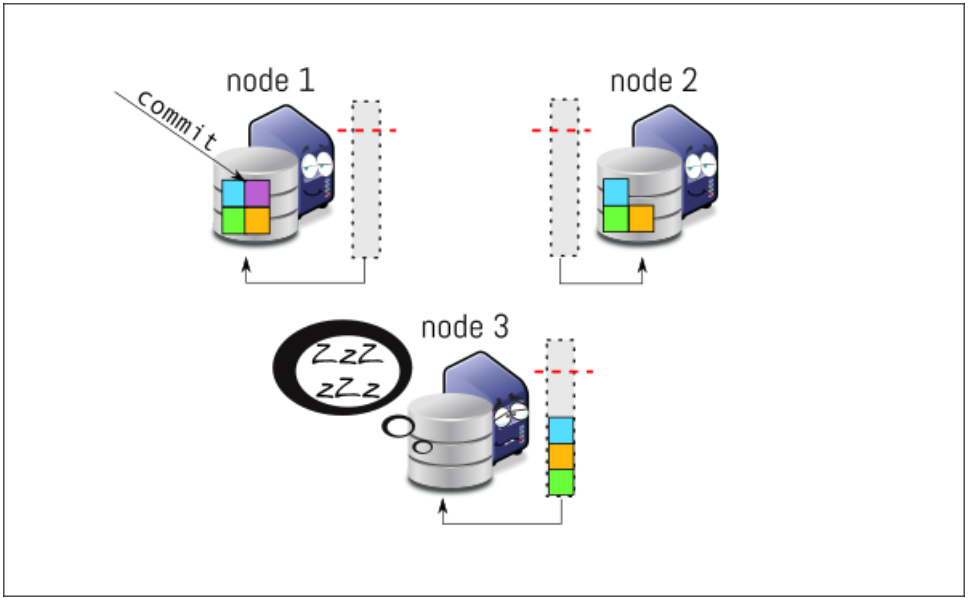

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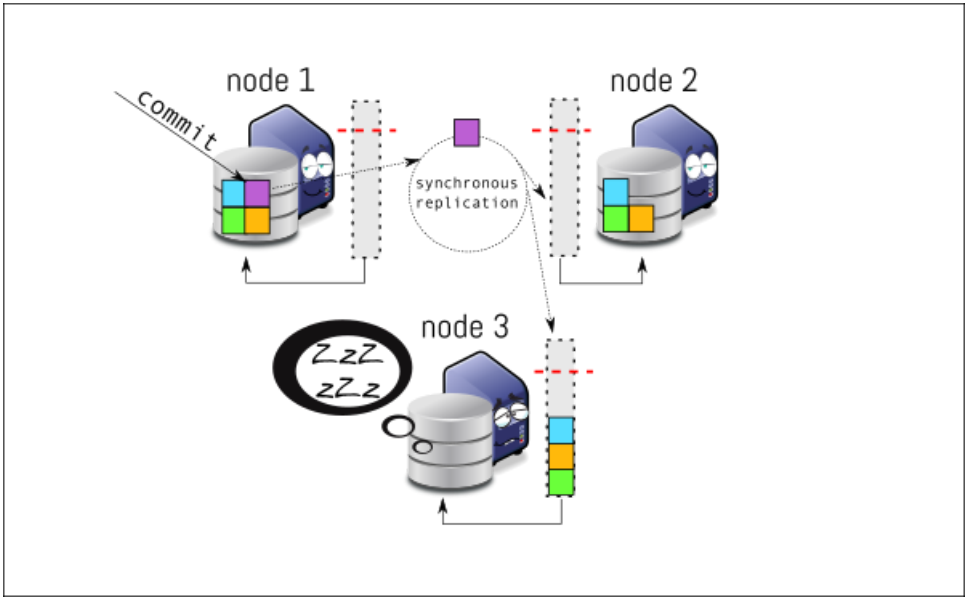

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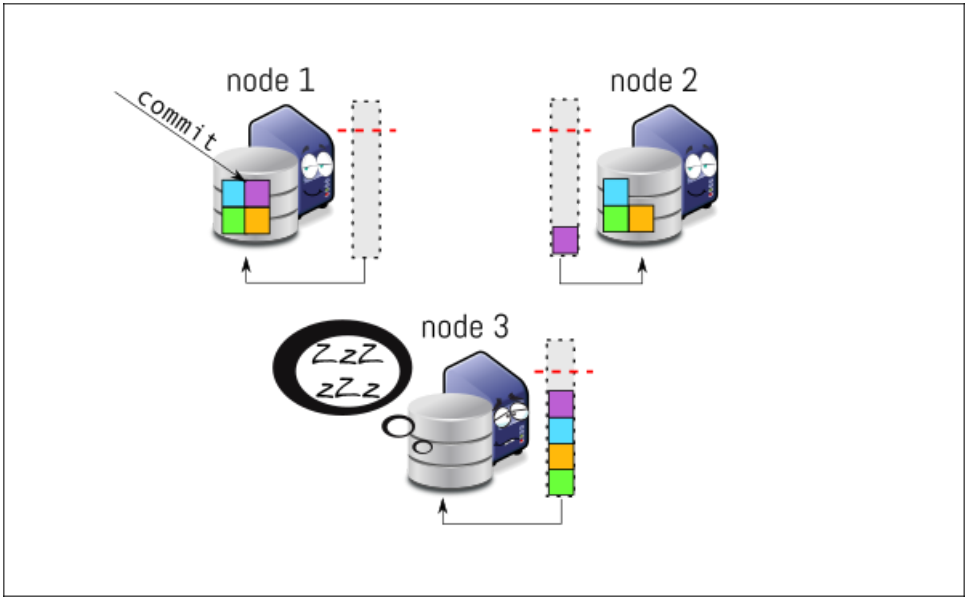

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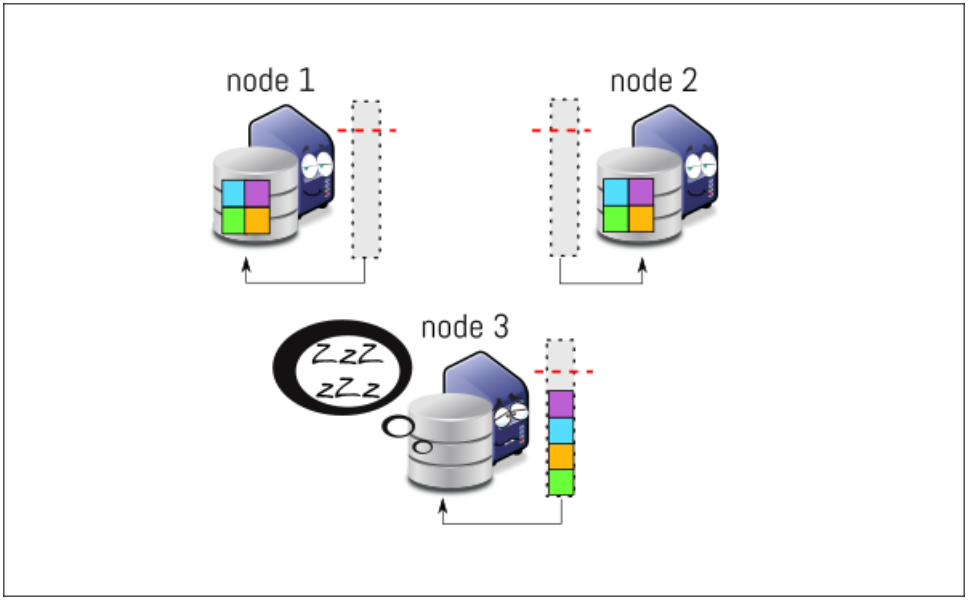

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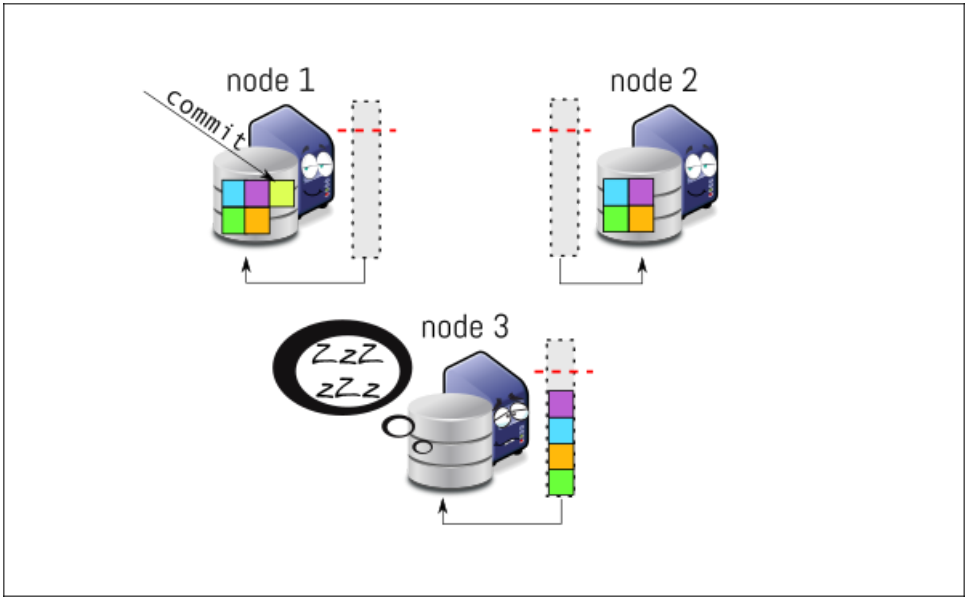
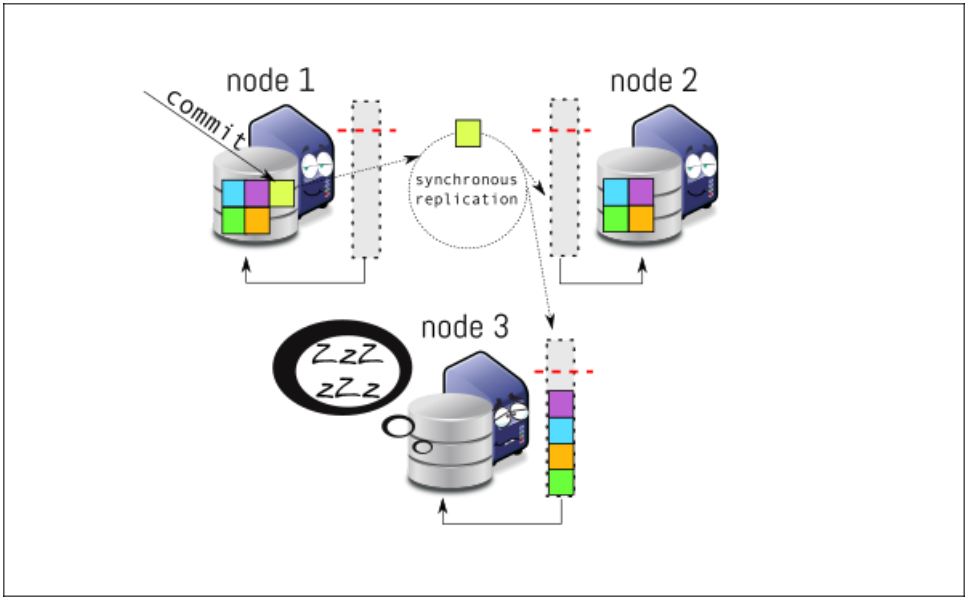


Flow Control



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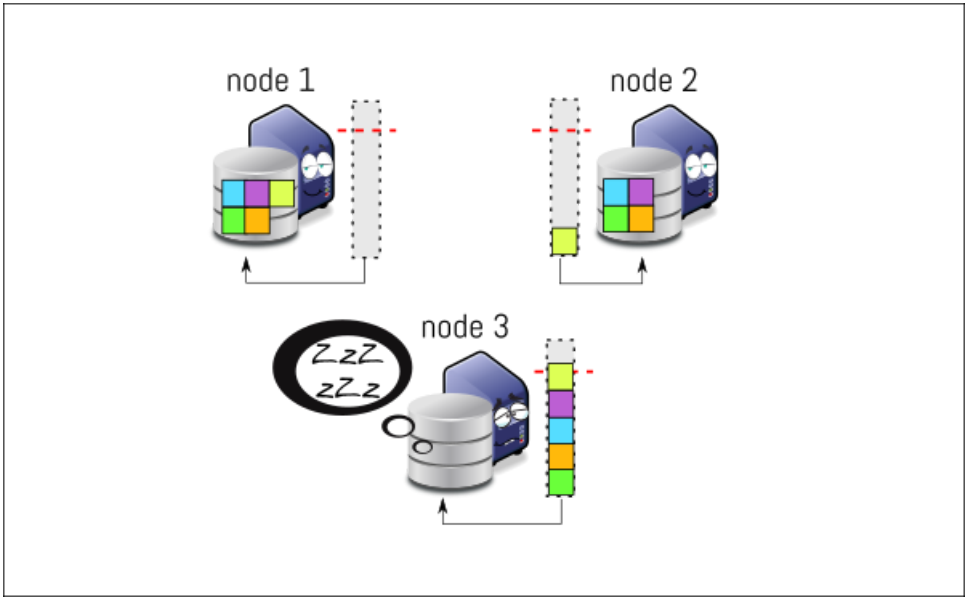

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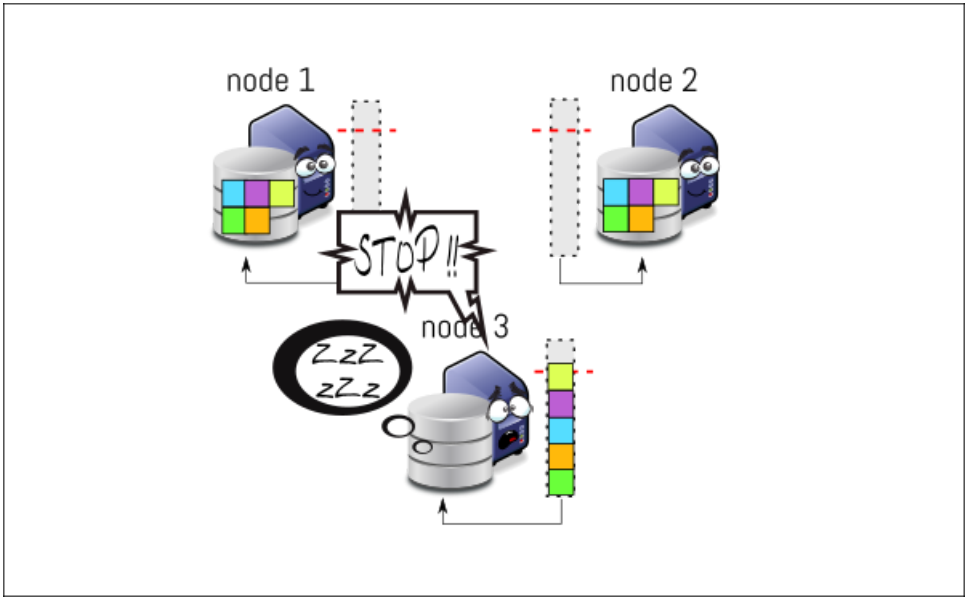

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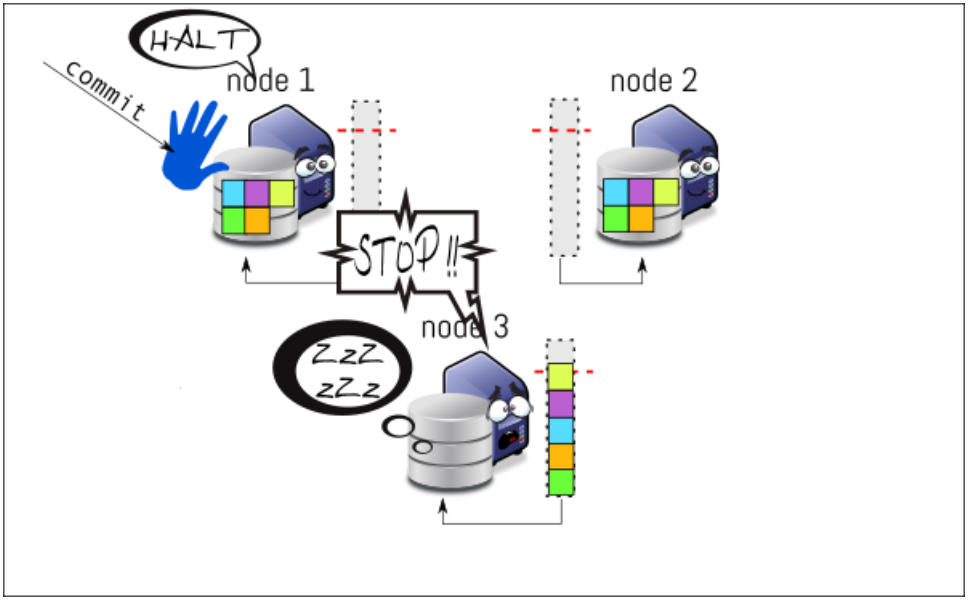

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`wsrep_sst_donor` can be used to specify the donor

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grastate.dat - example

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node is running or did not shutdown cleanly

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node aborted, SST on next restart

State Transfer: IST

When a node starts, it knowns the **UUID** of the cluster it belonged and the **last sequence number** it applied.

So, it sends that position to the other members of the cluster and if a node can send the next events (ws/trx), IST will be performed, if none, then SST will be triggered.

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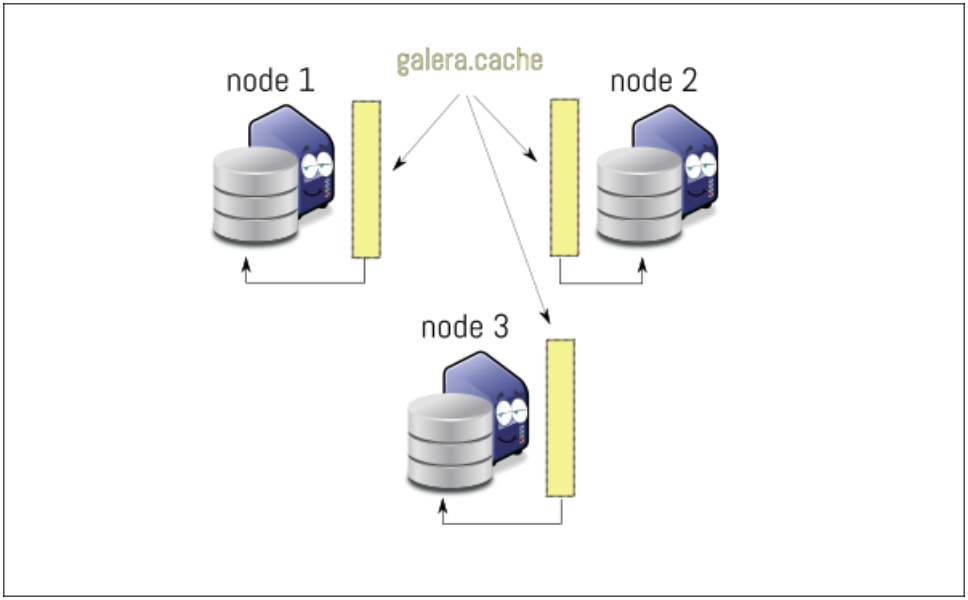
- `wsrep_local_cached_downto` provide the first seqno present in the cache for that node

Galera Cache & IST



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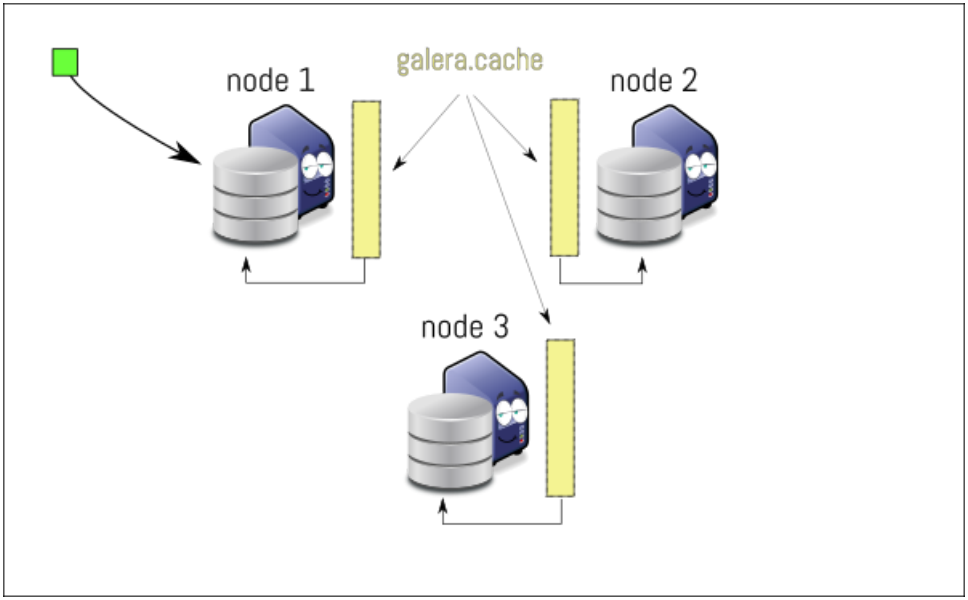

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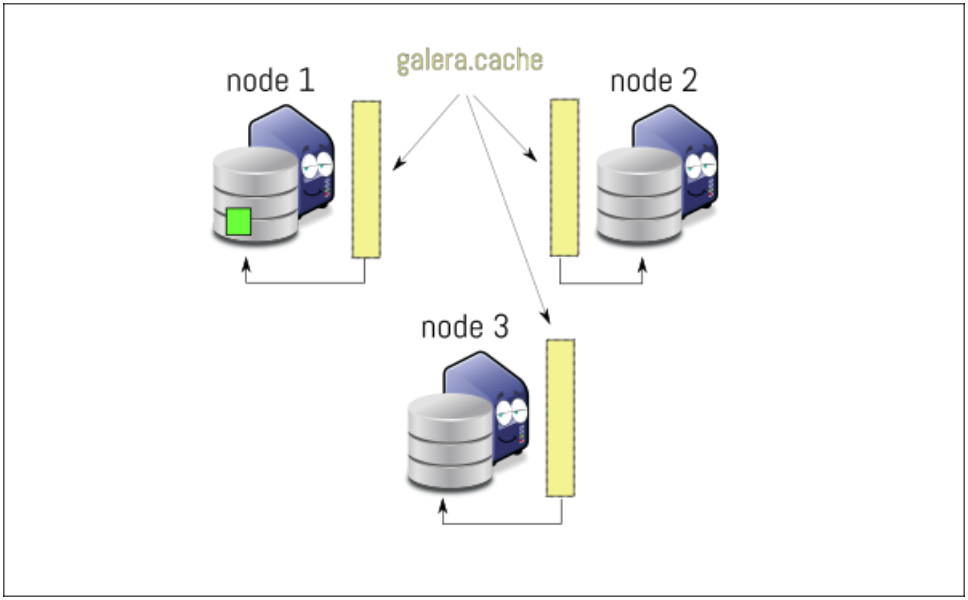

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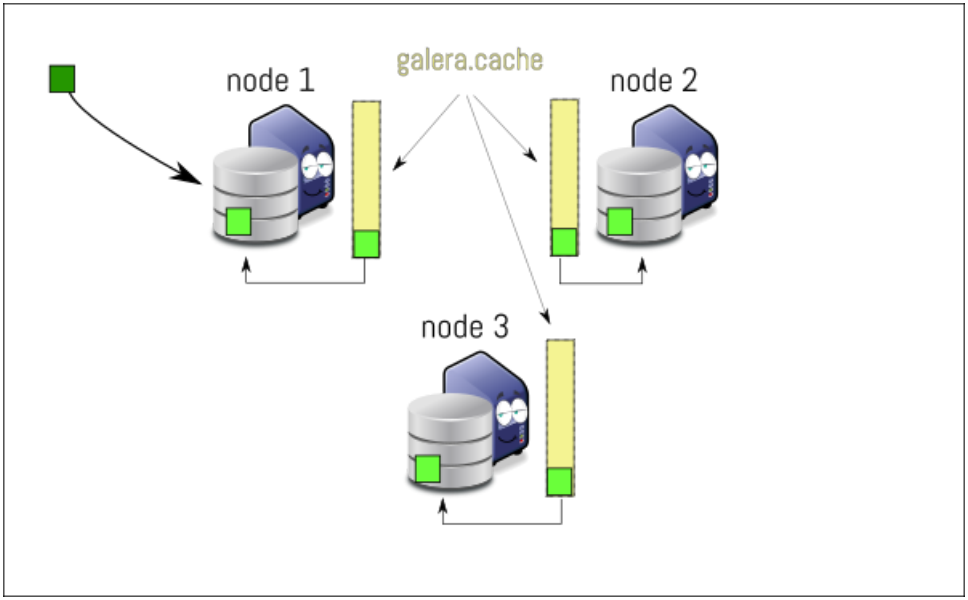

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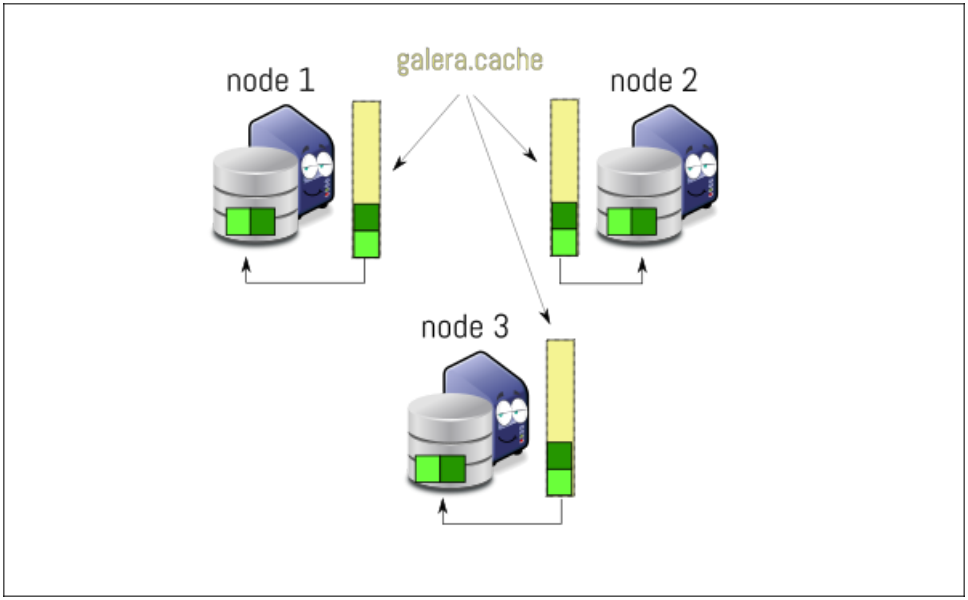

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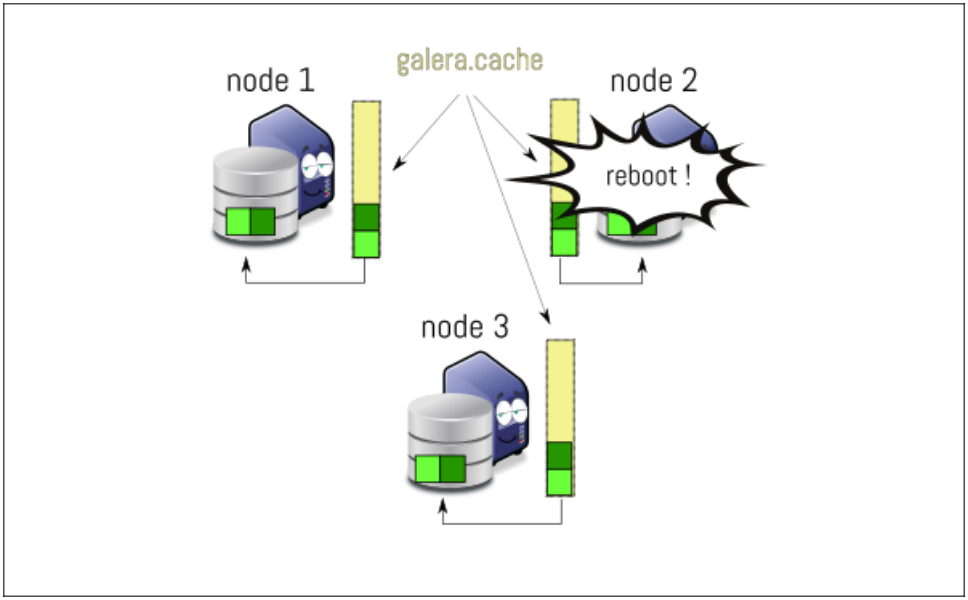

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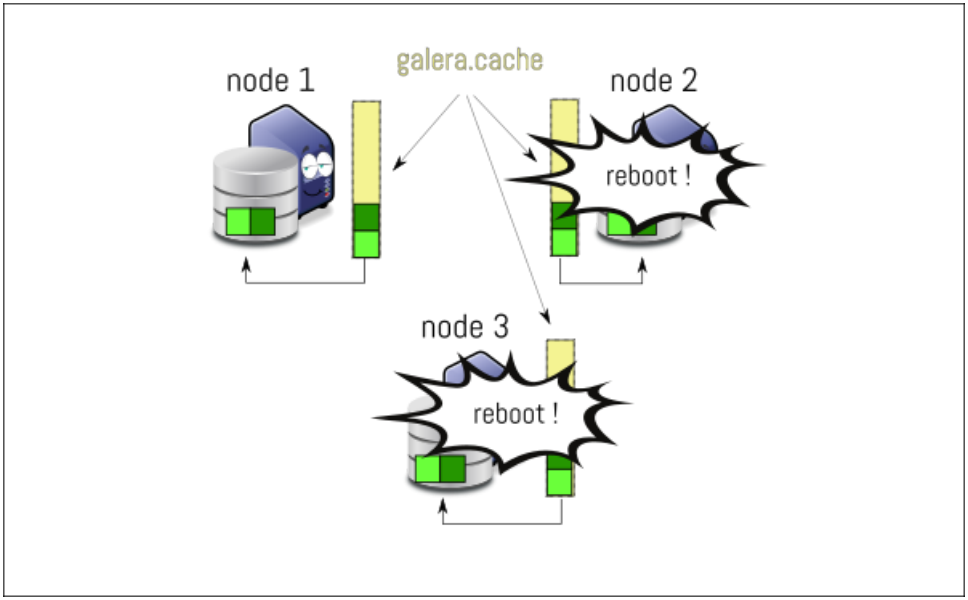

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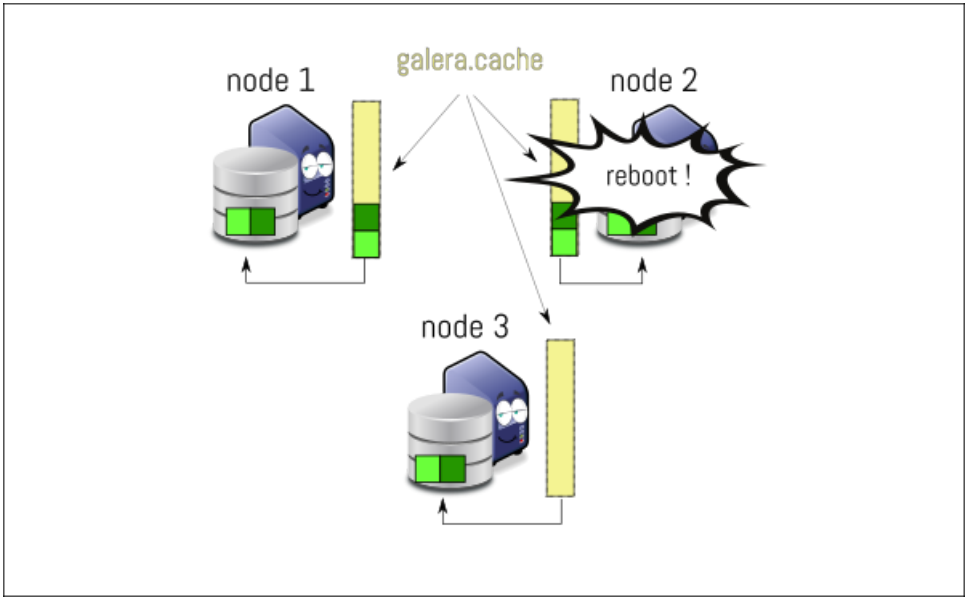

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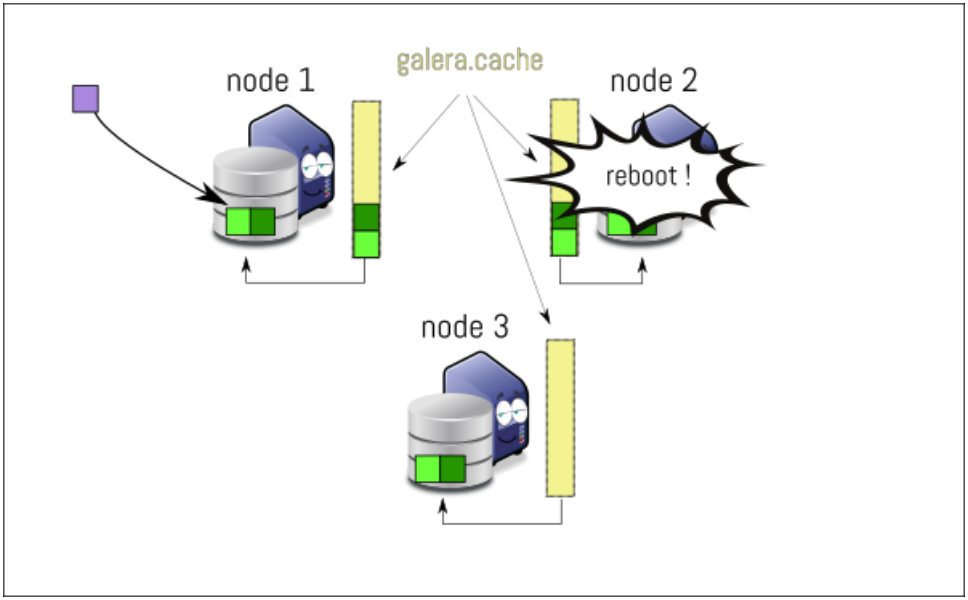

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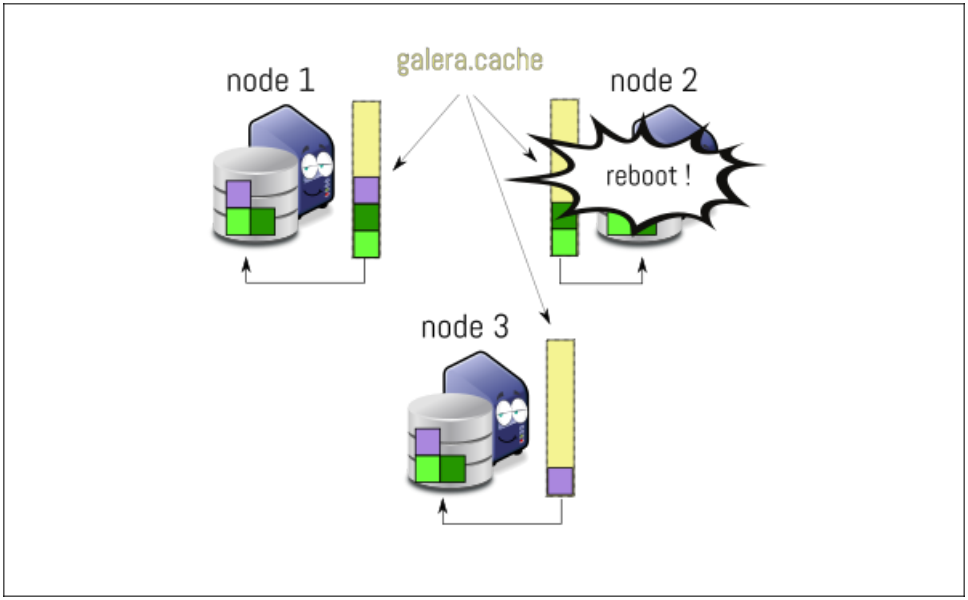

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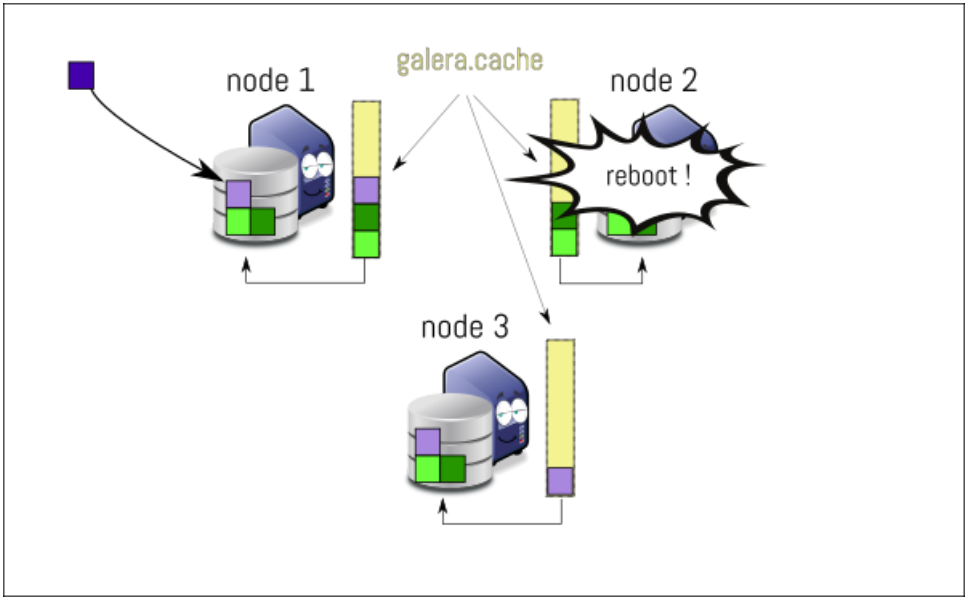

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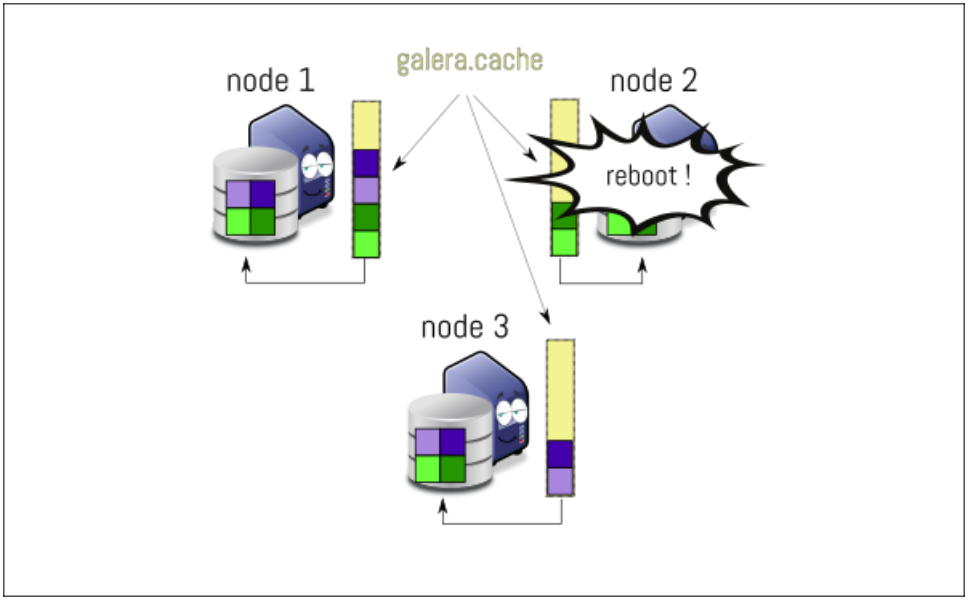

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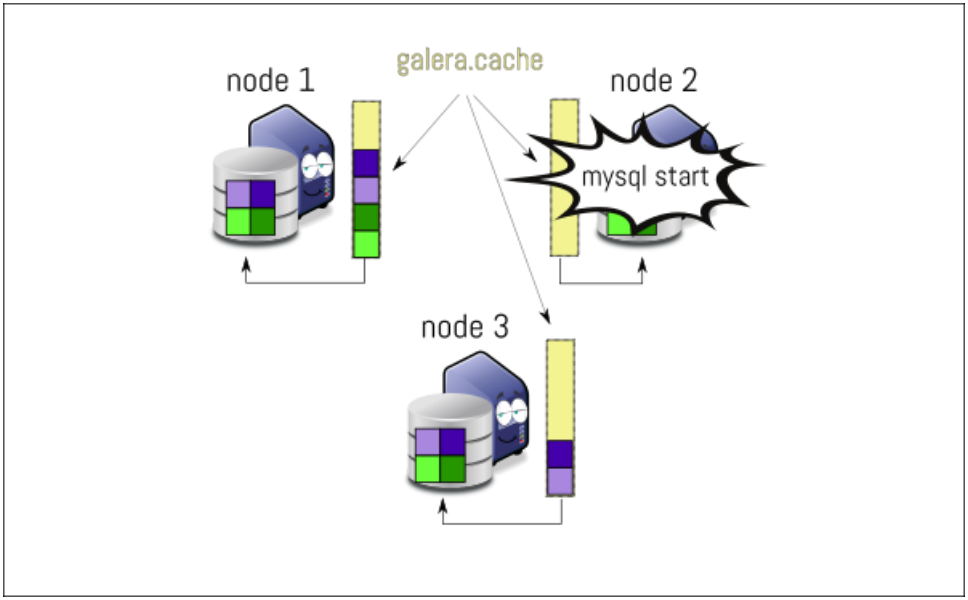

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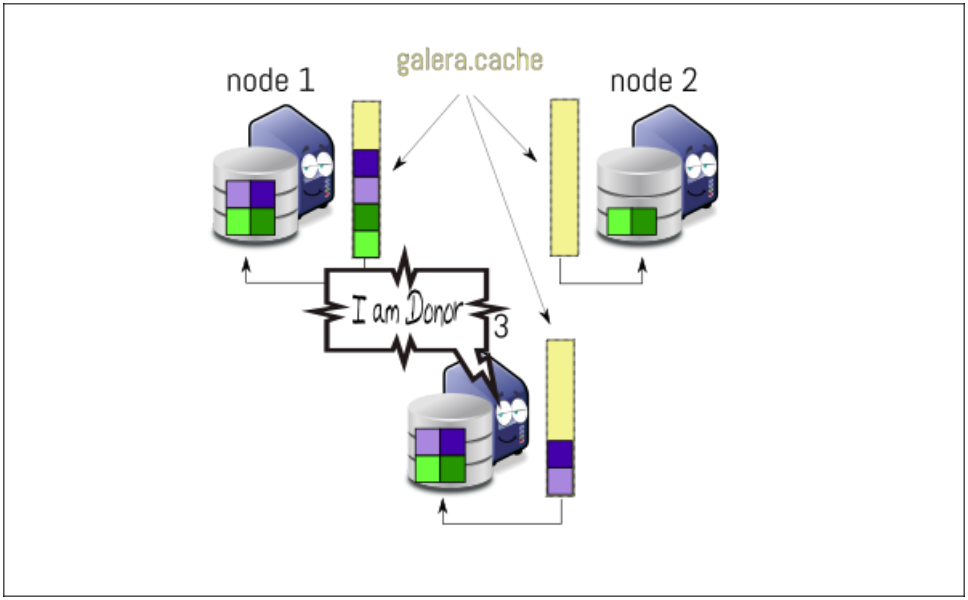

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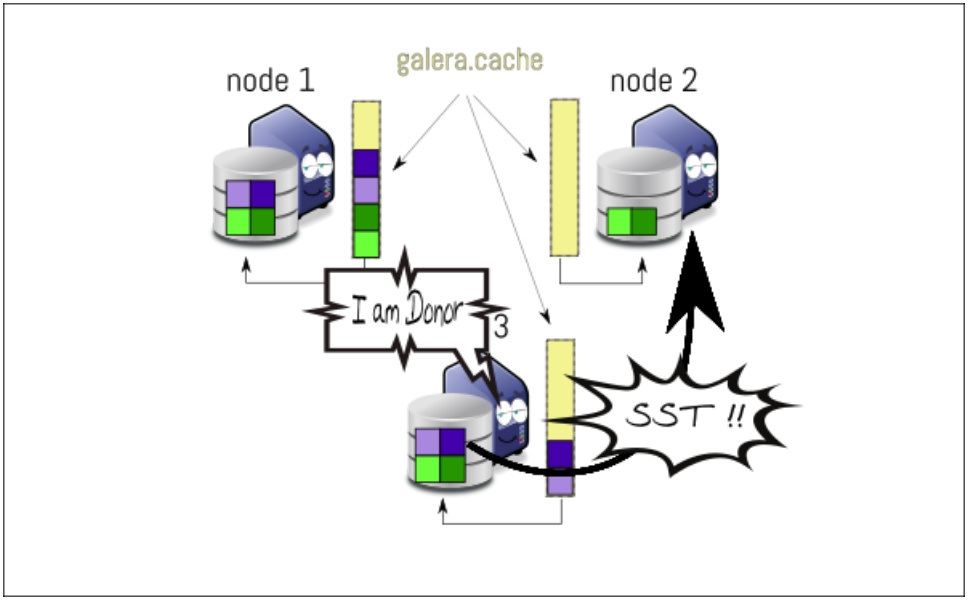

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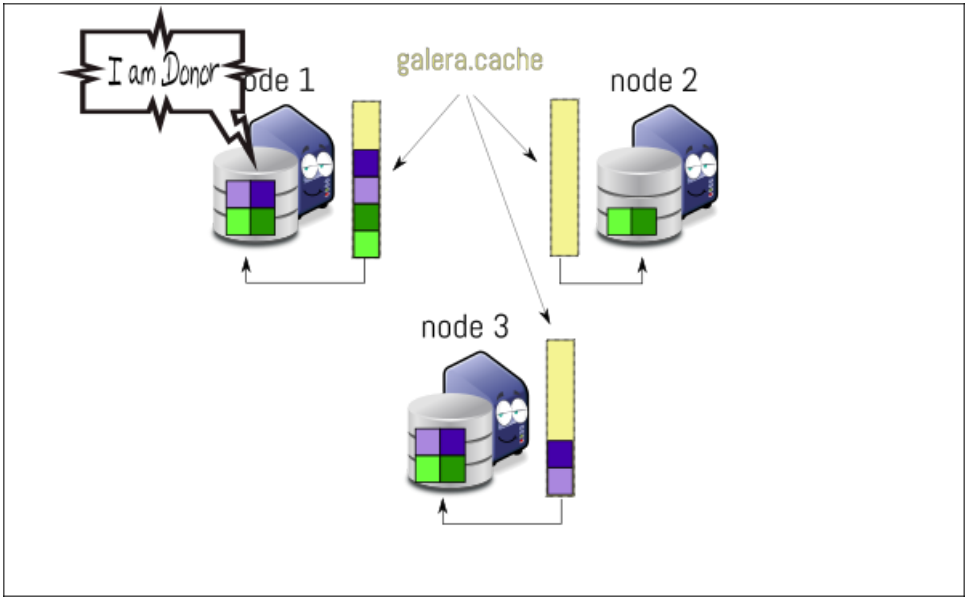

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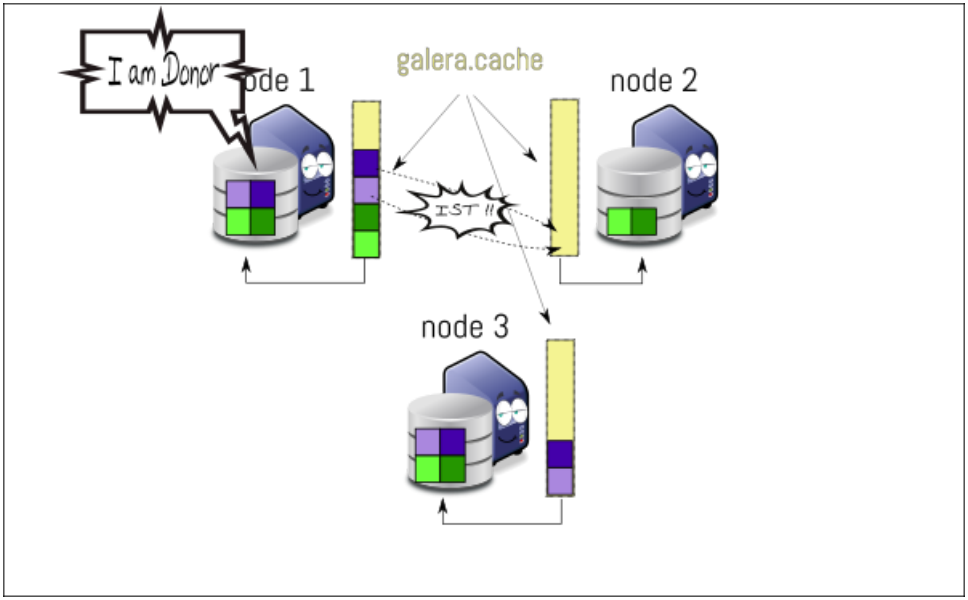

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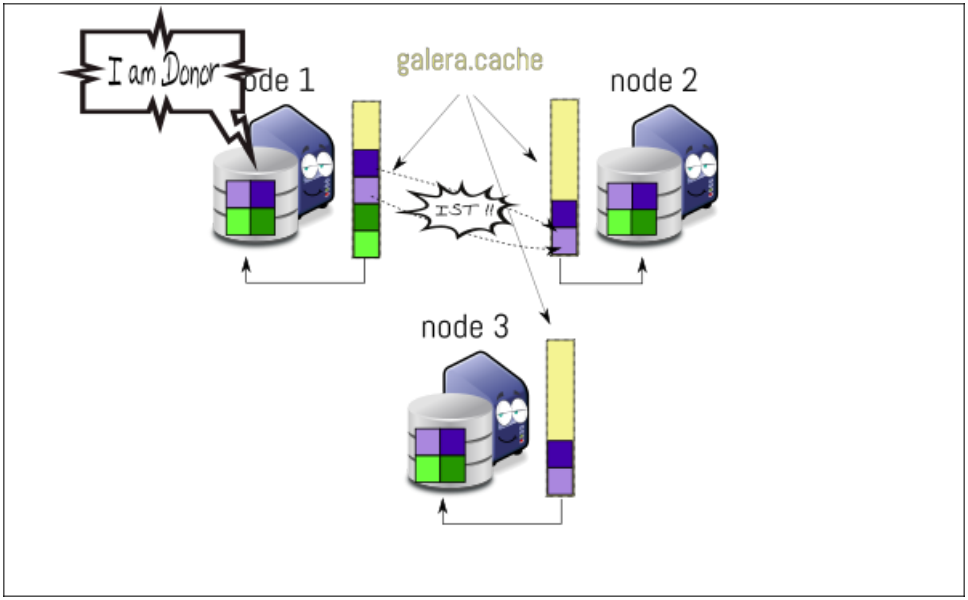

Thank you !