



MySQL Cluster Workshop

Ted Wennmark,
MySQL Solution Architect, MySQL, 2018



Program Agenda

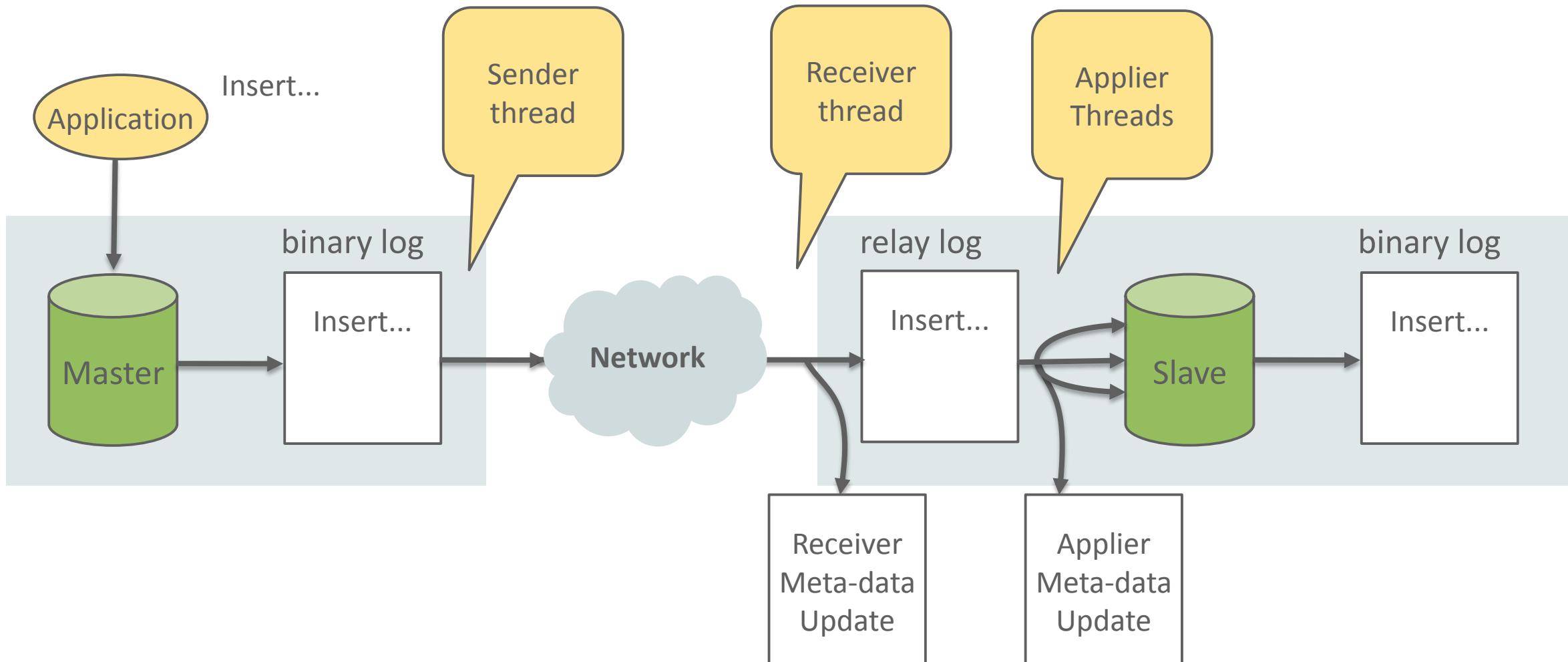
- 1 ➤ Introduction
- 2 ➤ Getting started: configuration/install/start/stop
- 3 ➤ Administration: backup/upgrade/logs/conf/sizing
- 4 ➤ Monitoring, surveillance and problem solving
- 5 ➤ Best practices, architectures and case studies
- 6 ➤ Geo-replication

MySQL High Availability Solutions

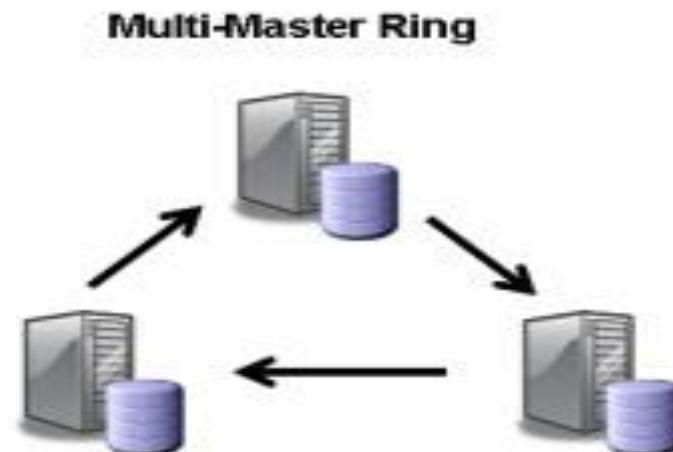
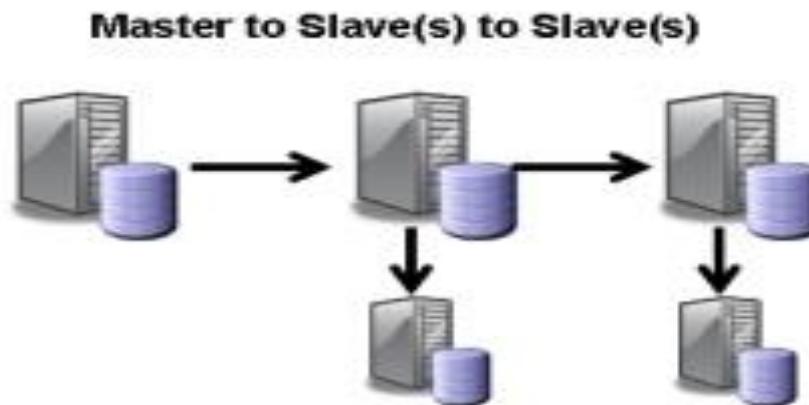
- MySQL NDB Cluster
 - NDB storage engine
 - Memory database
 - Automatic sharding of data
 - SQL Access via MySQL with cross shard join support
 - Native access via several API's
 - Read/write consistency
 - Read/write scalability
 - ACID and transactions
- MySQL InnoDB Cluster
 - Easy HA built into MySQL 5.7+ for InnoDB
 - MySQL Group Replication, Shell and Router
 - Write consistency
 - Read Scalability
 - Native CRUD API in MySQL 8
 - Synchronous (Paxos)
- MySQL Replication
 - Core part of MySQL, used by almost everyone.
 - Can be used by all storage engines
 - Asynchronous and semi-sync option
 - Scales our reads
 - GTID



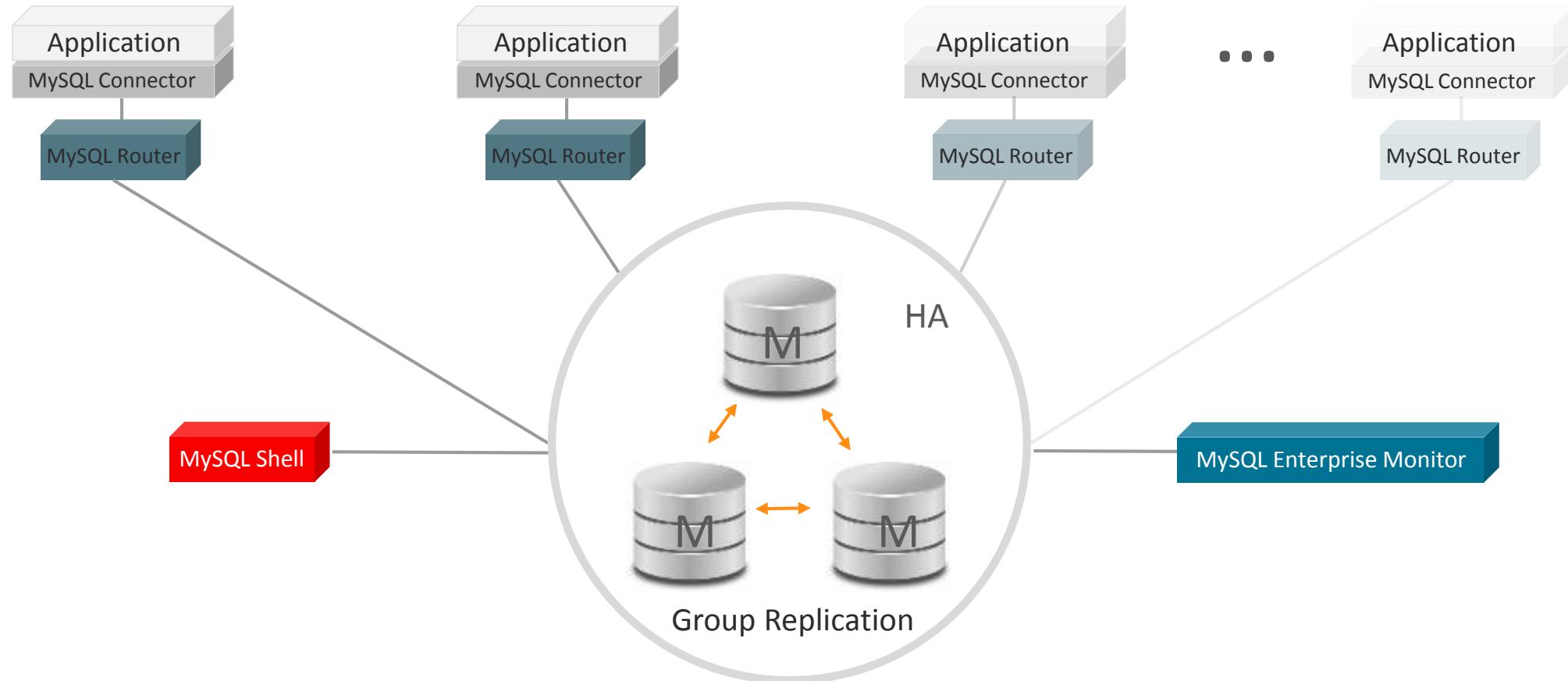
Background: Replication Components



Background: Replication Architectures



MySQL InnoDB Cluster: High Level Architecture



MySQL Replication vs InnoDB Cluster vs NDB Cluster

	MySQL Replication	MySQL InnoDB Cluster	MySQL NDB Cluster
Storage Engine	All	InnoDB	NDBCLUSTER
Distributed Architecture	Shared	Shared nothing	Shared nothing
Clustering Mode	Master + slaves	Multi-master (possible)	Multi-master (default)
Replication mode	Asynchronous	Paxos (Synchronous)	2PC (Synchronous)
Consistency Model	Weak Consistency	Medium Consistency	Strong Consistency
Sharding	No	No	Yes
Arbitration	No	No	Yes
Load Balancing	No	Partly via MySQL Shell	Yes
NoSQL APIs	MySQL CRUD API	MySQL CRUD API	Native NDB API
Operational Complexity	Easy	Medium	High
Administration	Standard (MySQL)	Standard (MySQL)	Custom (MySQL + NDB)

When TO consider MySQL Cluster



- What are consequences of downtime or failing to meet performance requirements?
- How much time and \$\$ are spent on developing/managing HA around your applications?
- Are you considering sharding your database to scale write operations? How would this impact your application and developers?
- Applications that need predictable real-time response times.
- Do you want the flexibility to manage your data with more than just SQL?

When NOT to consider MySQL Cluster



- Most 3rd party applications
- Lots of long running transactions
- Need for Geospatial or Full Text indexes
- Large dataset (> 20TB for NDB 7.6)
- Complex access pattern to data and many full table scans

Introduction to MySQL Cluster

History of MySQL Cluster "NDB"

The Network DataBase NDB

- MySQL Cluster aka Network DataBase NDB
- Designed/Developed at Ericsson in late 90's
- Original design paper: "Design and Modeling of a Parallel Data Server for Telecom Applications" from 1997 by Michael Ronström
- Originally written in PLEX (Programming Language for EXchanges) but later converted to C++.
- MySQL AB acquired Alzato (owned by Ericsson) late 2003.

History of MySQL Cluster "NDB"

The Network DataBase NDB

- Databases services back then:
 - SCP/SDP (Service Control/Data Point) in Intelligent Networks.
 - HLR (Home Location Register) for keeping track of mobile phones/users.
 - Databases for network management especially real-time charging information.

History of MySQL Cluster "NDB"

The Network DataBase NDB

- NDB was designed to:
 - Reliability, the availability class of the telecom databases should be 6. This means that downtime must be less than 30 seconds per year. This means that no planned down time of the system is allowed.
 - Performance, designed for high throughput, linear scalability when adding more servers (data nodes) for simple access patterns (PK lookups).
 - Real-time, data is kept in memory and system is designed for memory operations.

MySQL Cluster overview

Scaling
Reads & Writes

Auto-sharding + Multi-master
Transactional, ACID-compliant relational database

99.999%
Availability

Shared-nothing design, no Single Point of Failure
On-Line operations: Scale, Upgrade Schema, etc.

Real-Time
Responsiveness

High-load, real-time performance
Predictable low latency, bounded access times

SQL & NoSQL
APIs

Complex, relational queries + Key/Value Access
MySQL, Memcached, C++, Java, JPA, HTTP / REST

Low TCO,
Open platform

GPL & Commercial editions
Commodity hardware, management & monitoring tools

MySQL Cluster Components

SQL Node

(Applications)



- Standard SQL interface
- Scale out for performance
- Enables Geo Replication

NDB API

(Applications)



- Real-time applications
- C++/Java APIs
- Automatic failover & load balancing

Data Node

(Data Storage)



- Data storage (Memory & Disk)
- Automatic & User defined data partitioning
- Scale out for capacity and performance

MGM Node

(Management)



- Management, Monitoring & Configuration
- Arbitrator for split brain/network partitioning
- Cluster logs

Data Nodes (ndb[mt]d)

- Stores data and indexes
 - In memory
 - Non-indexed data possible on disk
 - Contains several blocks, most important, LQH, TUP, ACC and TC.
- Data check pointed to disk “LCP”
- Transaction coordination
- Handling fail-over
- Doing online backup
- All connect to each other
- Up to 48
 - Typically 2, 4.



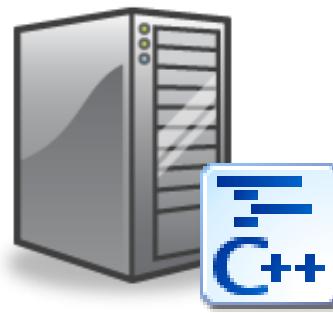
Management Nodes (ndb_mgmd)

- Distributing configuration
- Central log file
- Act as Arbitrator
 - Prevents split-brain
- OK when not running
 - Need to start others
- 1 is minimum, 3 too many, 2 is OK



API Nodes

- Applications written using NDB API
 - C/C++/Java
- Fast
 - No SQL parsing
- Examples:
 - NDBCluster storage engine
 - `ndb_restore`

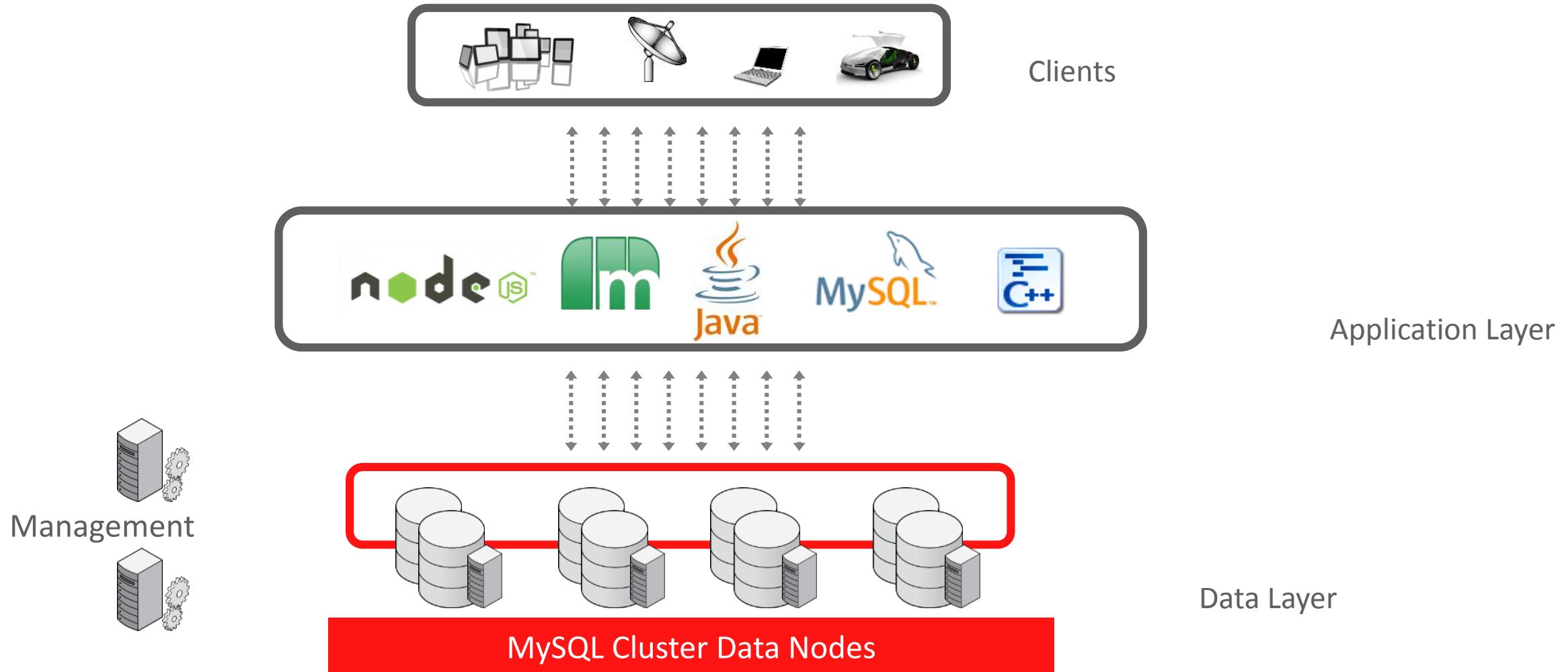


SQL Nodes

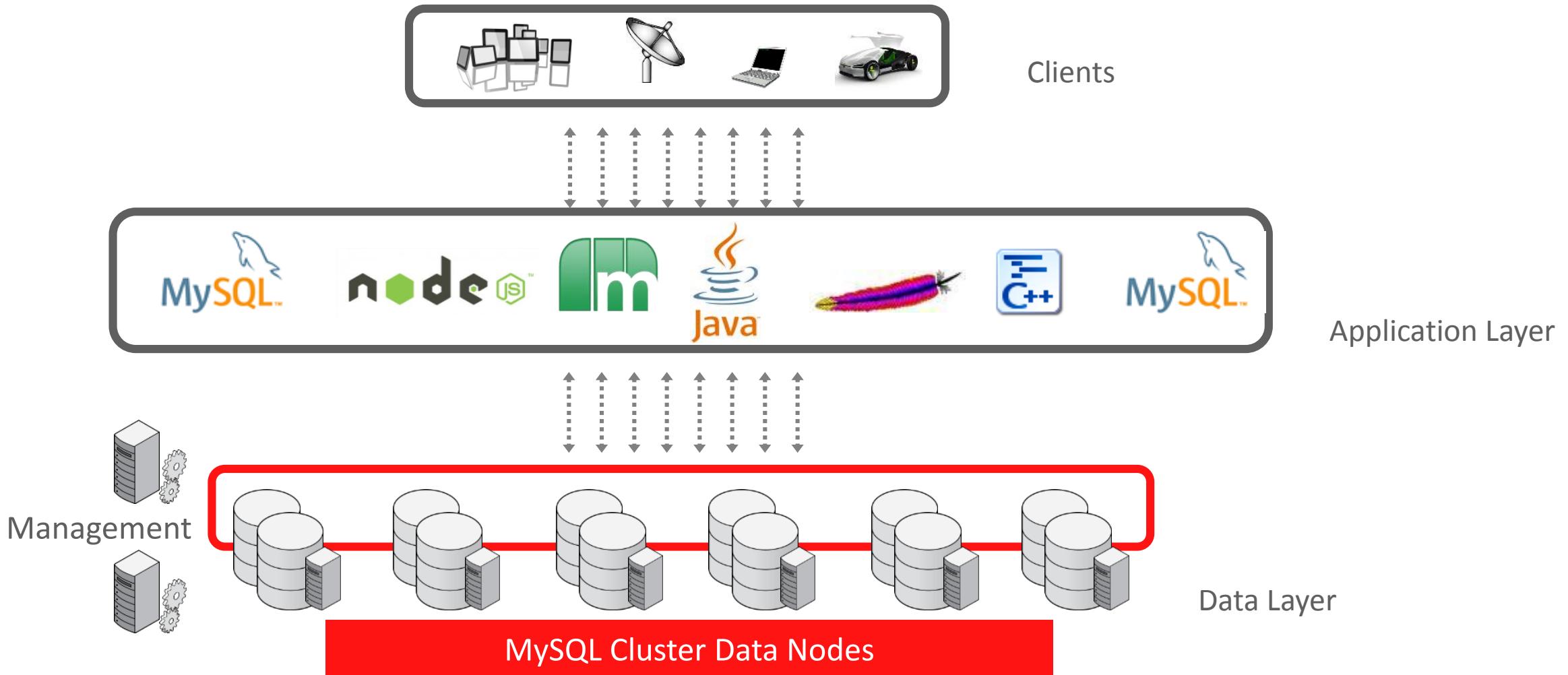
- MySQL using NDBCluster engine
 - Is just like any application connecting to data nodes
- Transparent for most applications
- Used to create tables
- Used for Geographical Replication
 - Binary logging all changes
- Can act as Arbitrator
- Connects to all Data Nodes



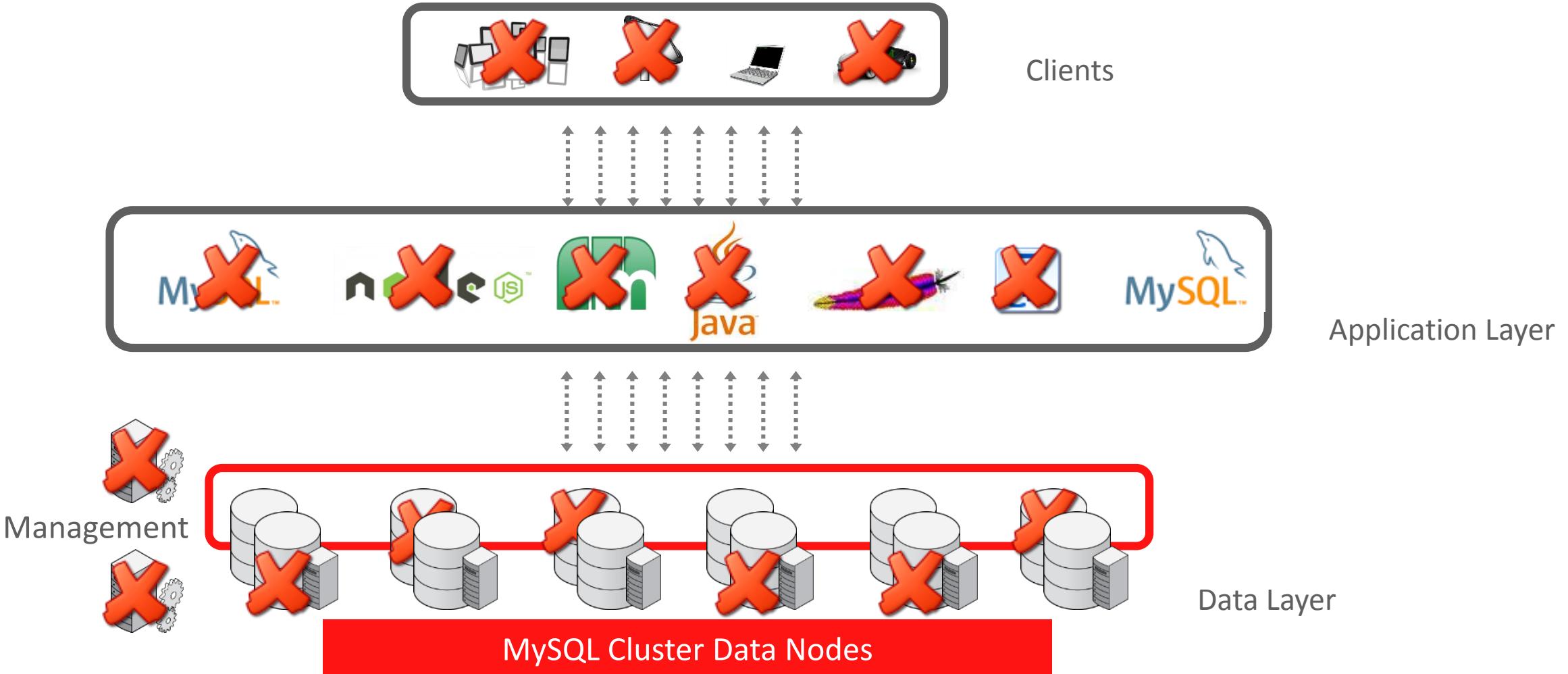
MySQL Cluster Architecture



MySQL Cluster Scaling



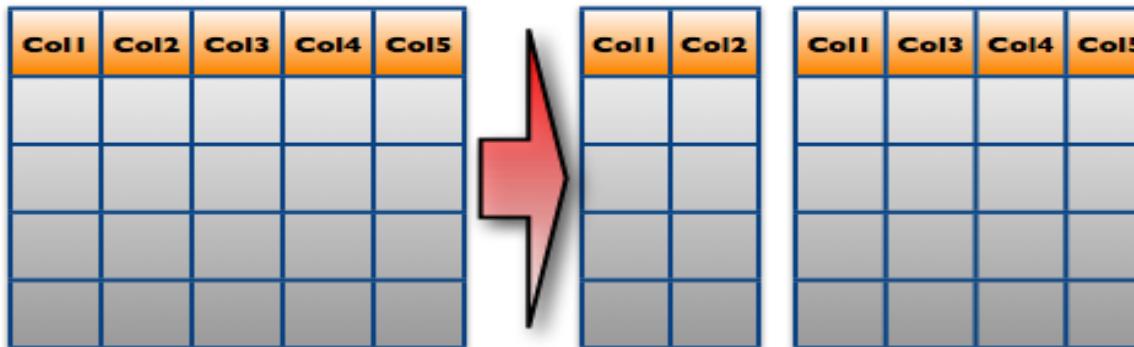
MySQL Cluster - Extreme Resilience



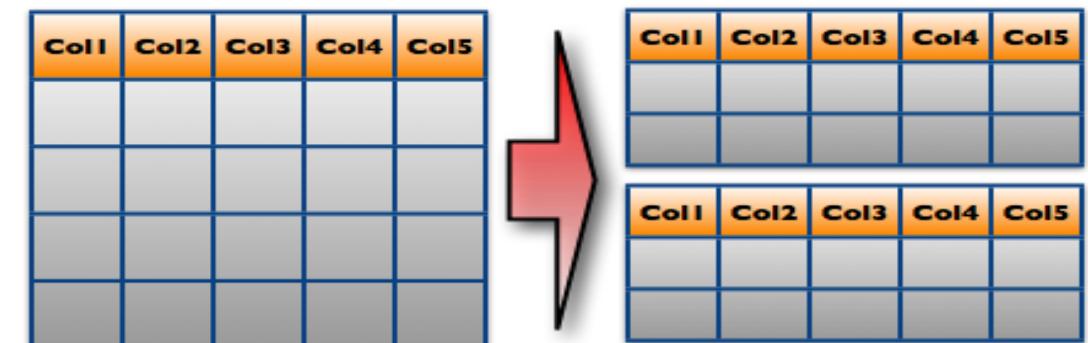
Partitioning I

- Vertical Partitioning - 1:1 tables to reduce the size of rows, tables and indexes
- Horizontal Partitioning - 1 table split on multiple tables with different rows

Vertical Partitioning

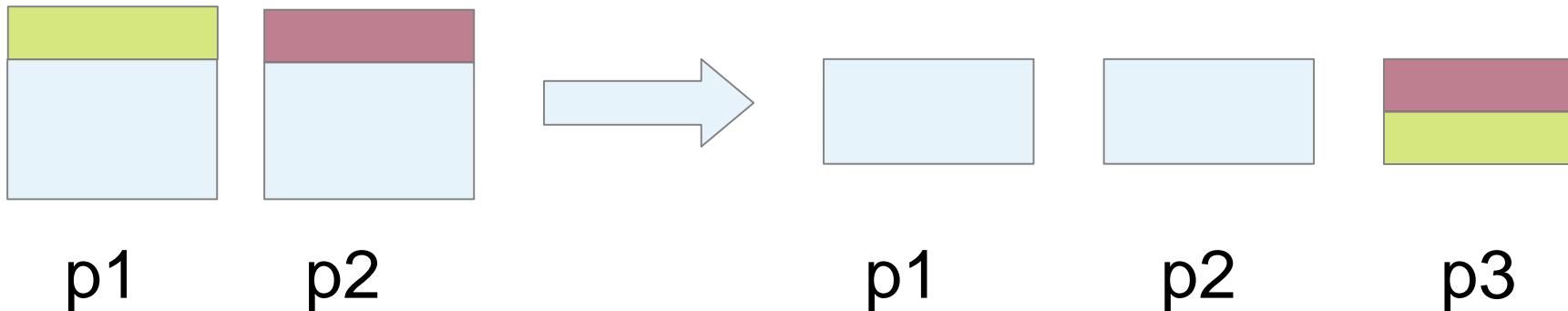


Horizontal Partitioning



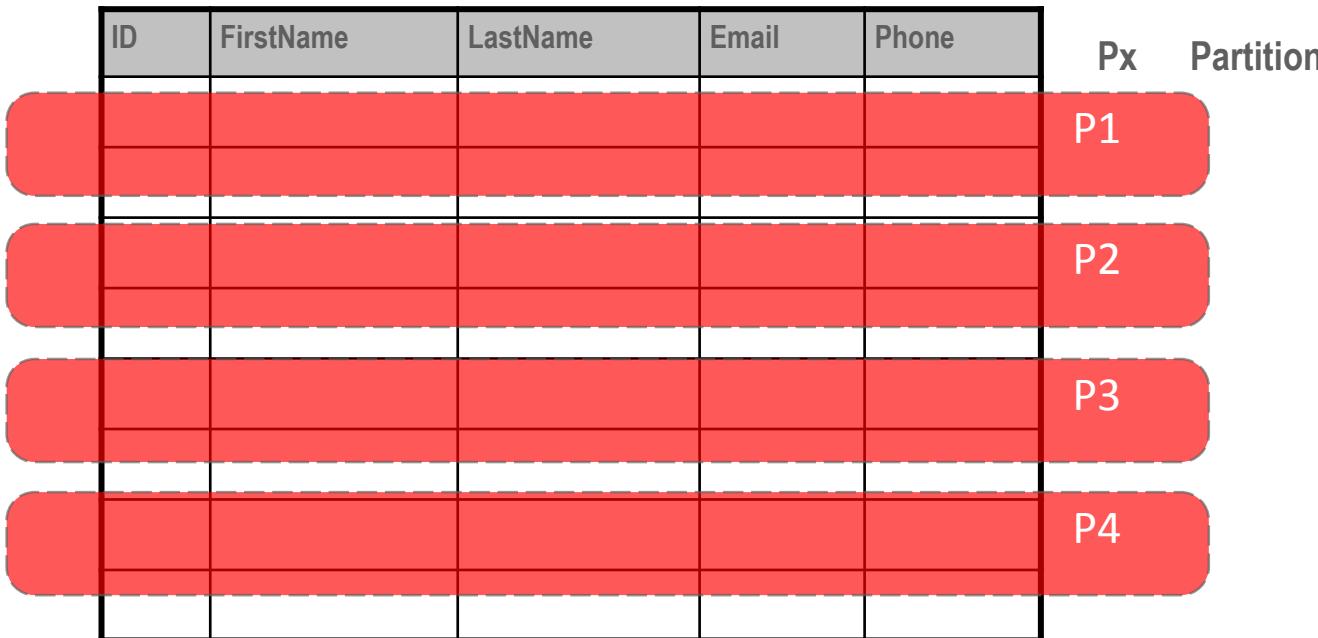
Data Partitioning II

- Data is partitioned on primary key per default ($\text{partition} = \text{md5(PK)} \% (\text{NoOfNodes})$, simplified, in reality we have many partitions)
- HASH value of PK, only selective if you provide full PK not “left most”
- Linear hashing, data is only moved away (low impact of reorganize)



Automatic Data Partitioning

Table T1



- A partition is a portion of a table (real hashmap has 3840 partitions)
- Number of partitions = number of data nodes (simplified view)
- Horizontal partitioning

Data Node 1



Data Node 2



Data Node 3



Data Node 4



Automatic Data Partitioning

Table T1

ID	FirstName	LastName	Email	Phone	Px	Partition
						P1
						P2
						P3
						P4

A fragment is a partition of your data on data nodes

Number of fragments = # of partitions * # of replicas

Data Node 1



Data Node 2



Data Node 3



Data Node 4



Automatic Data Partitioning

4 Partitions * 2 Replicas = 8 Fragments

Table T1

ID	FirstName	LastName	Email	Phone	Px	Partition
					P1	
					P2	
					P3	
					P4	

A fragment can be primary or secondary/backup

Number of fragments = # of partitions * # of replicas

Data Node 1



Data Node 2



Data Node 3

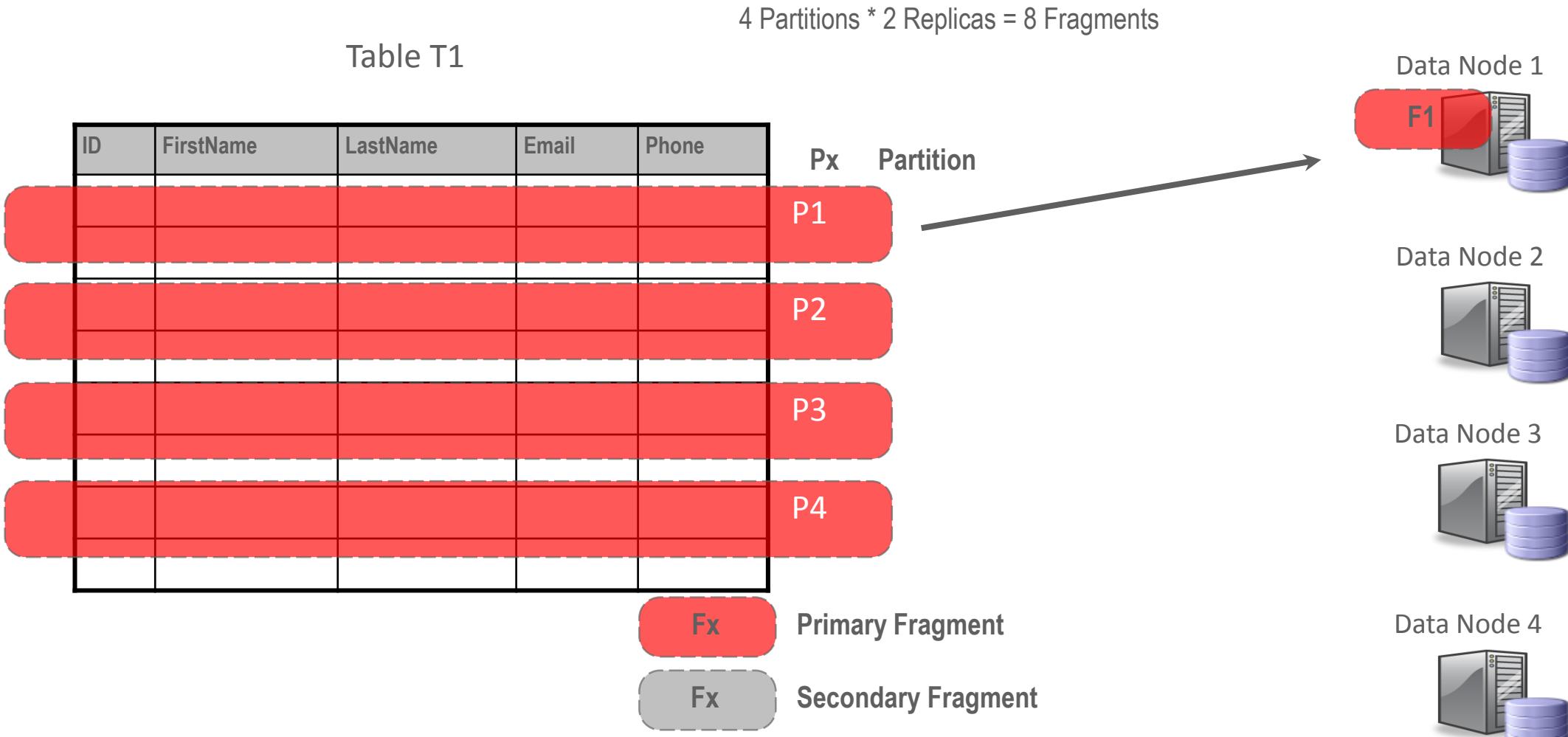


Data Node 4



Automatic Data Partitioning

Table T1



Automatic Data Partitioning

Table T1

ID	FirstName	LastName	Email	Phone

4 Partitions * 2 Replicas = 8 Fragments

Px Partition

P1

P2

P3

P4

Fx

Primary Fragment

Fx

Secondary Fragment

Data Node 1



Data Node 2



Data Node 3

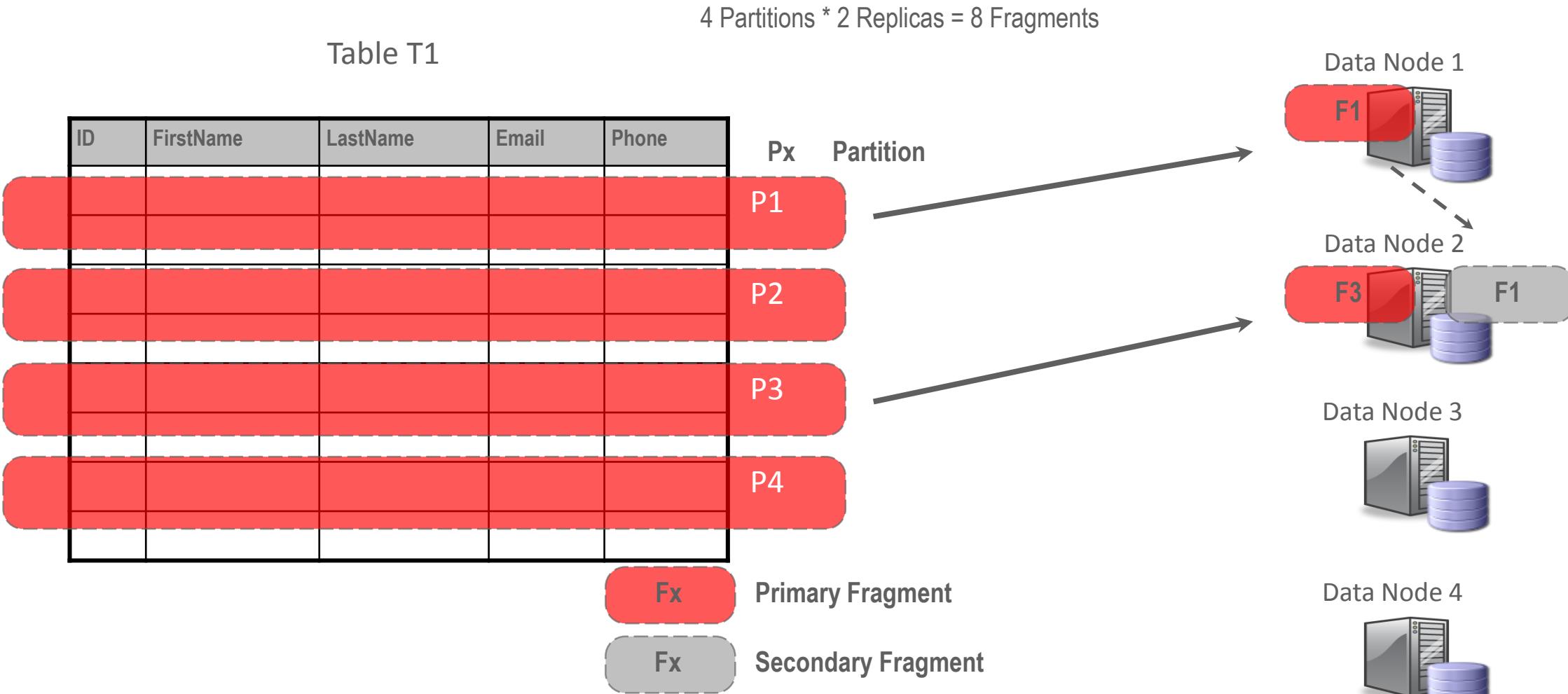


Data Node 4



Automatic Data Partitioning

Table T1



Automatic Data Partitioning

Table T1

ID	FirstName	LastName	Email	Phone

4 Partitions * 2 Replicas = 8 Fragments

Px Partition

P1

P2

P3

P4

Fx

Primary Fragment

Fx

Secondary Fragment

Data Node 1



Data Node 2



Data Node 3

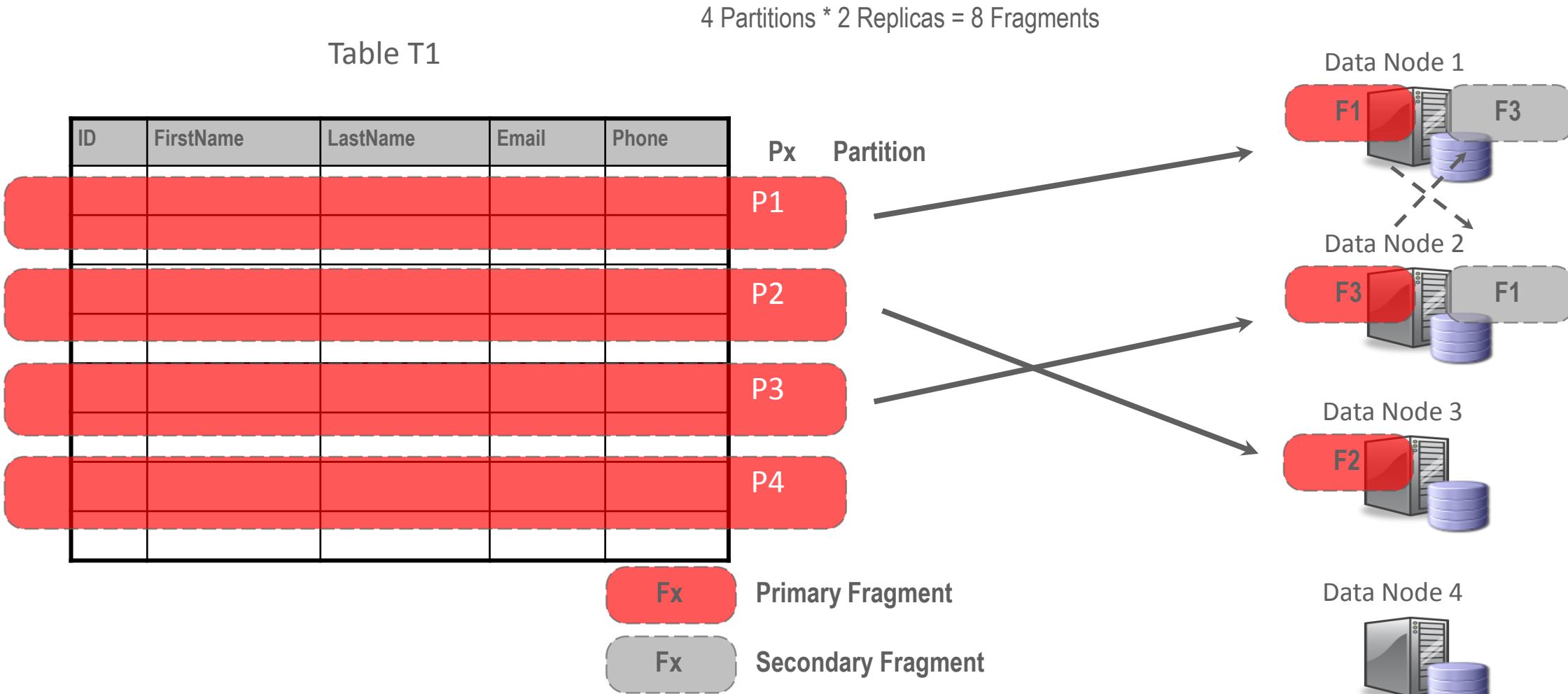


Data Node 4



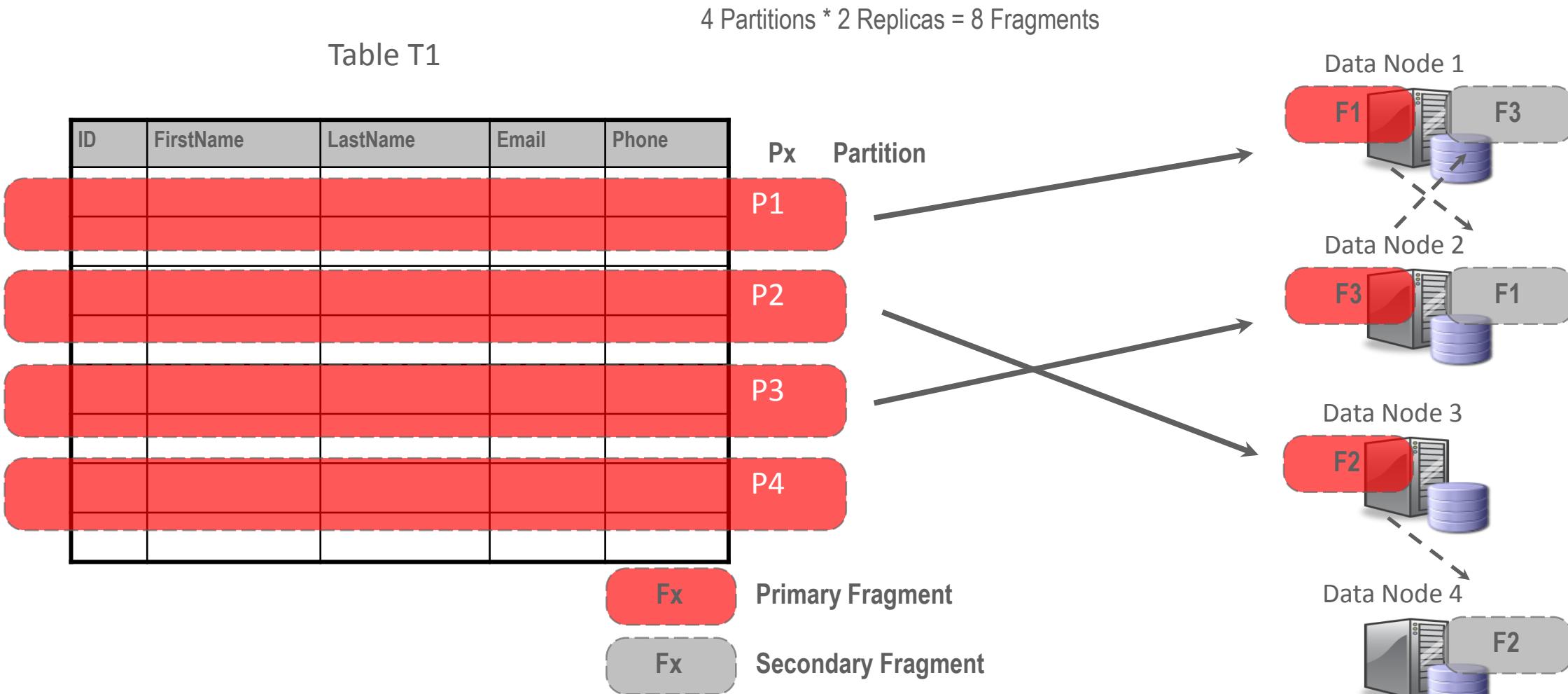
Automatic Data Partitioning

Table T1



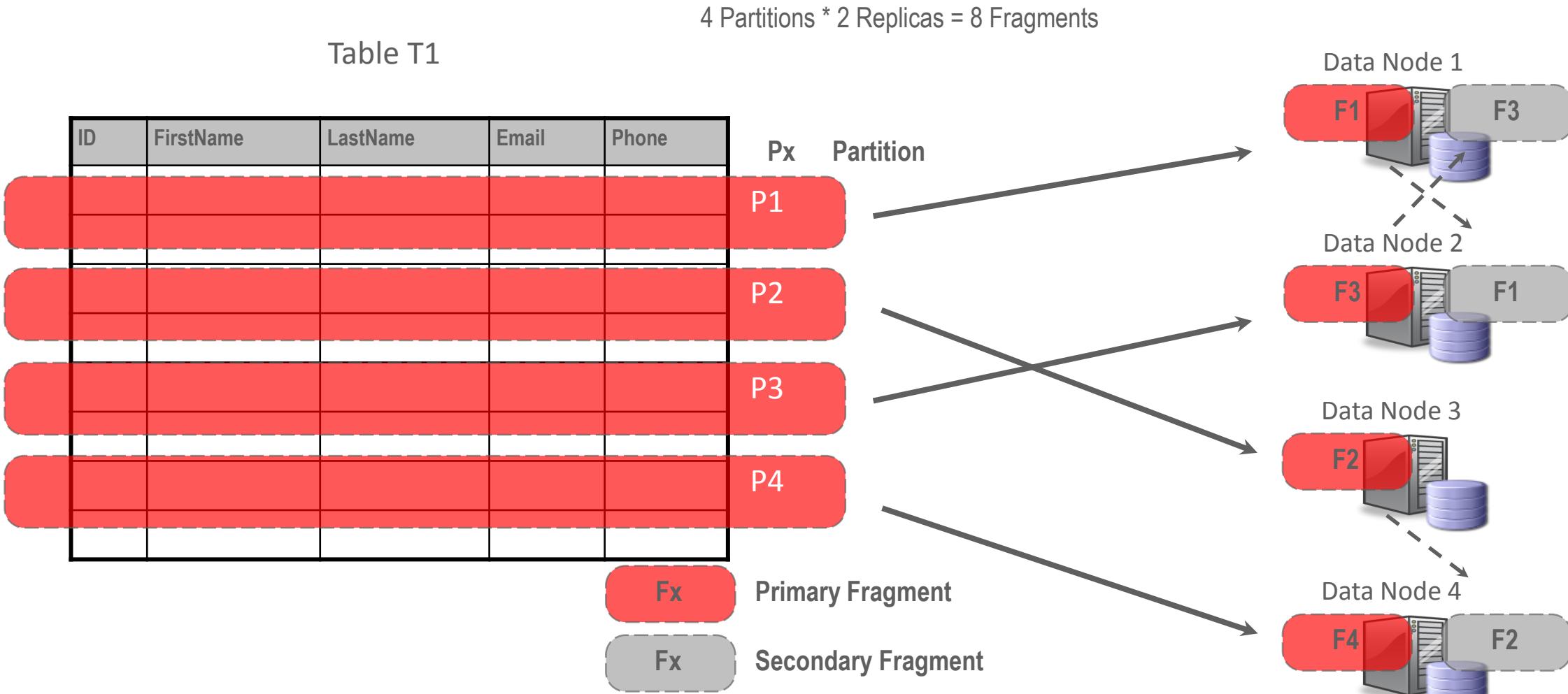
Automatic Data Partitioning

Table T1



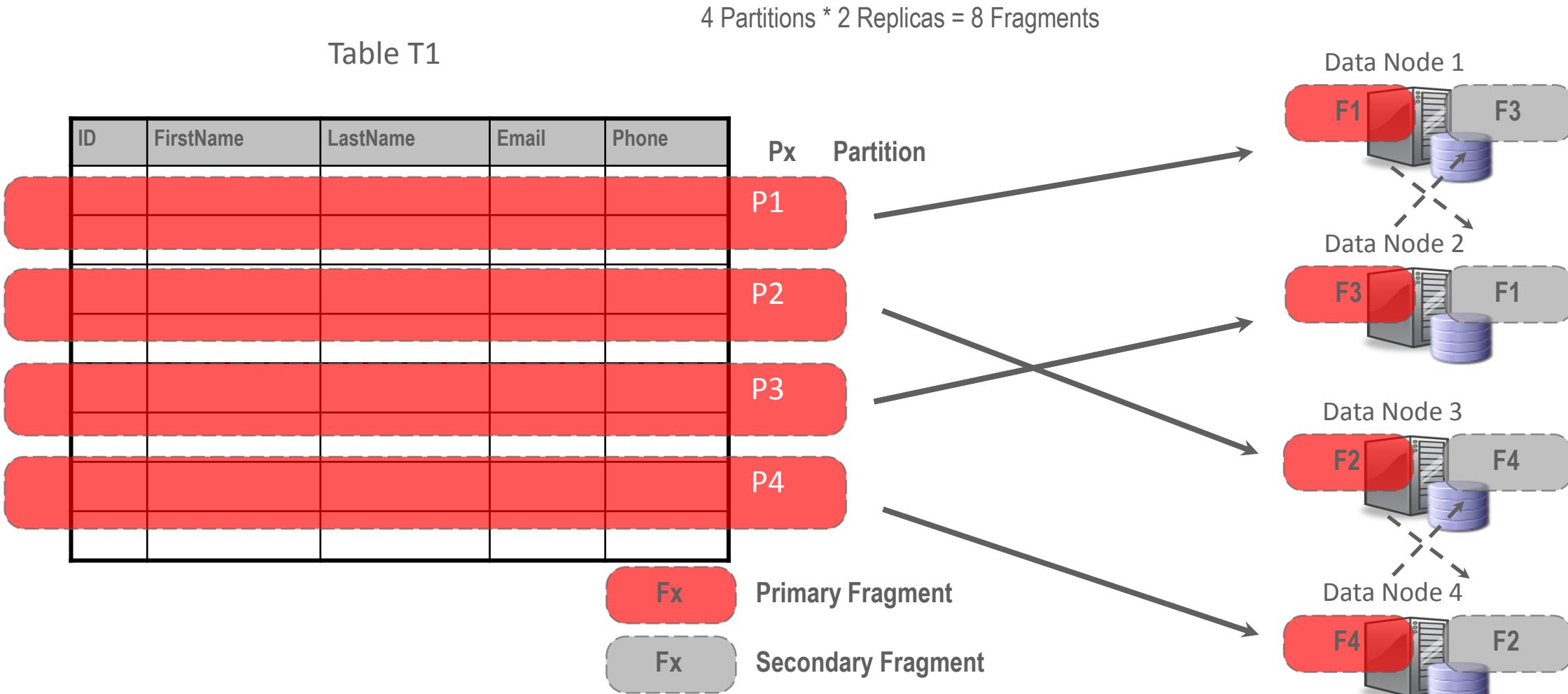
Automatic Data Partitioning

Table T1



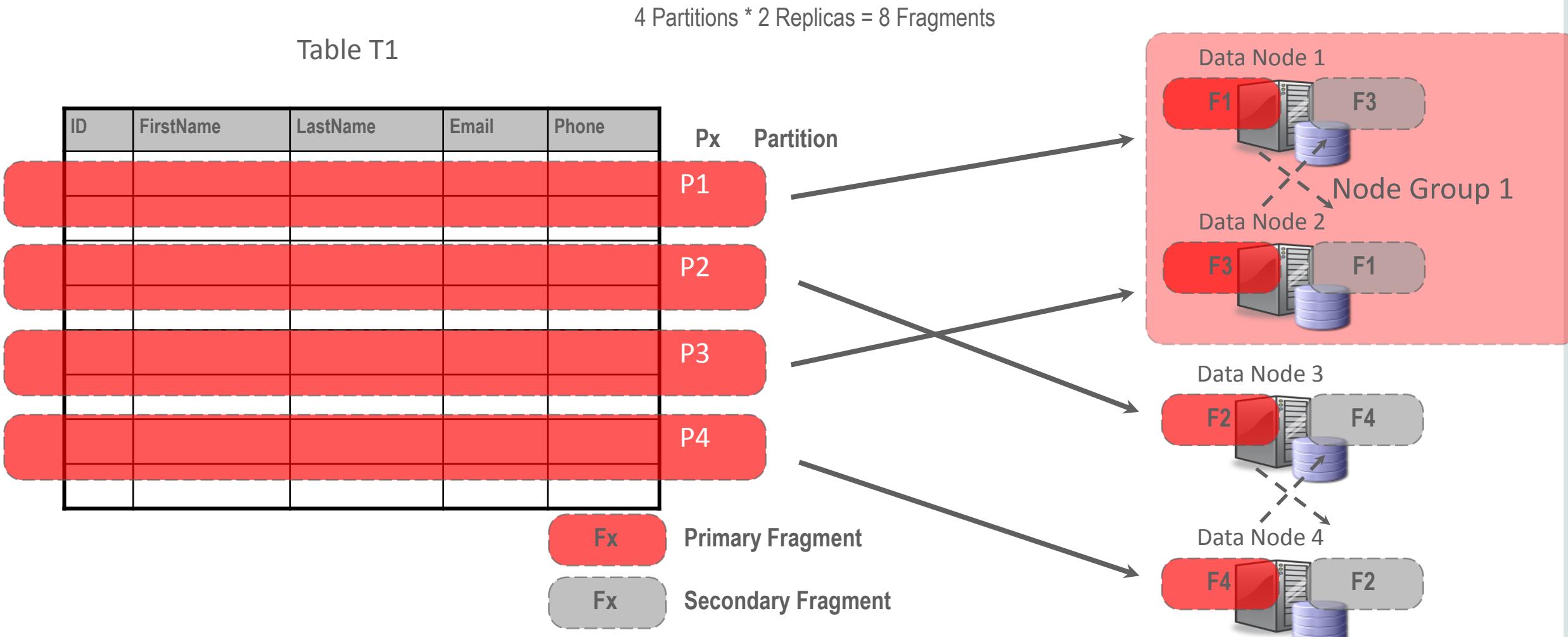
Automatic Data Partitioning

Table T1



Automatic Data Partitioning

Table T1



Automatic Data Partitioning

Table T1

ID	FirstName	LastName	Email	Phone

4 Partitions * 2 Replicas = 8 Fragments

Px Partition

P1

P2

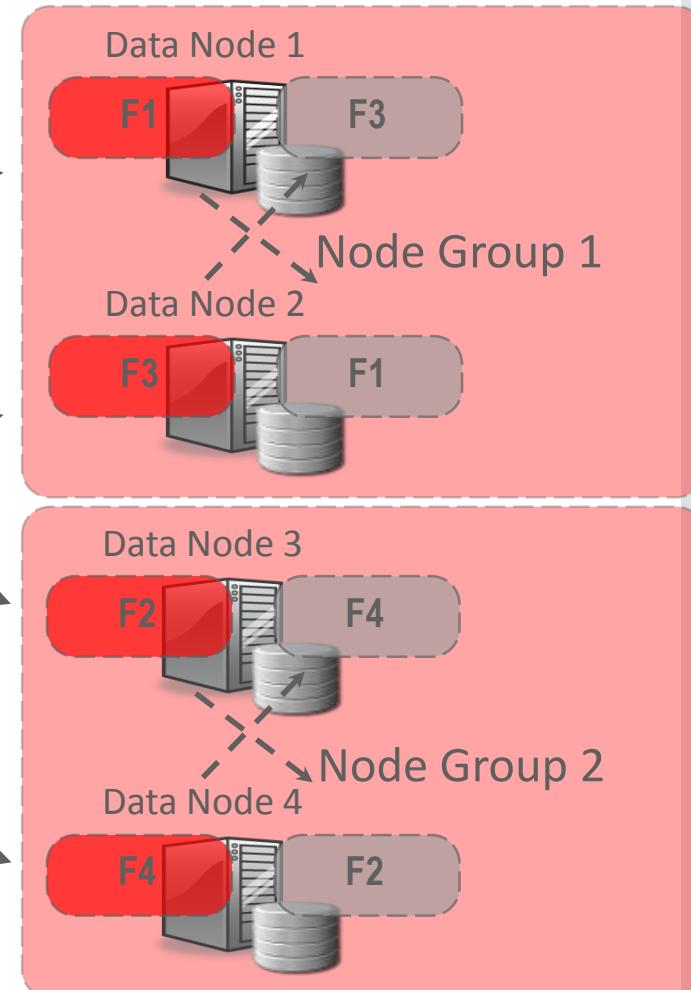
P3

P4

Fx Primary Fragment

Fx Secondary Fragment

- Node groups are created automatically
- # of groups = # of data nodes / # of replicas



Automatic Data Partitioning

Table T1

ID	FirstName	LastName	Email	Phone

4 Partitions * 2 Replicas = 8 Fragments

Px Partition

P1

P2

P3

P4

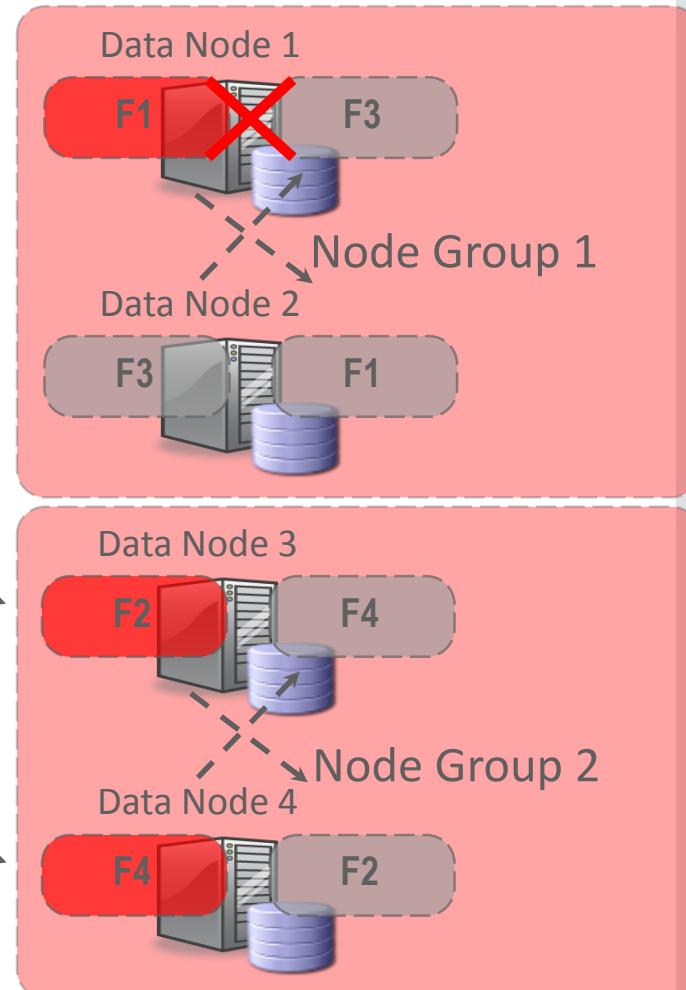
Fx

Fx

Primary Fragment

Secondary Fragment

As long as one data node in each node group is running we have a complete copy of the data



Automatic Data Partitioning

Table T1

ID	FirstName	LastName	Email	Phone

4 Partitions * 2 Replicas = 8 Fragments

Px Partition

P1

P2

P3

P4

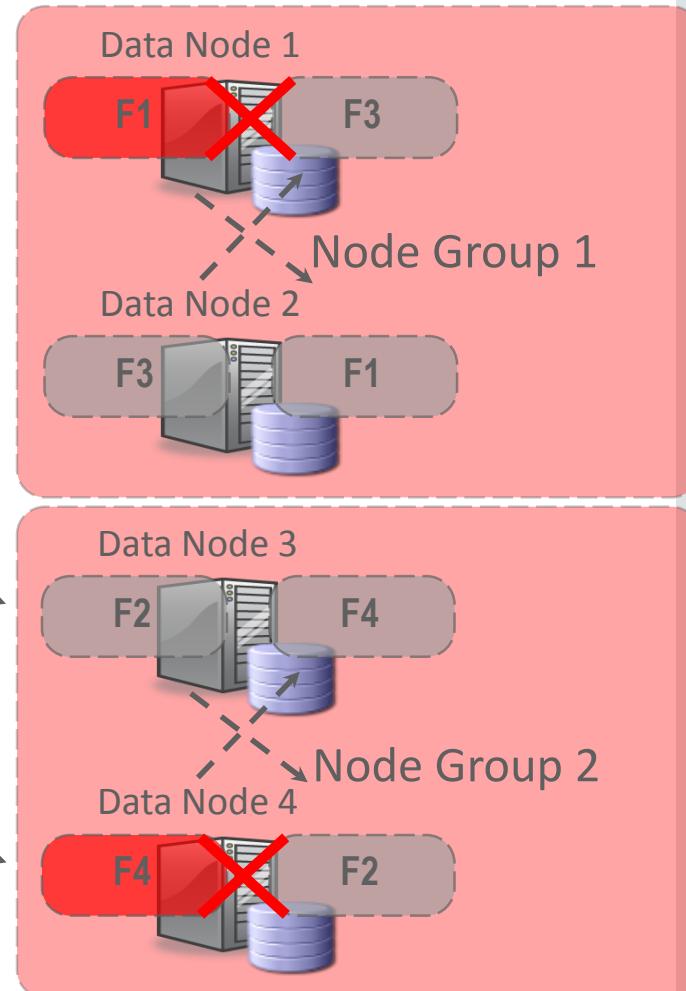
Fx

Fx

Primary Fragment

Secondary Fragment

As long as one data node in each node group is running we have a complete copy of the data



Automatic Data Partitioning

Table T1

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4 Partitions * 2 Replicas = 8 Fragments

Px Partition

P1

P2

P3

P4

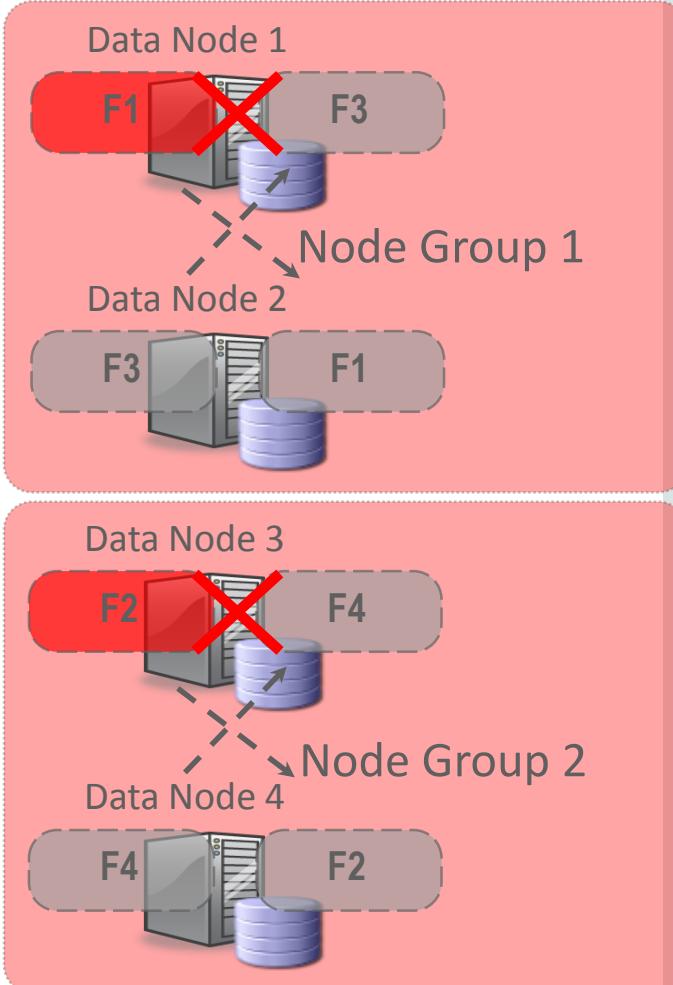
Fx

Fx

Primary Fragment

Secondary Fragment

As long as one data node in each node group is running we have a complete copy of the data



Automatic Data Partitioning

Table T1

ID	FirstName	LastName	Email	Phone

4 Partitions * 2 Replicas = 8 Fragments

Px Partition

P1

P2

P3

P4

Fx

Fx

Primary Fragment

Secondary Fragment

- No complete copy of the data
- Cluster shutdowns automatically

Data Node 1

F1

F3

Data Node 2

F3

F1

Data Node 3

F2

F4

Data Node 4

F4

F2

Data Partitioning III

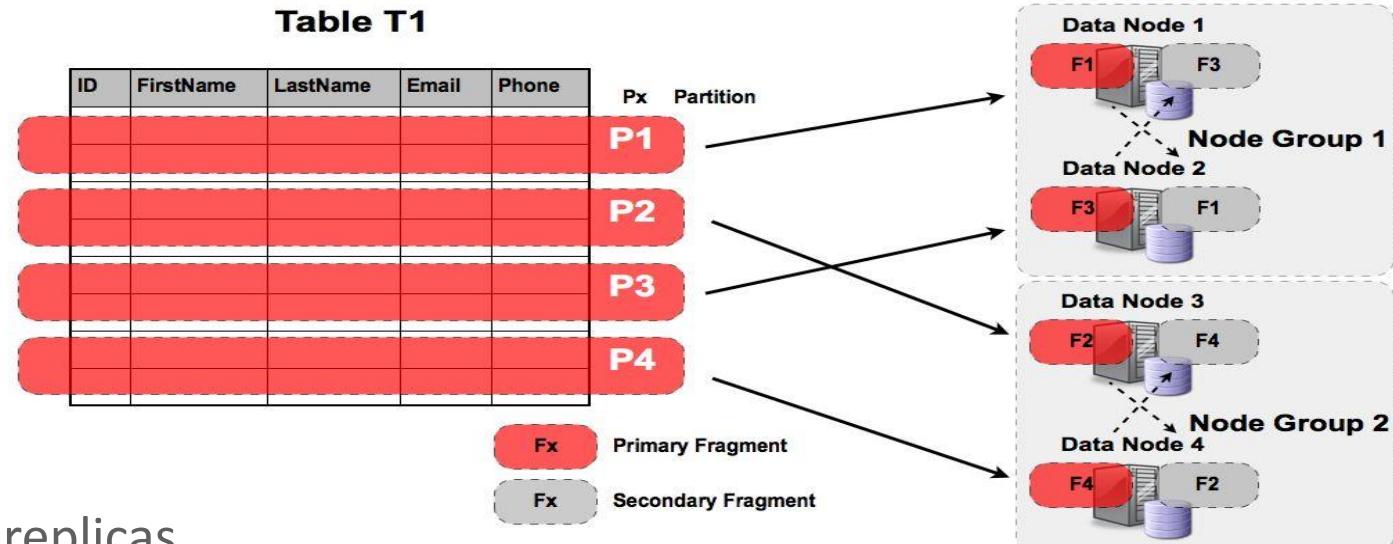
- Partition
 - Horizontal partitioning
 - A portion of a table, each partition contains a set of rows
 - Number of partitions == LQH

- Replica

- A complete copy of the data

- Node Group

- Created automatically
 - # of groups = # of data nodes / # of replicas
 - As long as there is one data node in each node group we have a complete copy of the data



Prepare
Phase

prepared

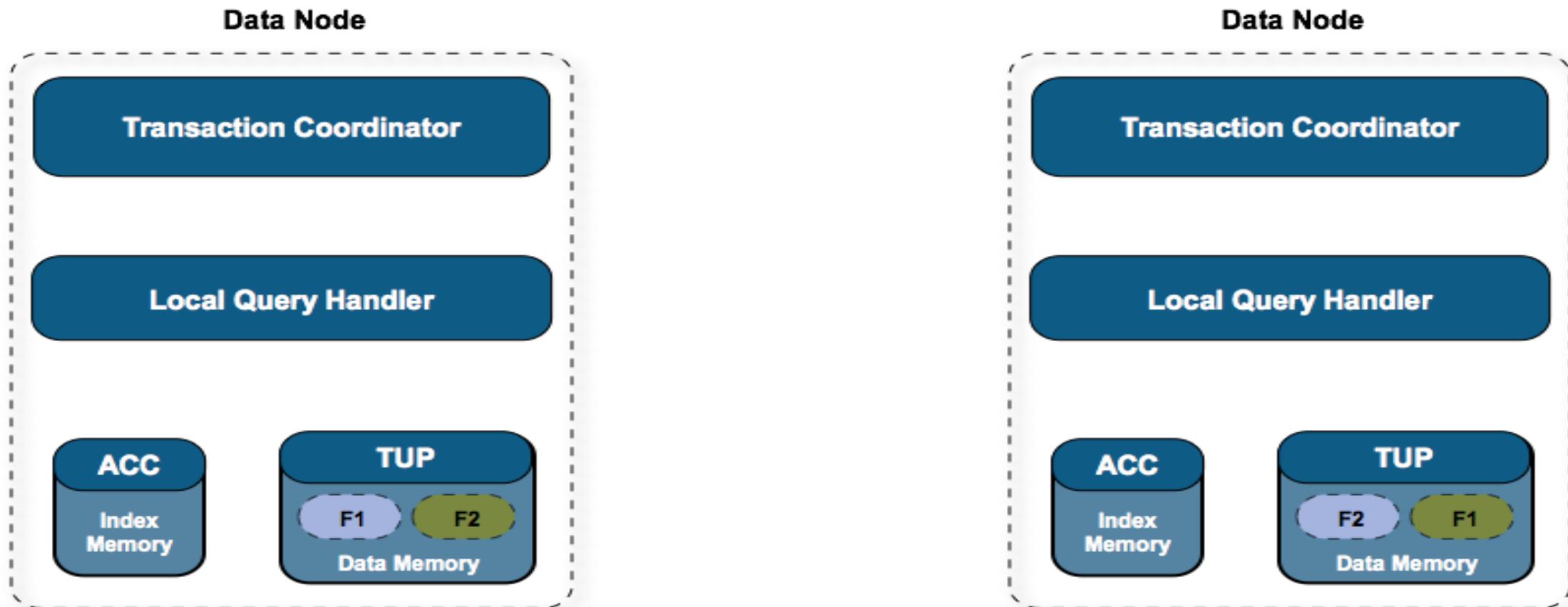
Internal Replication “2-Phase Commit”

Commit
Phase

Done

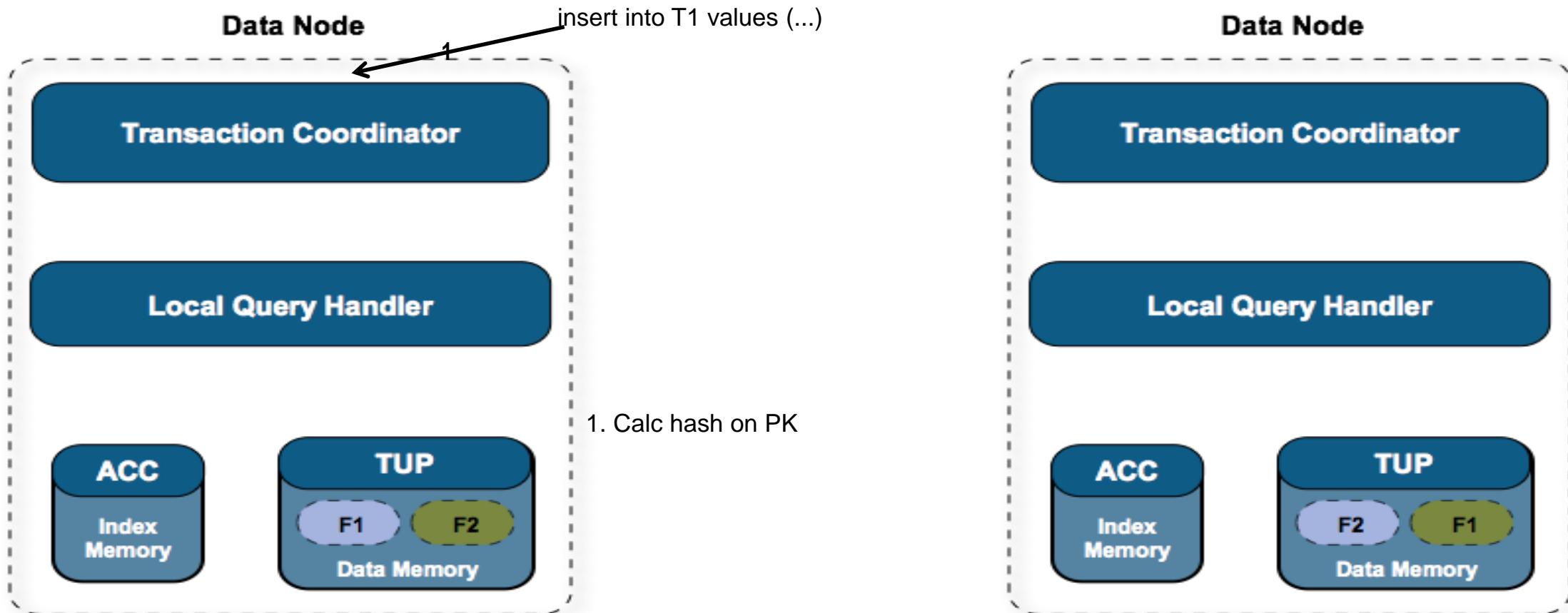
Internal Replication “2-Phase Commit”

Simplistic view of two Data Nodes



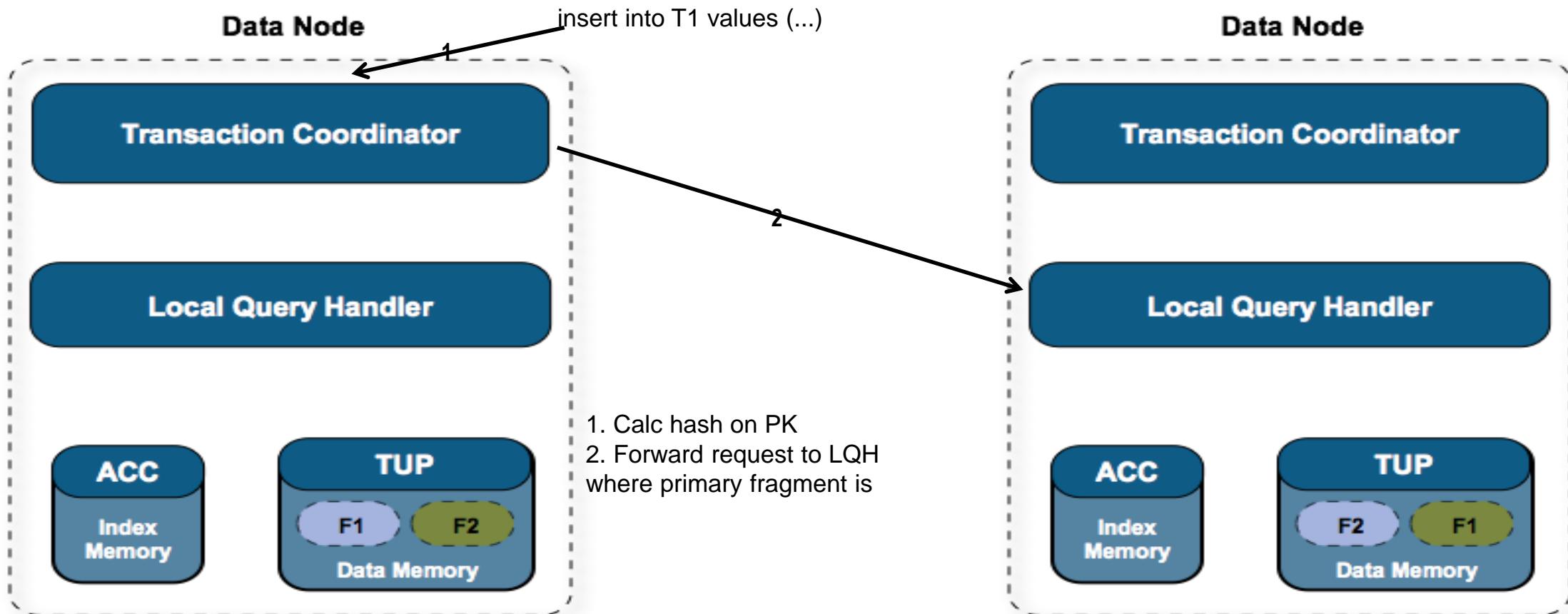
Internal Replication “2-Phase Commit”

Prepare Phase



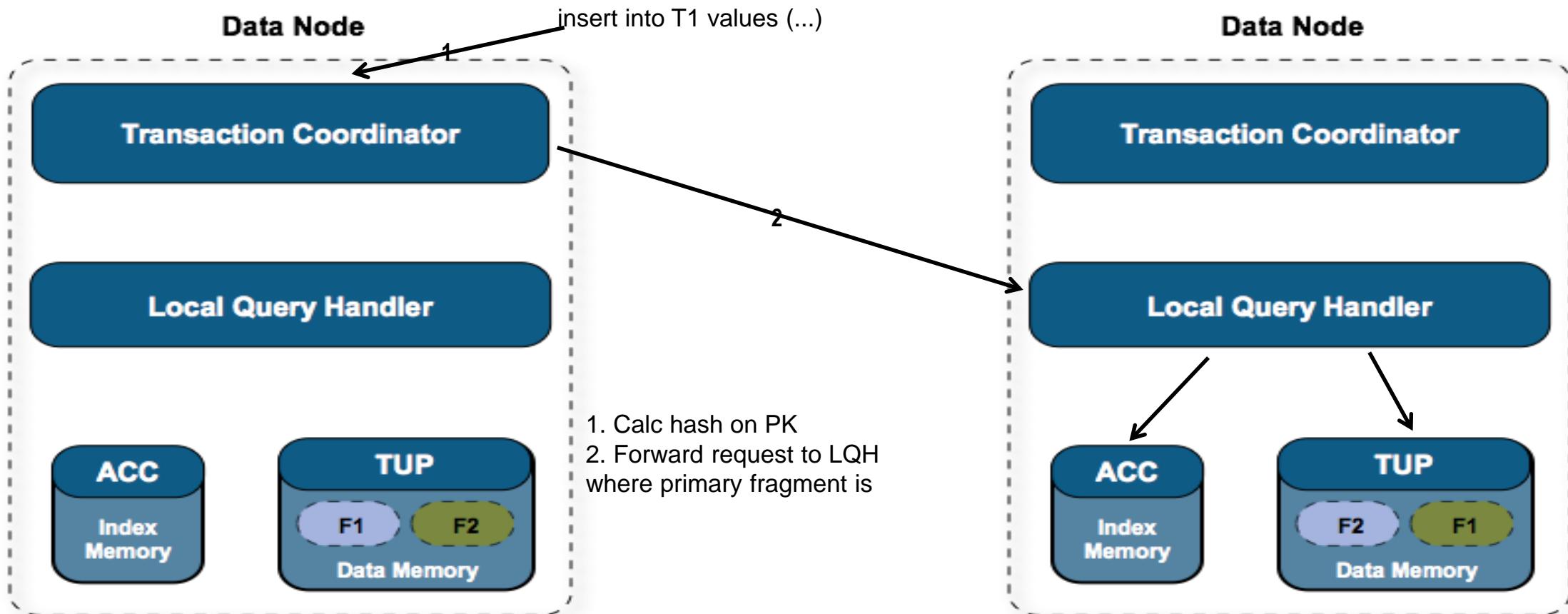
Internal Replication “2-Phase Commit”

Prepare Phase



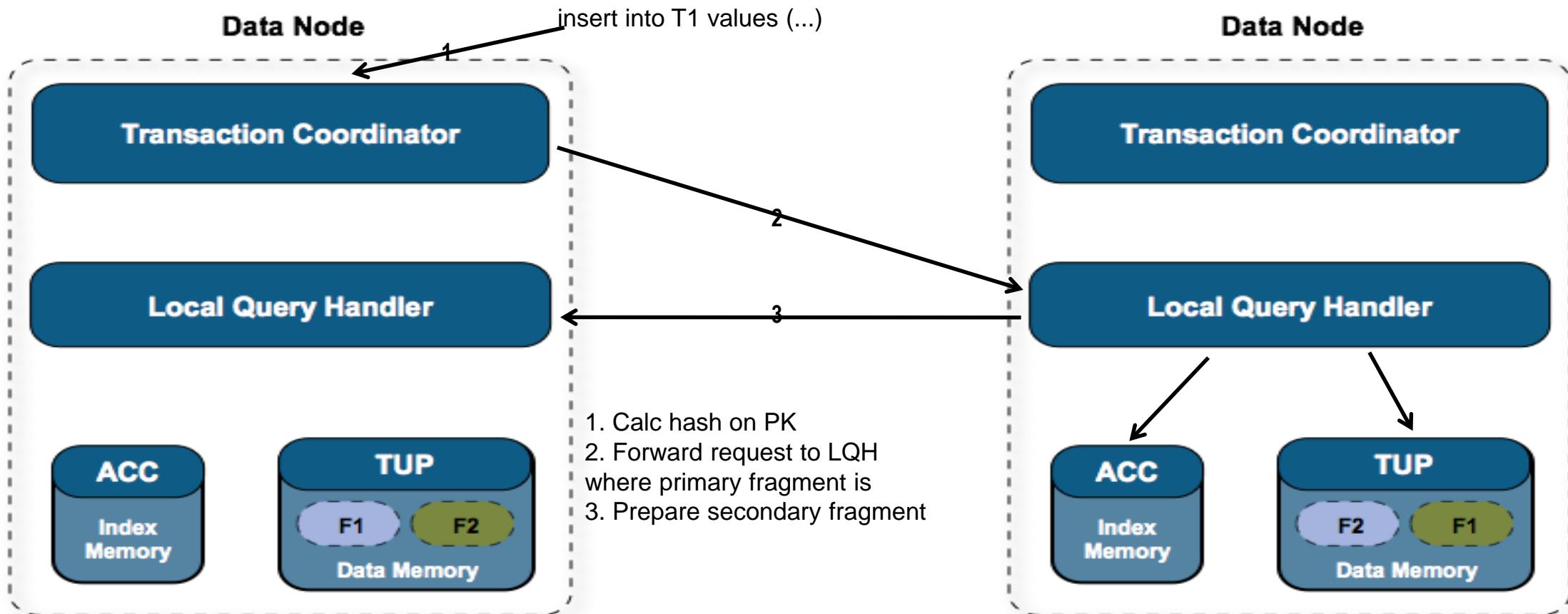
Internal Replication “2-Phase Commit”

Prepare Phase



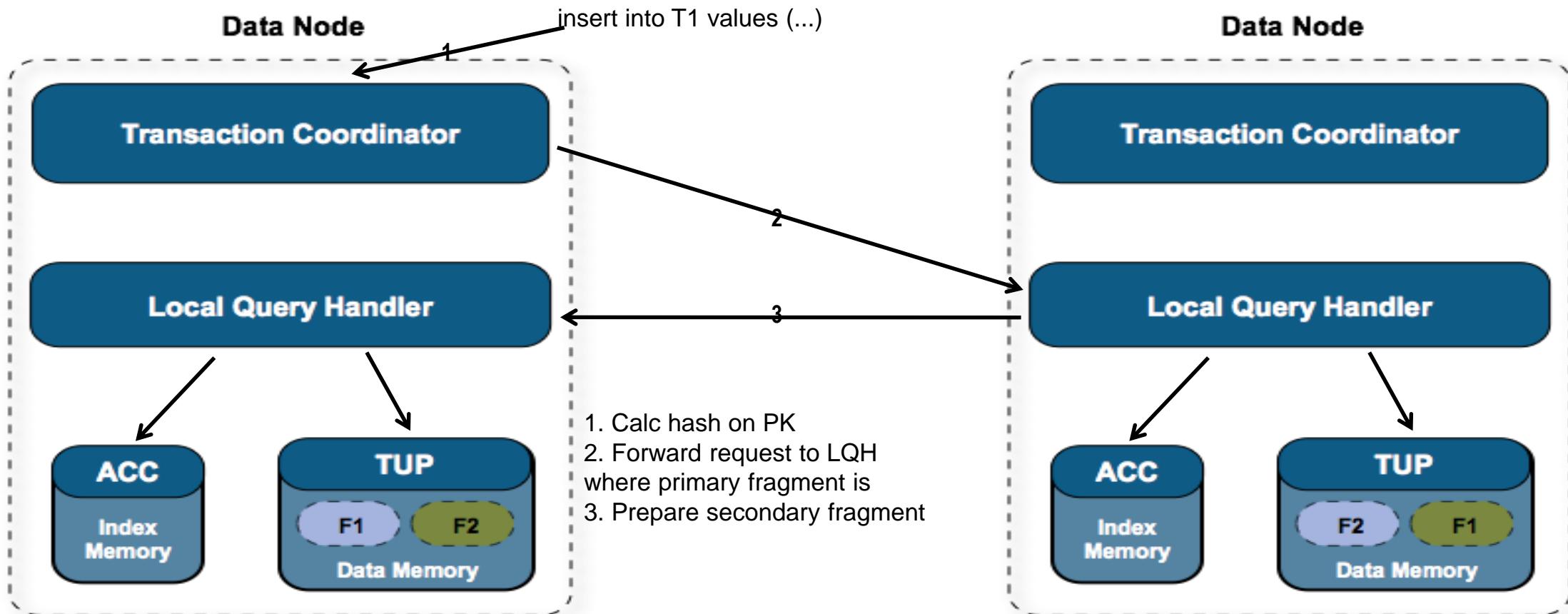
Internal Replication “2-Phase Commit”

Prepare Phase



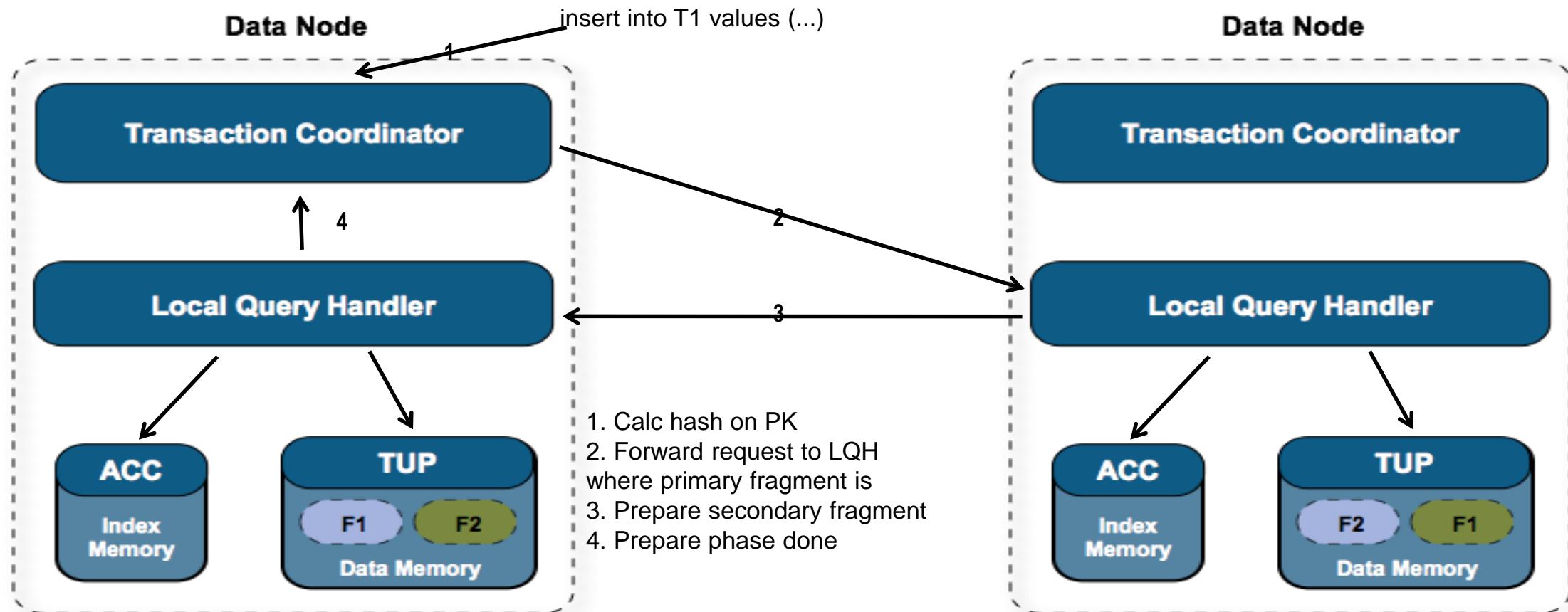
Internal Replication “2-Phase Commit”

Prepare Phase



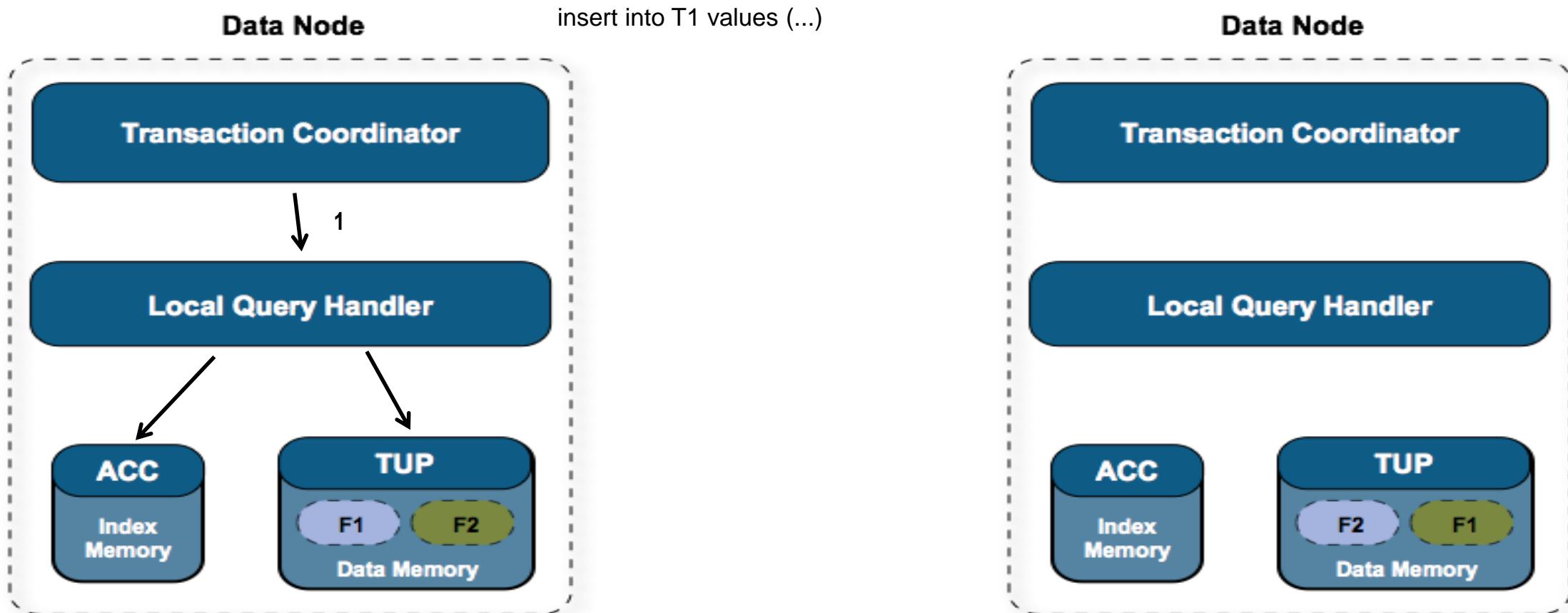
Internal Replication “2-Phase Commit”

Prepare Phase



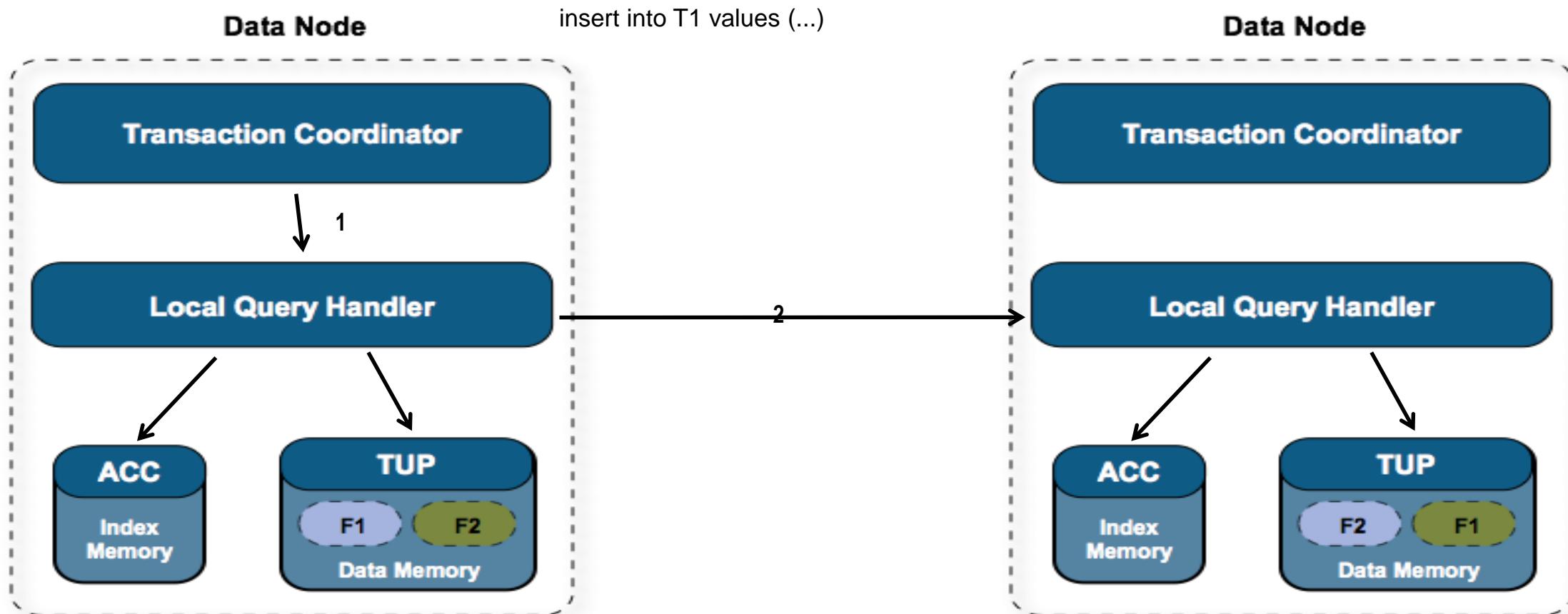
Internal Replication “2-Phase Commit”

Commit Phase



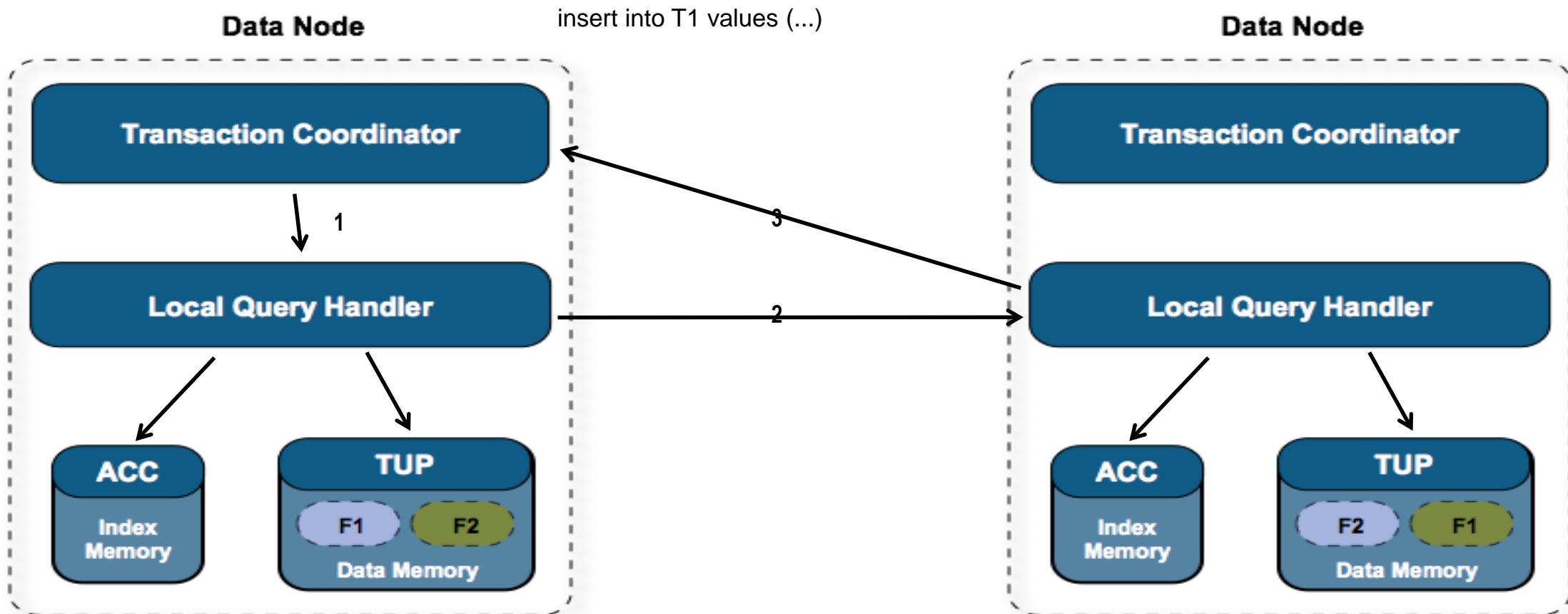
Internal Replication “2-Phase Commit”

Commit Phase



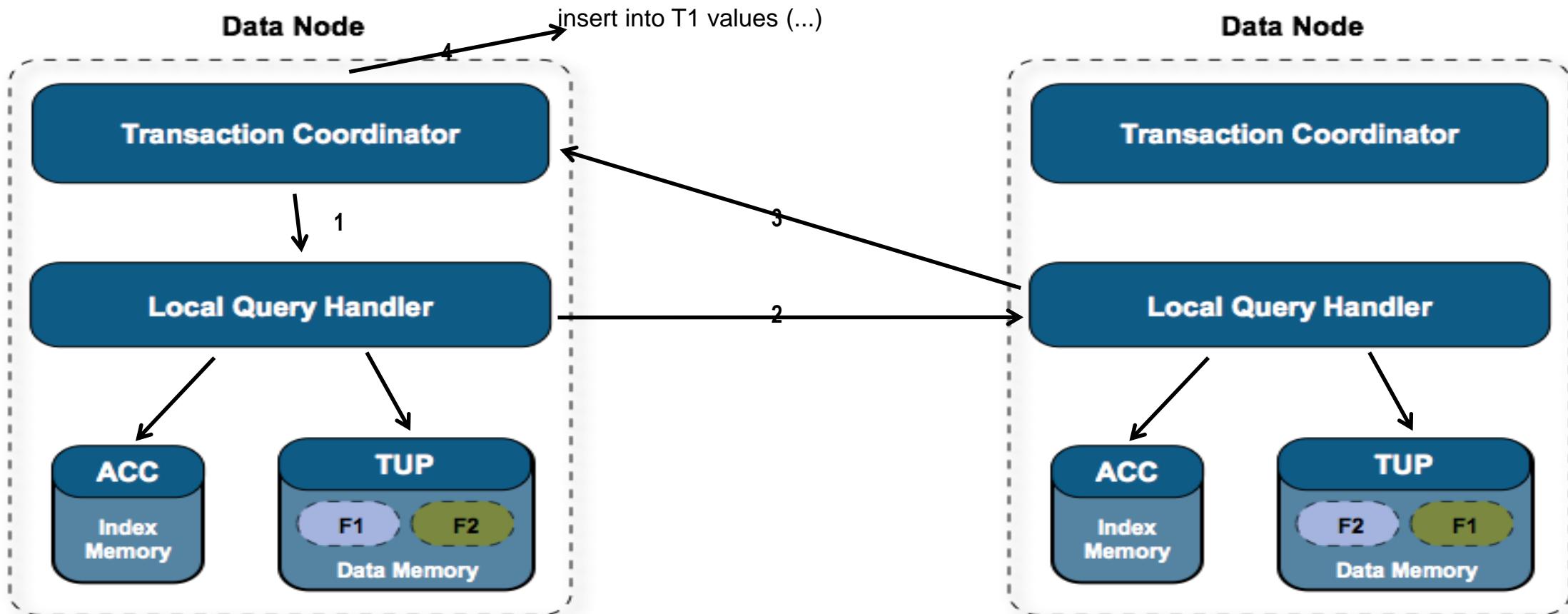
Internal Replication “2-Phase Commit”

Commit Phase



Internal Replication “2-Phase Commit”

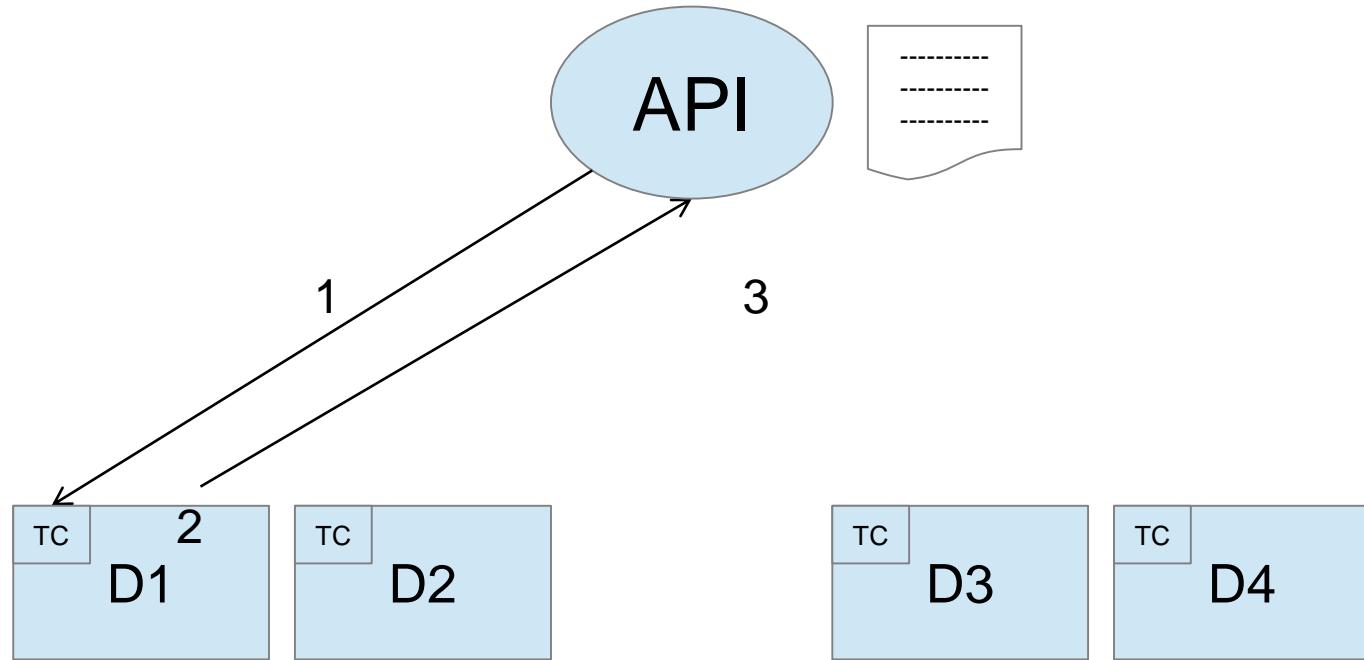
Commit Phase



Accessing data

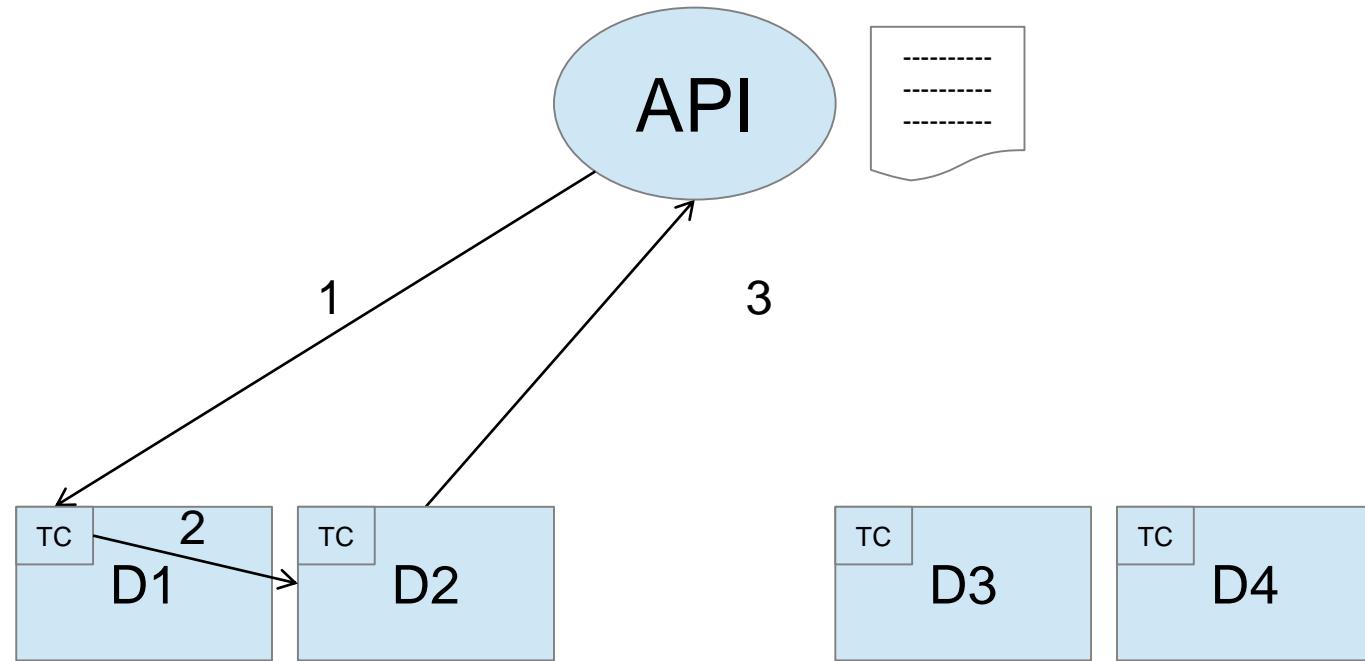
- Four operation types, each accessing a single table or index:
 - **Primary key operation.** Hash key to determine node and 'bucket' in node. $O(1)$ in rows and nodes. Batching gives intra-query parallelism.
 - **Unique key operation.** Two primary key operations back to back. $O(1)$ in rows and nodes
 - **Ordered index scan operation.** In-memory tree traversal on one or all table fragments. Fragments can be scanned in parallel. $O(\log N)$ in rows, $O(n)$ in nodes, unless pruned.
 - **Table scan operation.** In memory hash/page traversal on all table fragments. Fragments can be scanned in parallel. $O(n)$ in rows, $O(n)$ in nodes.

Accessing data: PK key lookup



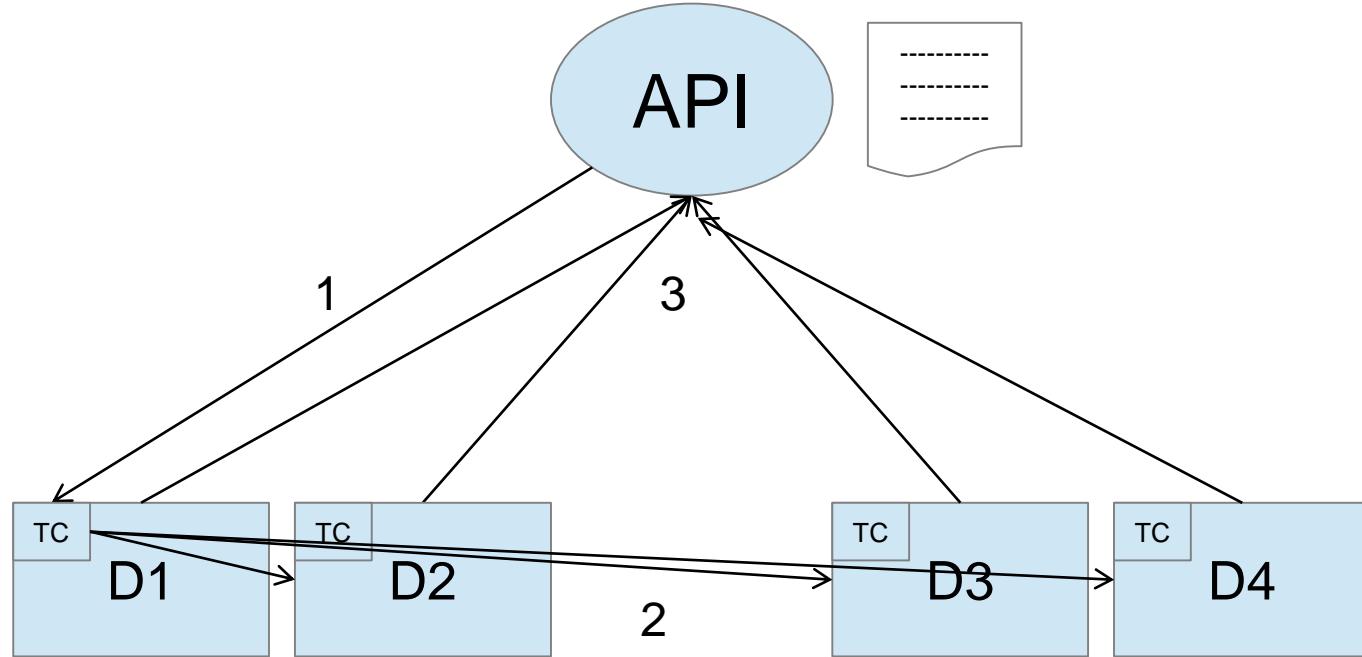
- You will have the same TC during all STMTS building up an transaction so after initial STMT the “distribution awareness” is gone.
- First Statement decides TC
- Keep transactions short!

Accessing data: Unique key lookup



- Secondary keys are implemented as “hidden” tables.
- These tables have the secondary key as PK and base table PK as value.
- Data may reside on same node not.

Accessing data: Table scan

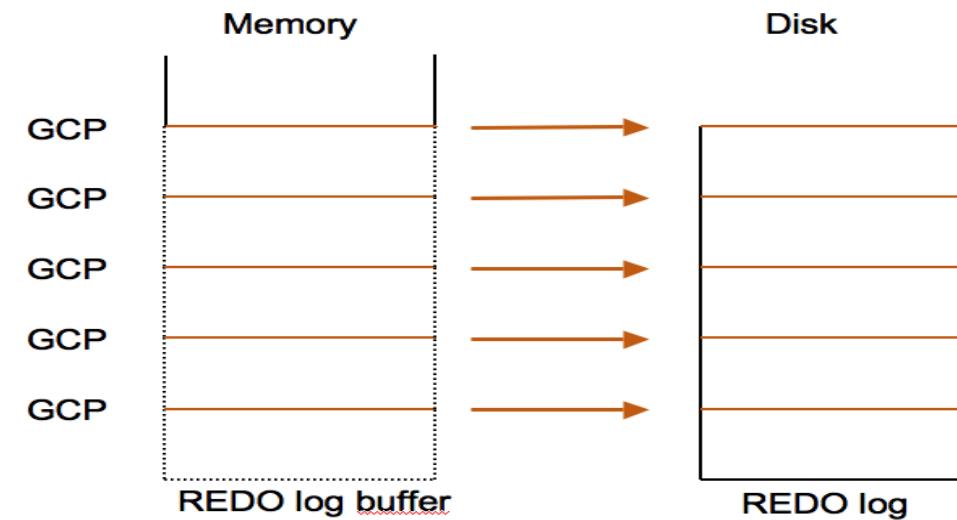


- TC is chosen using Round Robin
- Data nodes send data directly to API Node
- Flow:
 - Pick one TC
 - Send request to all LDM
 - Send back data to API node

Checkpoints and Redo Logging

Global

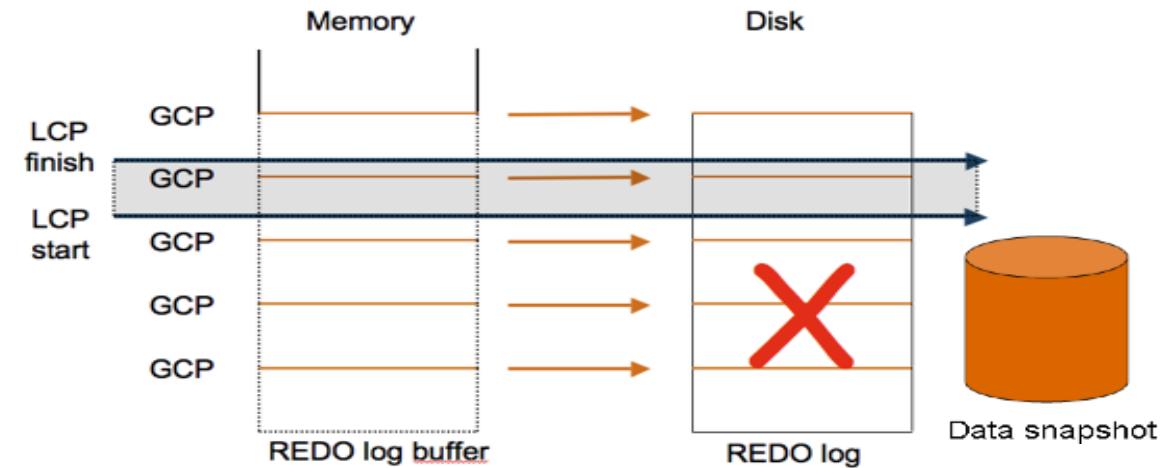
- Global Checkpoint Protocol/Group Commit - GCP
 - Transactions (+increase GCI) synchronized cross all data nodes.
 - Persists transactions that have been recorded in the REDO log buffer to disk.
 - Frequency controlled by `TimebetweenGlobalCheckpoints` setting
 - Default is 2000ms
 - Size of the Redo log is defined by:
$$(\text{NumOfFragmentLogFile} \times \text{FragmentLogFile} \times \text{NoOfFragmentLogParts})$$



Checkpoints and Logging

Local

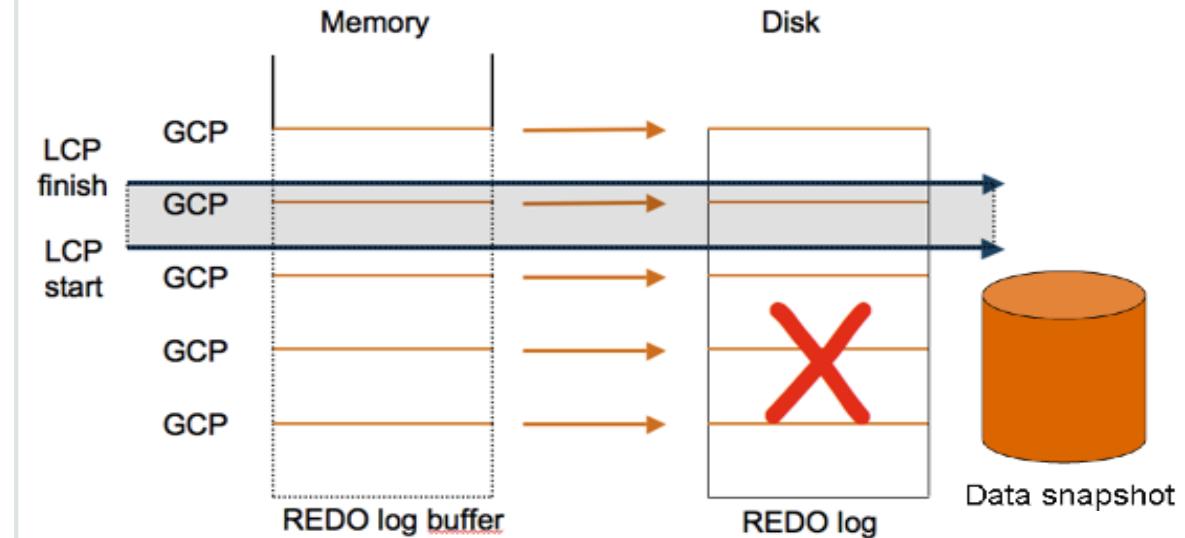
- Local Checkpoint Protocol - LCP
 - Persist data in memory to disk. After LCP the REDO log can be re-used.
 - GCP/GCI is important part of LCP
 - Frequency controlled by TimebetweenLocalCheckpoints setting
 - Specifies the amount of data that can change before flushing to disk
 - Not a time! Base-2 logarithm of the number of 4-byte words
 - Ex: Default value of 20 means $4 \cdot 2^{20} = 4\text{MB}$ of data changes, value of 21 = 8MB



Checkpoints and Logging

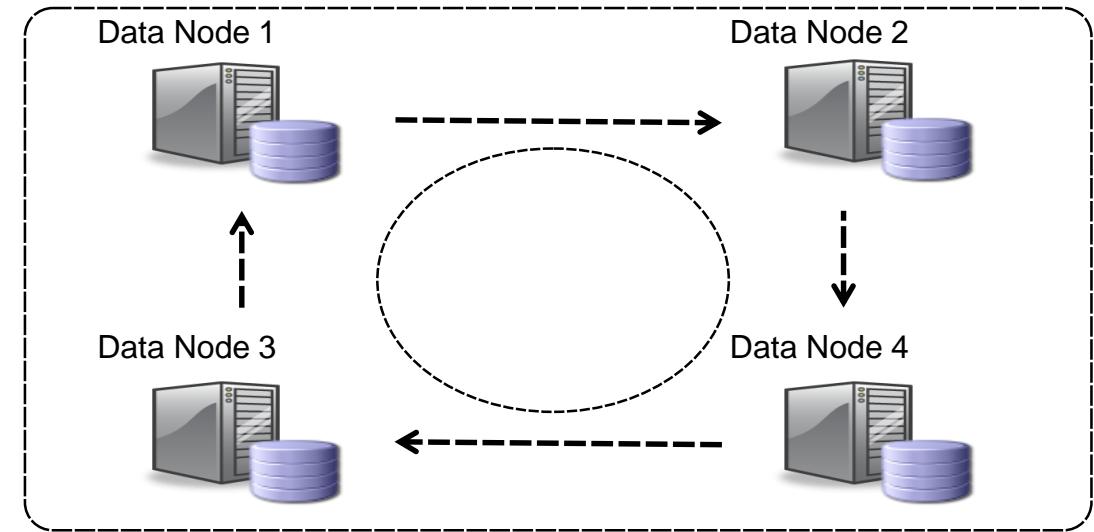
Local & Redo

- LCP and REDO Log are used to bring back the cluster online
 - System failure or planned shutdown
 - 1st Data Nodes are restored using the latest LCP
 - 2nd the REDO logs are applied until the latest GCP



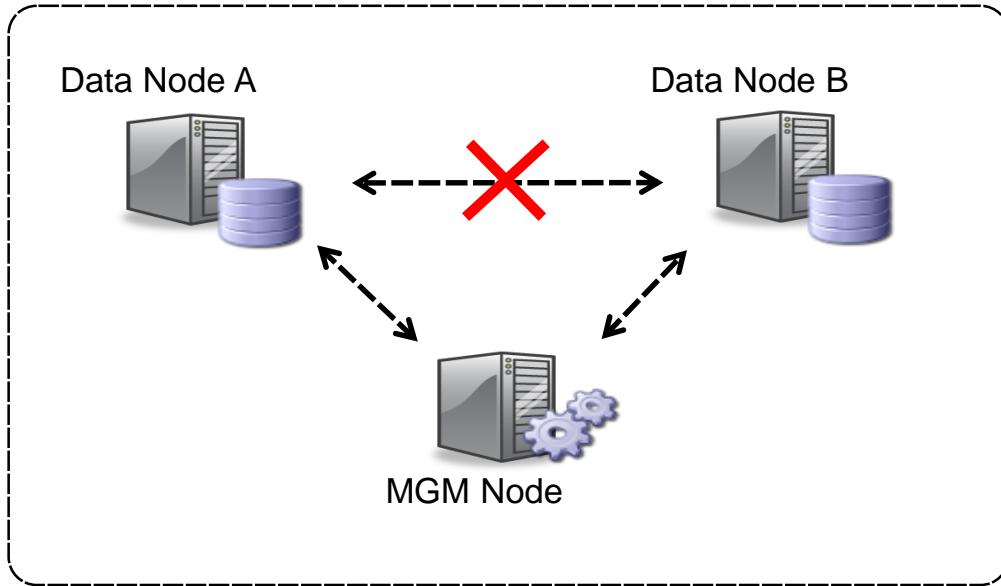
Failure Detection

- Node Failure
 - Heartbeat
 - Each Node is responsible for performing periodic heartbeat checks of other nodes
 - Requests/Response
 - After 3 failures, node is considered dead
- Failed heartbeat/response
 - The Node detecting the failed Node reports the failure to the rest of the cluster
- Hearbeat order can be set in configuration.



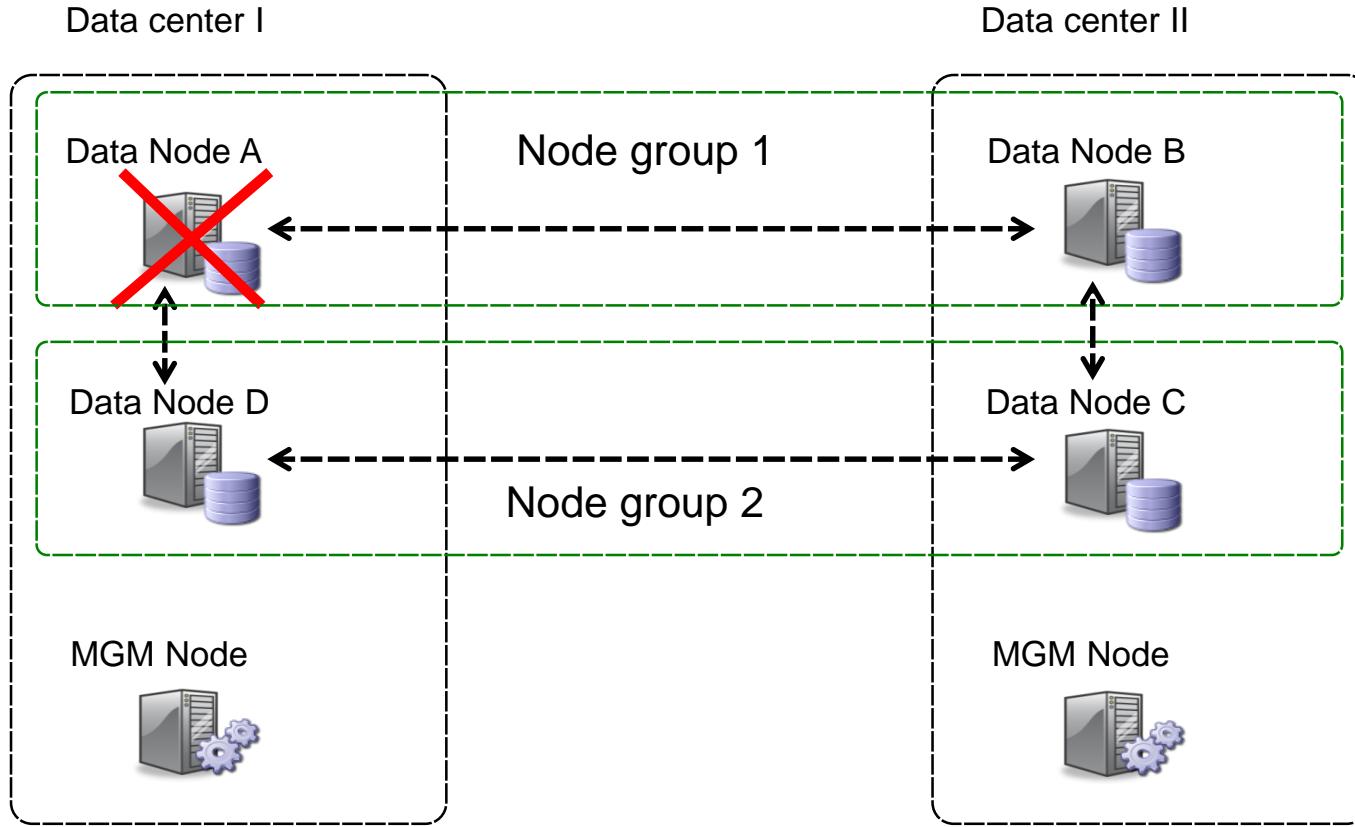
Data Nodes are organized in a logical circle
Heartbeat messages are sent to the next Data Node in the circle

Arbitration I



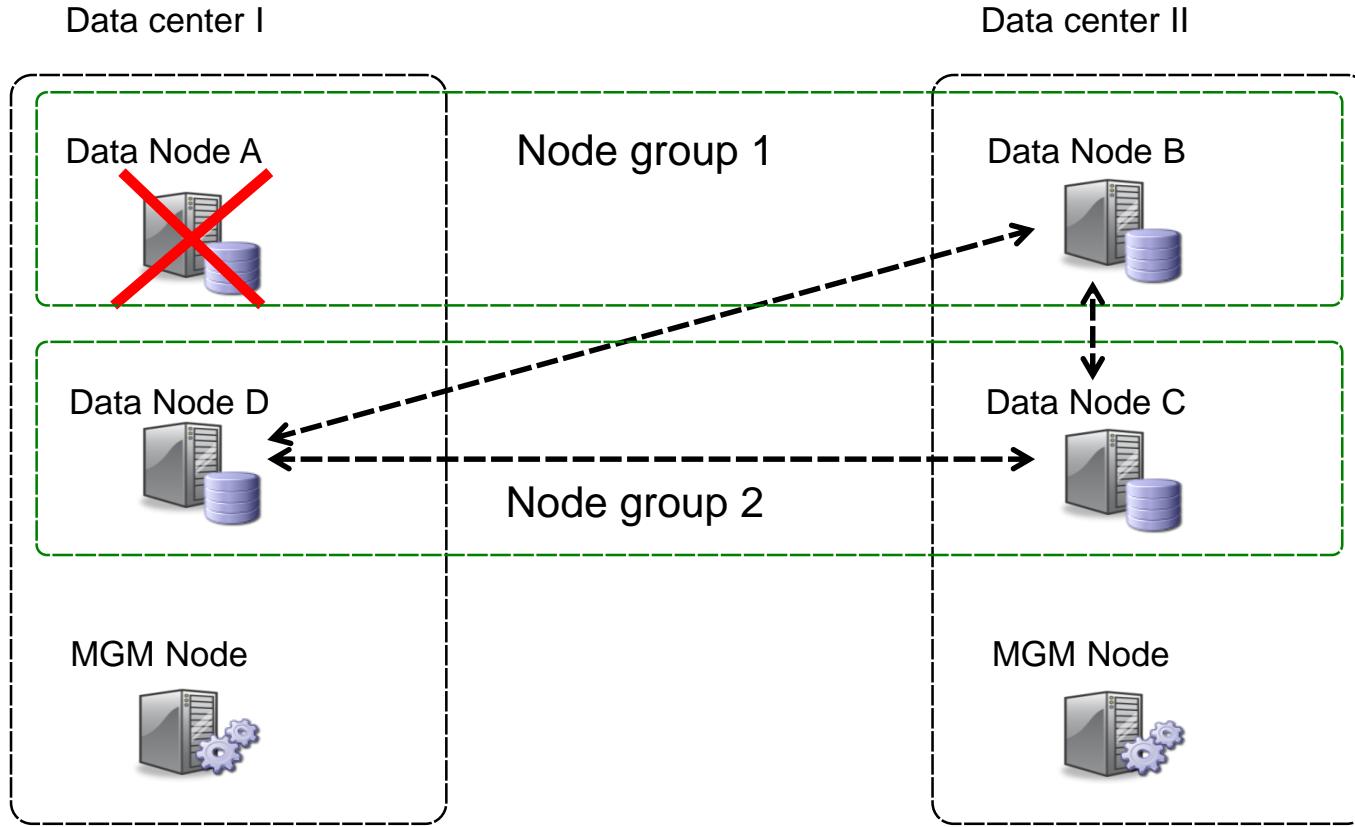
- What will happen:
 - $\text{NoOfReplicas}==2?$
 - $\text{NoOfReplicas}==1?$

Arbitration II



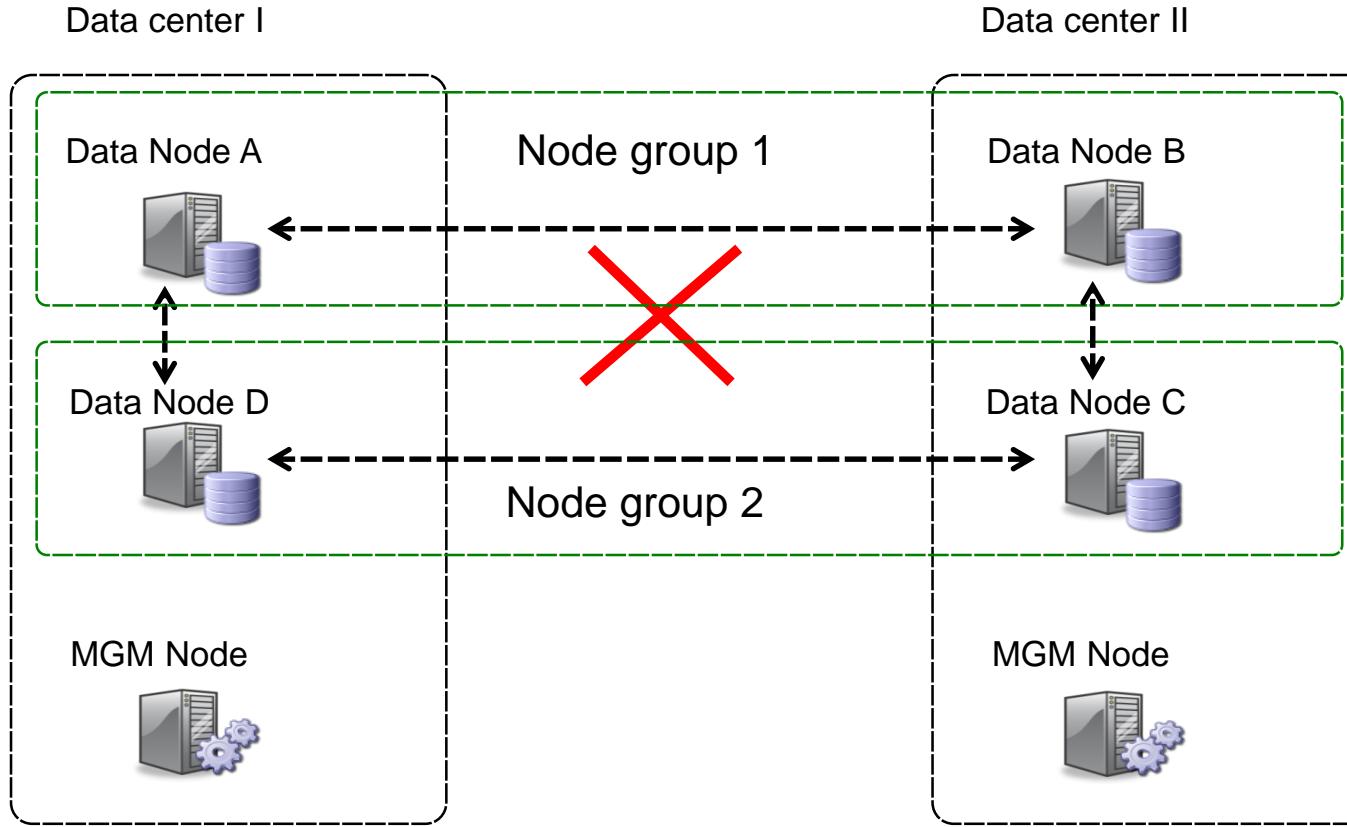
- What will happen:
 - Which side will survive?
 - And why?

Arbitration II



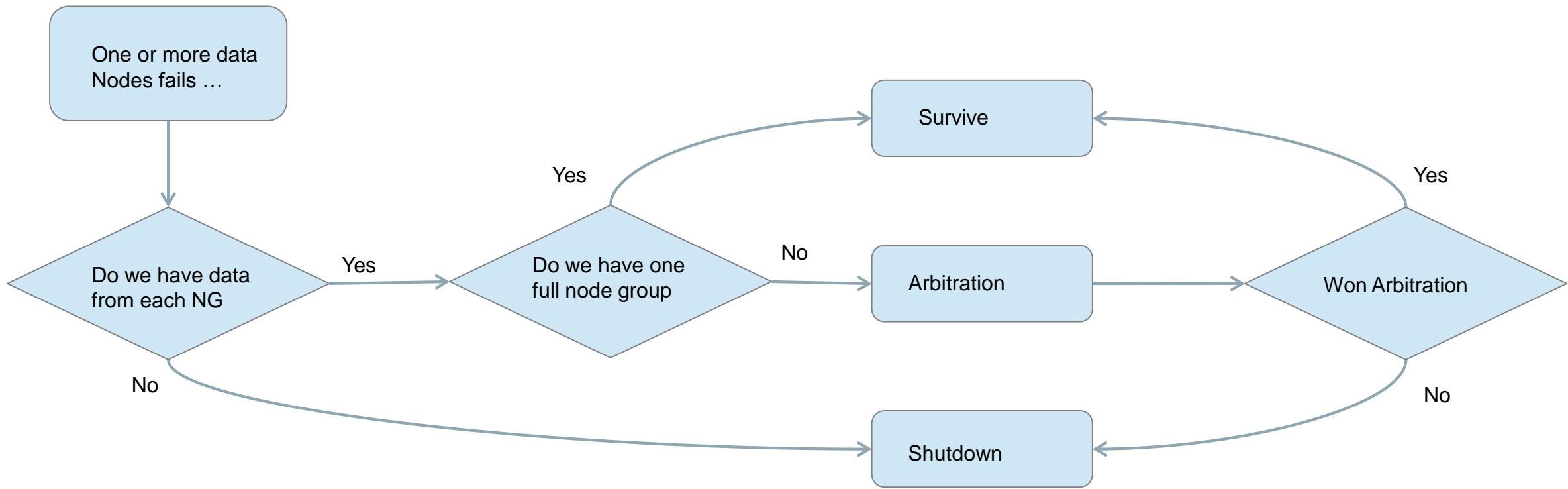
- What will happen:
 - New cluster with 3 nodes will continue!

Arbitration III



- What will happen:
 - Which side will survive?
 - And why?

Arbitration flow chart



1. Check whether a data node from each node group is present. If that is not the case, the data nodes will have to shutdown.
2. Are all data nodes from one of the node groups present? If so it is guaranteed that this fragment is the only one that can survive. If no, continue to 3.
3. Contact the arbitrator.
4. If arbitration was won, continue. Otherwise shutdown.



A

Application

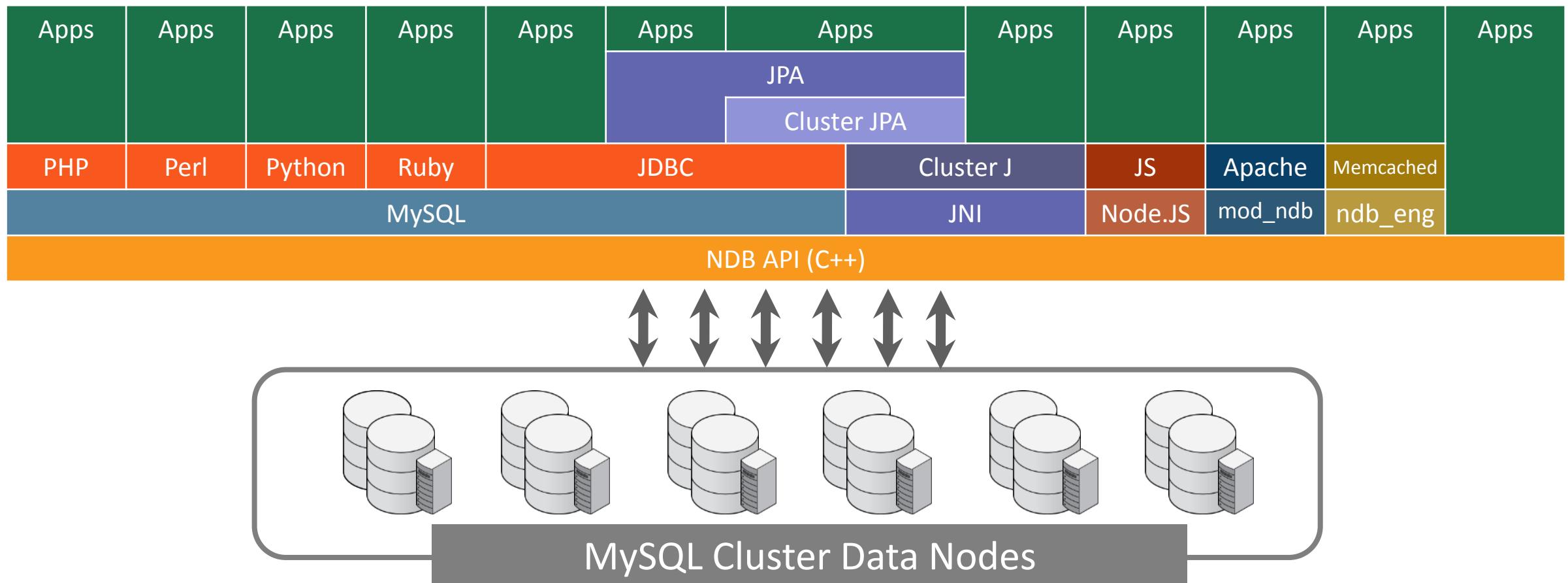
P

Program

I

Interface

NoSQL Access to MySQL Cluster data



Choosing the right application API

SQL

- Industry standard
- Joins & Complex queries
- Relational model

Memcached

- Simple to use API
- Key/value
- Drivers for many languages

Mod-ndb

- REST
- Html
- Plugin for Apache

ClusterJ

- Simple to Use Java API
- Web & telco
- Object Relational Mapping
- Native & fast access to data

ClusterJPA

- OpenJPA plugin
- Standards defined ORM
- Cross table Joins

JavaScript/Node.js

- Native JavaScript: client to DB
- Blazing fast asynchronous throughput

Program Agenda

- 1 ➤ Introduction
- 2 ➤ Getting started: configuration/install/start/stop
- 3 ➤ Administration: backup/upgrade/logs/conf/sizing
- 4 ➤ Monitoring, surveillance and problem solving
- 5 ➤ Best practices, architectures and case studies
- 6 ➤ Geo-replication

MySQL Cluster Installation options!

- Community / GPL
 - <http://dev.mysql.com/downloads/cluster>
- Carrier Grade Edition
 - <http://edelivery.oracle.com>
 - <http://support.oracle.com>
- Tarball
 - Manual “hands-on” install.
- RPM, DEB, PKG, DMG, MSI
 - O.S. specific install packages.
 - Specific paths, packages (server, client, etc.)
- Source code
 - Compile your own version.
 - `cmake .`
 - `make`
 - `make install`

MySQL Cluster Configuration

- All nodes are defined in config.ini
 - Devided into sections using “[...]”, sections for;
 - data nodes ndb{mt}d
 - Management nodes [ndb_mgmd]
 - MySQL servers [mysqld]
 - API nodes [ndbapi]
 - If keyword default is added to section values are applied to all
 - Management node is started with a config.ini. Should be same for all management nodes in one cluster.
- MySQL API nodes are configured both in config.ini and have their dedicated configuration file “my.cnf”

Configuration “config.ini”

Typical parameters

- IndexMemory **and** dataMemory.
- Set MaxNumberOfExecutionThreads <= #cores
 - Otherwise contention will occur → unexpected behaviour.
- RedoBuffer=32–64M
 - If you need to set much it higher → your disks are probably too slow
- FragmentLogFileSize=256M
- NoOfFragmentLogFiles= **6 x DataMemory (in MB) / (4x 256MB)**
 - Most common issue – customers never configure large enough redo log
- Data and index memory to cope with size of database/indexes
- LockPagesInMainMemory=1
- MaxNoOf* -parameters

Configuration

Disk-based tables

- Use Disk Data tables for
 - Simple accesses (read/write on PK)
 - Same for InnoDB – you can easily get IO BOUND (iostat)
- Set `DiskPageBufferMemory=3072M`
 - is a good start if you rely a lot on disk data – like the `Innodb_Buffer_Pool`, but set it as high as you can!
- Increased chance that a page will be cached
 - `SharedGlobalMemory=384M-1024M`
- `UNDO_BUFFER=64M to 128M (if you write a lot)`
 - You cannot change this BUFFER later!

MySQL Cluster Starting / Stopping config.ini

```
[ndb_mgmd default]
ArbitrationRank          =1
DataDir                  =/opt/mysql/735/mgmd_data

[ndb_mgmd]
hostname                =khollman-es
NodeId                  =1

[ndbd default]
noofreplicas            =2
DataDir                  =/opt/mysql/735/ndbd_data
DataMemory
IndexMemory
DiskPageBufferMemory     =20M
StringMemory              =10M
MaxNoOfConcurrentOperations =4M
MaxNoOfConcurrentTransactions =5
SharedGlobalMemory        =2K
LongMessageBuffer         =500K
MaxParallelScansPerFragment =512K
MaxNoOfAttributes         =16
MaxNoOfTables              =1000
MaxNoOfTables              =20
MaxNoOfOrderedIndexes     =20
ODirect                  =TRUE

[mysqld default]

[mysqld]
NodeId                  =10

[mysqld]
NodeId                  =11

[NDBAPI]
NodeId                  =12

[NDBAPI]
NodeId                  =13

HeartbeatIntervalDbDb    =500
HeartbeatIntervalDbApi    =500
StopOnError               =1
TransactionInactiveTimeout =500
TransactionDeadlockDetectionTimeout = 1200
LockPagesInMainMemory     =2
```

MySQL Cluster Starting / Stopping

my.cnf

```
[client]
socket                  =/tmp/mysql_7351.sock

[mysql]
prompt                 ='R:\m \d>\_'

[mysqld]
datadir                =/opt/mysql/735/data
ndb-connectstring      =khollman-es:1186
user                   =mysql
port                   =7351
socket                 =/tmp/mysql_7351.sock
general-log            =1
log-output             =FILE
log-error              =khollman-es_7351.err

slow-query-log          =1
max_connections         =20
innodb_log_buffer_size =8M
innodb_buffer_pool_size =64M
innodb_log_file_size   =16M
innodb_flush_log_at_trx_commit =2
innodb_file_per_table  =1
innodb_data_home_dir    =/opt/mysql/735/data
innodb_data_file_path   =ibdata1:50M;ibdata2:50M:autoextend

[mysql_cluster]
ndb-connectstring      =khollman-es:1186
```

MySQL Cluster Starting / Stopping

- First time & when configuration changes are needed: **--INITIAL**
 - When the config.ini changes, no need to do a complete shutdown. Restart ndb_mgmd with **--INITIAL** to clean the cached config information. And then just restart the datanodes (without **--initial**)
- Starting

```
# ndb_mgmd -f config.ini --config-dir=/usr/local/mysql-cluster/conf --INITIAL
# ndbd --INITIAL | ndbmtd -c localhost:1186 --INITIAL | ndbd -n (nostart)
# scripts/mysql_install_db --defaults-file=my.cnf --user=mysql
# mysqld_safe --defaults-file=my.cnf --user=mysql
```

MySQL Cluster Starting / Stopping

- **Starting**

- `ndb_mgmd -f config.ini --config-dir=/usr/local/mysql-cluster/conf`
- `ndbd | ndbmttd -c localhost:1186`
- `mysqld_safe --defaults-file=my.cnf`

- **Stopping**

- `ndb_mgm -e shutdown`
- `ndb_mgm -e [mgmt node & datanode] 1 | 3 | 4 stop`
- `ndb_mgm -e [mgmt node & datanode] 1 | 3 | 4 restart`
- `mysqladmin --defaults-file=my.cnf -uroot shutdown`

MySQL Cluster Starting / Stopping

nostart

```
ndbmtd --ndb-nodeid=3 -n
ndbmtd --ndb-nodeid=4 -n

ndb_mgm -e show
Cluster Configuration
-----
[ndbd(NDB)] 2 node(s)
id=3  @127.0.0.1  (mysql-5.6.17 ndb-7.3.5, not started)
id=4  @127.0.0.1  (mysql-5.6.17 ndb-7.3.5, not started)

ndb_mgm -e "all start"

ndb_mgm -e show
Cluster Configuration
-----
[ndbd(NDB)] 2 node(s)
id=3  @127.0.0.1  (mysql-5.6.17 ndb-7.3.5, starting, Nodegroup: 0, *)
id=4  @127.0.0.1  (mysql-5.6.17 ndb-7.3.5, starting, Nodegroup: 0)
```

MCM Hands On Lab

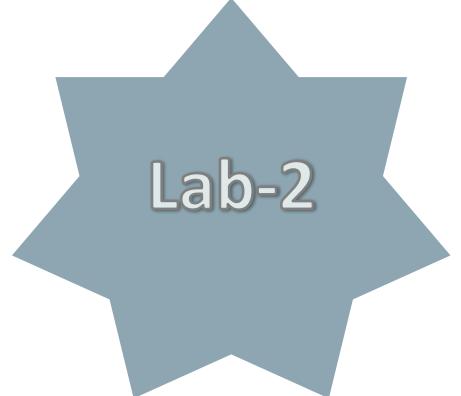
1 Installing MySQL Cluster Manager



- Lab-1
 - <https://github.com/wwwted/ndb-cluster-workshop>
- Environment for HOL
 - /home/<user>/MCM_LAB/
 - cluster-758/
 - mcm1.4.4/
 - mcm_data/
 - mcmd.ini

MCM Hands On Lab

2 Configure and start MySQL Cluster



Lab-2

- Lab-2
 - <https://github.com/wwwted/ndb-cluster-workshop>

```
mcm> show status -r mycluster;
+-----+-----+-----+-----+-----+
| NodeId | Process | Host      | Status   | Nodegroup | Package    |
+-----+-----+-----+-----+-----+
| 49     | ndb_mgmd | 127.0.0.1 | running  |           | cluster735 |
| 1      | ndbmtd   | 127.0.0.1 | running  | 0          | cluster735 |
| 2      | ndbmtd   | 127.0.0.1 | running  | 0          | cluster735 |
| 50     | mysqld   | 127.0.0.1 | running  |           | cluster735 |
| 51     | mysqld   | 127.0.0.1 | running  |           | cluster735 |
| 52     | ndbapi   | *127.0.0.1 | added    |           |             |
| 53     | ndbapi   | *127.0.0.1 | added    |           |             |
| 54     | ndbapi   | *127.0.0.1 | added    |           |             |
| 55     | ndbapi   | *127.0.0.1 | added    |           |             |
+-----+-----+-----+-----+-----+
9 rows in set (0,07 sec)
```

Program Agenda

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- 6 ➤ Geo-replication

Backup & Restore

Backup

- Backup of NDB tables
 - Online – can have ongoing transactions
 - Consistent – only committed data and changes are backed up
- `ndb_mgm -e "START BACKUP"`
 - Copy backup files from data nodes to safe location
 - Non-NDB tables must be backed up separately
 - MySQL system tables are stored only in MYISAM.
- You want to backup data in MySQL
 - Users in mysql database
 - Triggers, routines, events ...
- MySQL Users:
 - `mysqlpump --exclude-databases=% --users > users.sql`
- MySQL DB logic:
 - `mysqldump --no-data --no-create-info --skip-opt --routines --events --triggers --databases db1 db2 > dblogic.sql`
- Copy `my.cnf` & `config.ini` files

Backup

- `ndb_mgm> START BACKUP`
- Generates files holding the following information on each node, under the `BackupDataDir`, or datanode `datadir` `BACKUP/BACKUP-backup-id` :
 - **Metadata:** saved in controlfile
 - Holds table definitions and control information
 - `BACKUP-backup-id.nodeid.ctl`: eg. `BACKUP-1.6.ctl`
 - **Data:** saved in a file “`.Data`”
 - Holds per-fragment records
 - `khollman-es:/opt/mysql/735/ndbd_data/BACKUP/BACKUP-1/BACKUP-1-0.6.Data`
 - **Transaction log:** saved file “`.log`”
 - Stores transactions happening during backup, used to recover to a consistent state
 - `BACKUP-1.6.log`

Backup

What happens whilst backing up?

- Each data node scans its tables and adds them to the backup data buffer
 - `BackupDataBufferSize` (default 16Mb). 0 – 4Gb, min +188Kb > `BackupWriteSize` (min = 190Kb).
- Backup flushes data to disk determined by
 - `BackupWriteSize` (default 256Kb) 2Kb – 4Gb.
- Maximum size of disk writes controlled by:
 - `BackupMaxWriteSize` (default 1Mb) 2Kb – 4Gb.
- If the buffer fills up, the scan pauses until enough data has been written to disk before continuing.

Backup

And the other ongoing transactions?

- Backup process logs all data modifications during backup in:
 - `BackupLogBufferSize` (default 16Mb)
 - Needs to be `min +16Kb > BackupWriteSize` (min 18Kb).
- Log buffer flushes changes to disk same way as it does with the Data Buffer
 - `BackupWriteSize` & `BackupMaxWriteSize`.
- Depending on system activity, buffer to disk flushes might require moving `BackupDataDir` to separate disks than redo, disk data, etc.
- If the log buffer fills up during backup, the backup aborts.

Backup Config

- BackupMemory (**default 32M**) = BackupDataBufferSize + BackupLogBufferSize
- If either buffer is increased, explicitly set BackupMemory to the total in config.ini.
- Status reporting:
 - BackupReportFrequency (**default 0 max 4Gb**).
 - Number of seconds between status updates in management console or cluster log.

Backup management console

- For large backups, to regain control of management console:
 - START BACKUP NOWAIT
 - Immediate return
 - START BACKUP WAIT STARTED
 - Once it starts, return control.
 - START BACKUP = START BACKUP WAIT COMPLETED.

Backup

- By default the backup represents the state of the database at the end of the backup process.
- You can take a backup to reflect the state at the beginning:
 - `ndb_mgm> START BACKUP SNAPSHOTSTART`
 - If the dataset is large and you have high rate of changes, it may take some time to undo all changes that happened during the backup.

Backup Monitoring

- Whilst a backup is running we can check the status with:

```
ndb_mgm> 3 REPORT backupstatus
```

```
ndb_mgm> ALL REPORT backupstatus
```

```
Node 3: Local backup status: backup 3 started from node 1
  #Records: 0 #LogRecords: 0
  Data: 0 bytes Log: 0 bytes
Node 4: Local backup status: backup 3 started from node 1
  #Records: 0 #LogRecords: 0
  Data: 0 bytes Log: 0 bytes
Node 5: Local backup status: backup 3 started from node 1
  #Records: 0 #LogRecords: 0
  Data: 0 bytes Log: 0 bytes
Node 6: Local backup status: backup 3 started from node 1
  #Records: 0 #LogRecords: 0
  Data: 0 bytes Log: 0 bytes
Node 5: Backup 3 started from node 1
Node 5: Backup 3 started from node 1 completed
  StartGCP: 174775 StopGCP: 174778
  #Records: 14148 #LogRecords: 0
  Data: 1018516 bytes Log: 0 bytes
```

Backup Troubleshooting

- To abort the backup just run:

```
ndb_mgm> abort backup 3
```

- Typical errors:

- Disk full: Change BackupDataDir to a new path.
 - Set CompressedBackup=1 in the config.ini.
- Disk slow: Choose a faster IO subsystem or increase BackupDataBufferSize & BackupLogBufferSize.
- Memory errors: Remember BackupMemory is the sum of BackupDataBufferSize & BackupLogBufferSize so if we change these, we might need to reduce some other memory parameters.

Backup Restore

- Use the **ndb_restore** CLI.
 - Enter single user mode on API node to avoid conflicts with other API nodes.
 - Repeatable-reads not supported so while restore takes place, data could be accessed inconsistently.
 - Restore Metadata separately from Data:
 - Metadata restore to a new or initialized Cluster.
 - Restore data only for the same cluster.
 - **Ndb_restore** is executed once for each backed up data node.
 - Nodeid is specific in all statements.

Backup Restore

- 2 ways to launch restore:

```
ndb_restore --backup_path=/backups/BACKUP/BACKUP-4 -n 2 -r -b 4
ndb_restore --backup-path=/backups/BACKUP/BACKUP-4 --nodeid=2 --restore_data --
    backupid=4
```

- So if there are 4 datanodes in the cluster:

```
ndb_mgm> ENTER SINGLE USER MODE 2
# ndb_restore --backup_path=/backups/BACKUP/BACKUP-4 -n 2 -r -b 4
# ndb_restore --backup_path=/backups/BACKUP/BACKUP-4 -n 3 -r -b 4
# ndb_restore --backup_path=/backups/BACKUP/BACKUP-4 -n 4 -r -b 4
# ndb_restore --backup_path=/backups/BACKUP/BACKUP-4 -n 5 -r -b 4
ndb_mgm> EXIT SINGLE USER MODE
```

Backup

Restore cont.

- If it's a new cluster, i.e. not restoring on the same system, make sure the metadata is restored first:

```
ndb_mgm> ENTER SINGLE USER MODE 2
# ndb_restore --backup_path=/backups/BACKUP/BACKUP-4 -n 2 -b 4 --restore_meta
# ndb_restore --backup_path=/backups/BACKUP/BACKUP-4 -n 2 -r -b 4
# ndb_restore --backup_path=/backups/BACKUP/BACKUP-4 -n 3 -r -b 4
# ndb_restore --backup_path=/backups/BACKUP/BACKUP-4 -n 4 -r -b 4
# ndb_restore --backup_path=/backups/BACKUP/BACKUP-4 -n 5 -r -b 4
ndb_mgm> EXIT SINGLE USER MODE
```

Backup

Being selective

- Restore only specific databases:

--include-databases=db1, db2

- Restore all except specific databases:

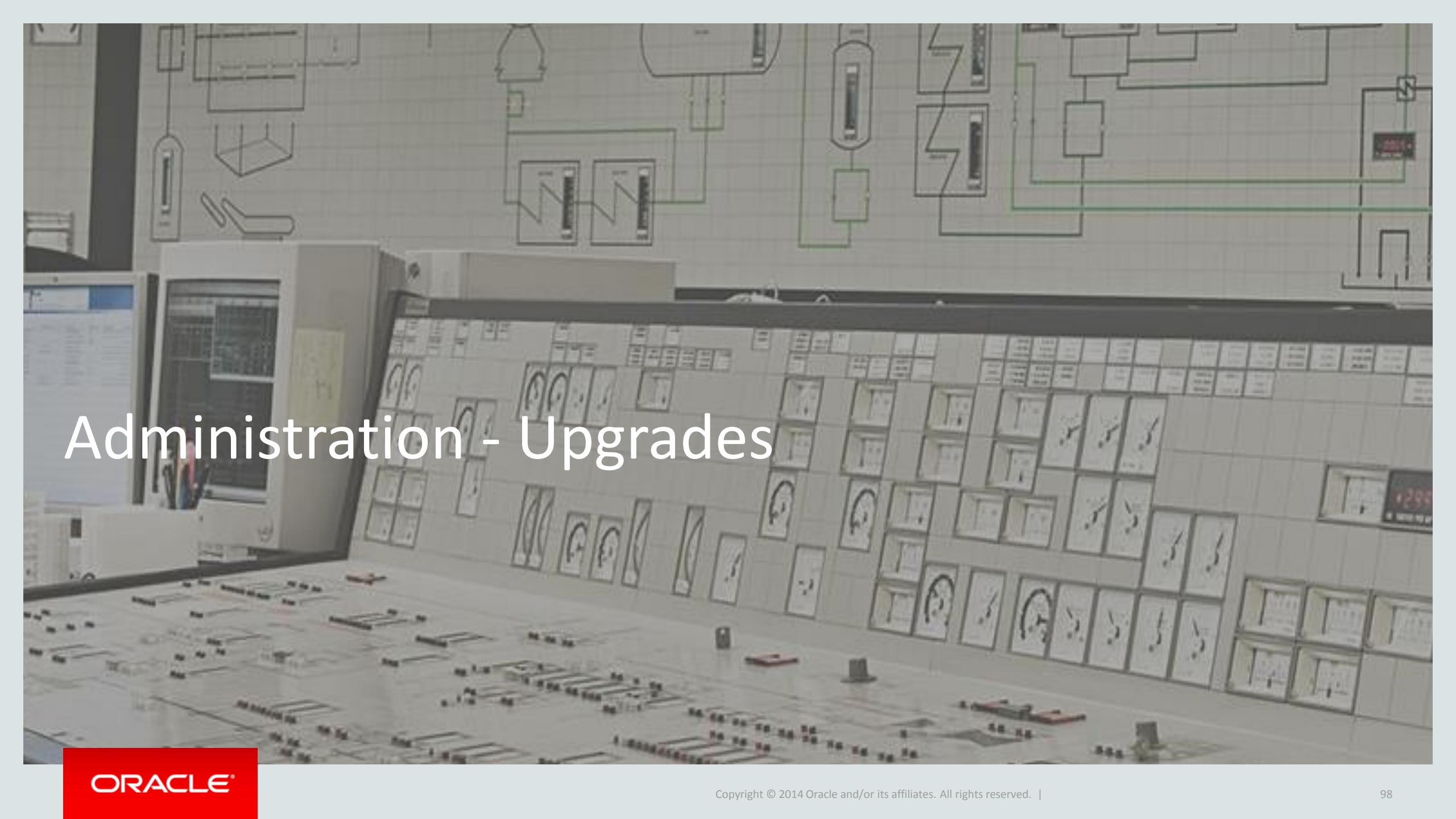
--exclude-databases=db3

- Restore selected tables:

--include-tables=db3.tb11

- Restore all but selected tables:

--exclude-tables=db1.tb12



Administration - Upgrades

Hot Database Upgrades

Alternatives

- In order to keep it Hot, a “Rolling Restart” is the best and only alternative:
 1. Stop all Cluster management nodes, replace `ndb_mgmd` binary with new version & restart them.
 2. Stop, replace and restart each data node, each in turn, one-by-one.
 3. Stop, replace and restart each sql node, in turn.
 - “Replace” being either redirecting to the new software install on the node (`In -s`, or using direct path).
 - “software” means the new Cluster distribution package, in “`mysql-cluster-gpl-7.3.6-linux-glibc2.5-i686`” format.

Hot Database Upgrades

Alternatives cont.

- Use MySQL Replication
 - Slave's can have a superior version compared to Master.
- If you want to use MySQL Cluster Manager:

```
mcm> add package --basedir=/opt/MCM_LAB/cluster-736 cluster736;  
mcm> upgrade cluster --package=cluster736 mycluster;
```



Highest Levels of Performance,
Security & Availability

MySQL Enterprise
Security

MySQL Enterprise
Audit

MySQL Enterprise
Scalability

MySQL Cluster
Manager

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Lifetime Support

Oracle Product
Certifications/Integrations

MySQL Enterprise
Monitor/Query Analyzer

MySQL Enterprise
Backup

MySQL Workbench



How Does MySQL Cluster Manager Help?

Initiating upgrade from MySQL Cluster 7.0 to 7.3



Before MySQL Cluster Manager

- 1 x preliminary check of cluster state
- 8 x ssh commands per server
- 8 x per-process stop commands
- 4 x scp of configuration files (2 x mgmd & 2 x mysqld)
- 8 x per-process start commands
- 8 x checks for started and re-joined processes
- 8 x process completion verifications
- 1 x verify completion of the whole cluster.
- Excludes manual editing of each configuration file.

*Total: 46 commands -
2.5 hours of attended operation*

With MySQL Cluster Manager

```
upgrade cluster --package=7.3 mycluster;
```

*Total: 1 Command -
Unattended Operation*

Enhancing DevOps Agility, Reducing Downtime



Automated Management

- Start / Stop node or whole cluster
- On-Line Scaling
- On-Line Reconfiguration
- On-Line Upgrades
- On-Line Backup & Restore
- Import Running Cluster

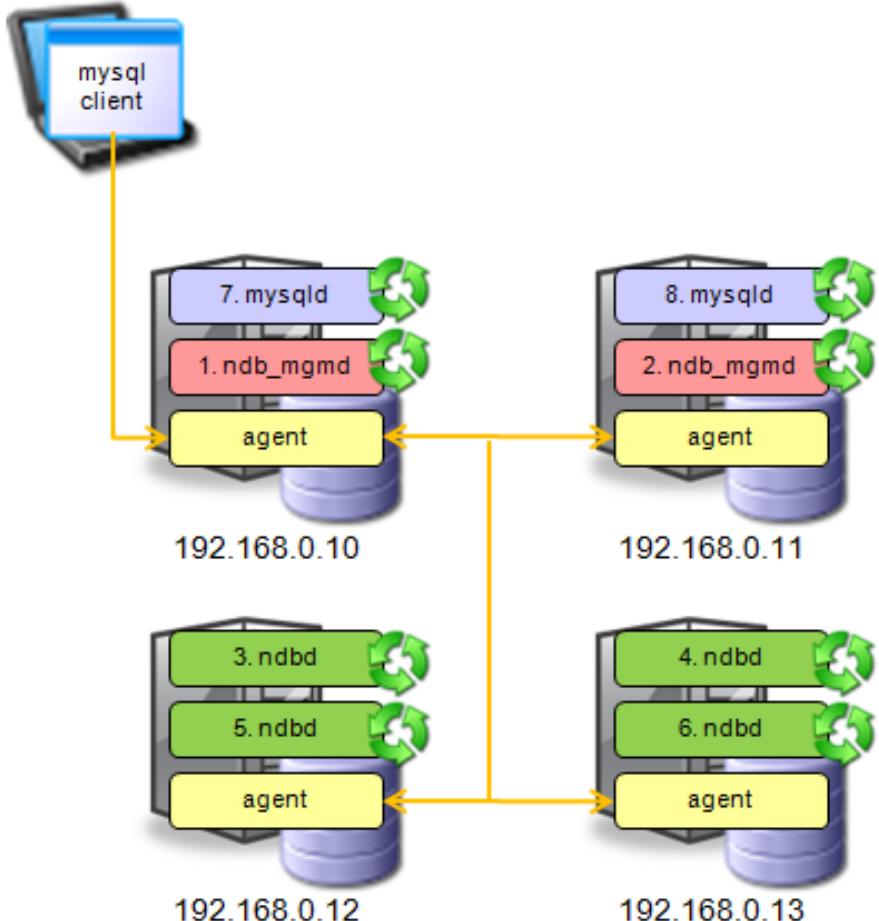
Self-Healing

- Node monitoring
- Auto-recovery extended to SQL + mgmt nodes

HA Operations

- Cluster-wide configuration consistency
- Persistent configurations
- HA Agents

MCM: Upgrade Cluster



```
mcm> upgrade cluster --package=cluster736  
mycluster;
```

Administration - Logs

Logfiles

- Logs
 - Management
 - Datadir: /opt/mysql/735/mgmd_data/ **ndb_1_cluster.log** / `ndb_1_out.log`
 - Datanodes
 - Datadir: /opt/mysql/735/ndbd_data/ **ndb_3_out.log** / `ndb_3_out.err`
 - SQLNodes
 - Datadir /opt/mysql/735/data/ **hostname.err**
- Errors
 - Cluster logfile **ndb_1_cluster.log** best starting point.

Logfile: configuring

- To write the cluster log in 1 or more destinations use LogDestination:
 - CONSOLE writes to same console where `ndb_mgmd` was launched.
 - FILE (default) can be relative or absolute: `filename=cluster_log` or `filename=/var/log/mysql-cluster`
 - `maxsize`= number of bytes at which it rotates. Default 1000000.
 - `maxfiles`= max number of log files. Default 6.
 - `LogDestination=FILE:filename=/var/log/mysql-cluster,maxsize=500000,maxfiles=15`
 - SYSLOG Can be used in conjunction with available facilities:
 - Sends the log to a syslog facility, possible values auth, authpriv, cron, daemon, ftp, kern, news, syslog, user, local0, local1 ... etc
- Sample: `CONSOLE;SYSLOG:facility=local0;FILE:filename=/var/log/mgmd`

Troubleshooting cluster logfile

- By default on, as mentioned before. There are other options:

CLUSTERLOG ON [<severity>] ...	Enable Cluster logging
CLUSTERLOG OFF [<severity>] ...	Disable Cluster logging
CLUSTERLOG TOGGLE [<severity>] ...	Toggle severity filter on/off
CLUSTERLOG INFO	Print cluster log information

- Changing this will only affect the management node you're connected to. Two different management nodes in the same cluster can have different settings.
- Use `clusterlog TOGGLE` to enable & disable different severities.

`severity = ALERT | CRITICAL | ERROR | WARNING | INFO | DEBUG`

(from most severe to least severe)

Troubleshooting

Event filtering

- Every event is in a Category, with a specific Severity and a Priority level.

category = STARTUP | SHUTDOWN | STATISTICS | CHECKPOINT | NODERESTART |
CONNECTION | INFO | ERROR | CONGESTION | DEBUG | BACKUP |
SCHEMA

level = 0 - 15 (0 only prints the most important messages,
15 prints all messages)

- Each category has a threshold, events with priority <= threshold will be recorded.
 - ERROR default threshold = 15 (records all events by default)
 - All other categories have default threshold = 7 (only events with priority level <= 7 will be reported)

Troubleshooting

Adjusting thresholds

- For example, to remove all reporting for category STARTUP on nodeid 3:

```
ndb_mgm> 3 CLUSTERLOG STARTUP=0
```

- To include all events in the STARTUP category for all nodes:

```
ndb_mgm> ALL CLUSTERLOG STARTUP=15
```

- List of events, ordered by category & severity:

<http://dev.mysql.com/doc/refman/5.7/en/mysql-cluster-log-events.html>

Logfiles: ndb_1_cluster.log

```
2014-05-22 10:35:14 [MgmtSrvr] INFO -- Got initial configuration from '/usr/local/mysql-cluster/conf/config.ini', will try to set it when all ndb_mgmd(s) started
2014-05-22 10:35:15 [MgmtSrvr] INFO -- Id: 1, Command port: *:1186
2014-05-22 10:35:15 [MgmtSrvr] INFO -- Node 1: Node 1 Connected
2014-05-22 10:35:15 [MgmtSrvr] INFO -- MySQL Cluster Management Server mysql-5.6.17 ndb-7.3.5 started
2014-05-22 10:35:15 [MgmtSrvr] INFO -- Node 1 connected
2014-05-22 10:35:15 [MgmtSrvr] INFO -- Starting initial configuration change
2014-05-22 10:35:15 [MgmtSrvr] INFO -- Configuration 1 committed
2014-05-22 10:35:15 [MgmtSrvr] INFO -- Config change completed! New generation: 1
2014-05-22 10:35:58 [MgmtSrvr] INFO -- Nodeid 3 allocated for NDB at 127.0.0.1
2014-05-22 10:35:59 [MgmtSrvr] INFO -- Node 1: Node 3 Connected
2014-05-22 10:36:01 [MgmtSrvr] INFO -- Nodeid 4 allocated for NDB at 127.0.0.1
2014-05-22 10:36:02 [MgmtSrvr] INFO -- Node 1: Node 4 Connected
2014-05-22 10:36:02 [MgmtSrvr] INFO -- Node 3: Initial start, waiting for 4 to connect, nodes [ all: 3 and 4 connected: 3 no-wait: ]
2014-05-22 10:36:02 [MgmtSrvr] INFO -- Node 4: Node 3 Connected
2014-05-22 10:36:02 [MgmtSrvr] INFO -- Node 3: Node 4 Connected
2014-05-22 10:36:02 [MgmtSrvr] INFO -- Node 3: Initial start with nodes 3 and 4 [ missing: no-wait: ]
...
2014-10-20 10:48:49 [MgmtSrvr] INFO -- Node 5: LQH: index 17 rebuild done
2014-10-20 10:48:49 [MgmtSrvr] INFO -- Node 5: LQH: Rebuild ordered indexes complete
...
2014-10-20 10:48:49 [MgmtSrvr] WARNING -- Failed to allocate nodeid for API at 127.0.0.1. Returned error: 'No free node id found for mysqld(API).'
2014-10-20 10:48:49 [MgmtSrvr] WARNING -- Failed to allocate nodeid for API at 127.0.0.1. Returned error: 'No free node id found for mysqld(API).' - Repeated 3 times
2014-10-20 10:48:50 [MgmtSrvr] INFO -- Node 3: Local checkpoint 28 started. Keep GCI = 29779 oldest restorable GCI = 29397
2014-10-20 10:48:50 [MgmtSrvr] WARNING -- Failed to allocate nodeid for API at 127.0.0.1. Returned error: 'No free node id found for mysqld(API).'
2014-10-20 10:48:52 [MgmtSrvr] WARNING -- Failed to allocate nodeid for API at 127.0.0.1. Returned error: 'No free node id found for mysqld(API).' - Repeated 3 times
2014-10-20 10:48:53 [MgmtSrvr] INFO -- Node 3: Local checkpoint 28 completed
...
2014-10-20 14:37:44 [MgmtSrvr] INFO -- Node 5: ParticipatingLQH = 0000000000000000
2014-10-20 14:37:44 [MgmtSrvr] INFO -- Node 5: m_LCP_COMPLETE REP_Counter_DIH = [SignalCounter: m_count=0 0000000000000000]
2014-10-20 14:37:44 [MgmtSrvr] INFO -- Node 5: m_LCP_COMPLETE REP_Counter_LQH = [SignalCounter: m_count=0 0000000000000000]
2014-10-20 14:37:44 [MgmtSrvr] INFO -- Node 5: m_LAST_LCP_FRAG_ORD = [SignalCounter: m_count=0 0000000000000000]
2014-10-20 14:37:44 [MgmtSrvr] INFO -- Node 5: m_LCP_COMPLETE REP_From_Master_Received = 1
2014-10-20 14:37:44 [MgmtSrvr] INFO -- Node 5: LCP Take over completed (state = 4)
2014-10-20 14:37:44 [MgmtSrvr] INFO -- Node 5: ParticipatingDIH = 0000000000000000
2014-10-20 14:37:44 [MgmtSrvr] INFO -- Node 5: ParticipatingLQH = 0000000000000000
2014-10-20 14:37:44 [MgmtSrvr] INFO -- Node 5: m_LCP_COMPLETE REP_Counter_DIH = [SignalCounter: m_count=0 0000000000000000]
2014-10-20 14:37:44 [MgmtSrvr] INFO -- Node 5: m_LCP_COMPLETE REP_Counter_LQH = [SignalCounter: m_count=0 0000000000000000]
2014-10-20 14:37:44 [MgmtSrvr] INFO -- Node 5: m_LAST_LCP_FRAG_ORD = [SignalCounter: m_count=0 0000000000000000]
2014-10-20 14:37:44 [MgmtSrvr] INFO -- Node 5: m_LCP_COMPLETE REP_From_Master_Received = 1
2014-10-20 14:37:44 [MgmtSrvr] ALERT -- Node 4: Node 3 Disconnected
2014-10-20 14:37:44 [MgmtSrvr] INFO -- Node 5: GCP Monitor: unlimited lags allowed
2014-10-20 14:37:44 [MgmtSrvr] INFO -- Node 5: GCP Take over completed
2014-10-20 14:37:44 [MgmtSrvr] INFO -- Node 5: kk: 35115/10 0 0
2014-10-20 14:37:44 [MgmtSrvr] ALERT -- Node 5: Node 3 Disconnected
2014-10-20 14:37:44 [MgmtSrvr] INFO -- Node 3: Node shutdown completed.
2014-10-20 14:37:47 [MgmtSrvr] INFO -- Node 6: Communication to Node 3 opened
2014-10-20 14:37:48 [MgmtSrvr] INFO -- Node 5: Communication to Node 3 opened
2014-10-20 14:37:48 [MgmtSrvr] INFO -- Node 4: Communication to Node 3 opened
```

For baseline understanding:

- **WARNING & INFO** is normal cluster activity.

For error investigation:

- Isolate time period.
- Focus on **ERROR, CRITICAL & ALERT** events.
- Check time differences between events.

Logfiles:

ndb_3_out.log

```
2014-05-22 10:35:59 [ndbd] INFO -- Angel pid: 12371 started child: 12372
2014-05-22 10:35:59 [ndbd] INFO -- Configuration fetched from 'localhost:1186', generation: 1
NDBMT: non-mt
2014-05-22 10:35:59 [ndbd] INFO -- NDB Cluster -- DB node 3
2014-05-22 10:35:59 [ndbd] INFO -- mysql-5.6.17 ndb-7.3.5 --
2014-05-22 10:35:59 [ndbd] INFO -- numa_set_interleave_mask(numa_all_nodes) : OK
2014-05-22 10:35:59 [ndbd] INFO -- Ndbslave_mem_manager::init(1) min: 78Mb initial: 78Mb
Adding 36Mb to ZONE_LO (1,1151)
Instantiating DBSPJ instanceNo=0
Started thread, index = 0, id = 12375, type = SocketClientThread
Started thread, index = 1, id = 12374, type = WatchDogThread
Started thread, index = 2, id = 12376, type = SocketServerThread
2014-05-22 10:35:59 [ndbd] INFO -- Start initiated (mysql-5.6.17 ndb-7.3.5)
NDBFS/AsyncFile: Allocating 310392 for In/Deflate buffer
Started thread, index = 4, id = 12377, type = NdbfsThread
.

RESTORE table: 15 3021 rows applied
RESTORE table: 15 3032 rows applied
RedoPageCache: avoided 0 (0/0) page-reads
RedoOpenFileCache: Avoided 0 file-open/close closed: 0
Dbspj::execSTTOR() inst:0 phase=4
2014-10-20 10:48:49 [ndbd] INFO -- Start phase 4 completed
2014-10-20 10:48:53 [ndbd] INFO -- Start phase 5 completed
2014-10-20 10:48:53 [ndbd] INFO -- Start phase 6 completed
2014-10-20 10:48:53 [ndbd] INFO -- President restarts arbitration thread [state=1]
m_active_buckets.set(0)
2014-10-20 10:48:53 [ndbd] INFO -- Start phase 7 completed
2014-10-20 10:48:53 [ndbd] INFO -- Start phase 8 completed
2014-10-20 10:48:53 [ndbd] INFO -- Start phase 9 completed
2014-10-20 10:48:53 [ndbd] INFO -- Start phase 100 completed
2014-10-20 10:48:53 [ndbd] INFO -- Start phase 101 completed
2014-10-20 10:48:53 [ndbd] INFO -- Node started
2014-10-20 10:48:54 [ndbd] INFO -- Started arbitrator node 1 [ticket=6bcd00010ef206a4]
alloc_chunk(1492 16) -
2014-10-20 13:41:58 [ndbd] WARNING -- timerHandlingLab, expected 10ms sleep, not scheduled for: 2395 (ms)
2014-10-20 13:41:58 [ndbd] WARNING -- Time moved forward with 2386 ms
2014-10-20 13:41:58 [ndbd] INFO -- Watchdog: User time: 3543 System time: 5435
2014-10-20 13:41:58 [ndbd] WARNING -- Watchdog: Warning overslept 2475 ms, expected 100 ms.
.
2014-10-20 14:37:37 [ndbd] INFO -- Suma: handover to node 4 gci: 35115 buckets: 00000001 (2)
35115/0 (35114/4294967295) switchover complete bucket 0 state: 100 shutdown handover
2014-10-20 14:37:44 [ndbd] INFO -- Shutdown initiated
2014-10-20 14:37:44 [ndbd] INFO -- Shutdown completed - exiting
2014-10-20 14:37:44 [ndbd] INFO -- Angel shutting down
2014-10-20 14:37:44 [ndbd] INFO -- Node 3: Node shutdown completed.
```

ndb_4_out.log

```
2014-05-22 10:36:01 [ndbd] INFO -- Angel pid: 12381 started child: 12382
2014-05-22 10:36:01 [ndbd] INFO -- Configuration fetched from 'localhost:1186', generation: 1
NDBMT: non-mt
2014-05-22 10:36:02 [ndbd] INFO -- NDB Cluster -- DB node 4
2014-05-22 10:36:02 [ndbd] INFO -- mysql-5.6.17 ndb-7.3.5 --
2014-05-22 10:36:02 [ndbd] INFO -- numa_set_interleave_mask(numa_all_nodes) : OK
2014-05-22 10:36:02 [ndbd] INFO -- Ndbslave_mem_manager::init(1) min: 78Mb initial: 78Mb
Adding 36Mb to ZONE_LO (1,1151)
Instantiating DBSPJ instanceNo=0
Started thread, index = 0, id = 12385, type = SocketClientThread
Started thread, index = 1, id = 12384, type = WatchDogThread
Started thread, index = 2, id = 12386, type = SocketServerThread
2014-05-22 10:36:02 [ndbd] INFO -- Start initiated (mysql-5.6.17 ndb-7.3.5)
NDBFS/AsyncFile: Allocating 310392 for In/Deflate buffer
Started thread, index = 4, id = 12387, type = NdbfsThread
.

RESTORE table: 10 0 rows applied
RESTORE table: 15 3021 rows applied
RESTORE table: 15 3032 rows applied
RedoPageCache: avoided 0 (0/0) page-reads
RedoOpenFileCache: Avoided 0 file-open/close closed: 0
Dbspj::execSTTOR() inst:0 phase=4
2014-10-20 10:48:49 [ndbd] INFO -- Start phase 4 completed
2014-10-20 10:48:53 [ndbd] INFO -- Start phase 5 completed
2014-10-20 10:48:53 [ndbd] INFO -- Start phase 6 completed
2014-10-20 10:48:53 [ndbd] INFO -- Start phase 7 completed
m_active_buckets.set(1)
2014-10-20 10:48:53 [ndbd] INFO -- Start phase 8 completed
2014-10-20 10:48:53 [ndbd] INFO -- Start phase 9 completed
2014-10-20 10:48:53 [ndbd] INFO -- Start phase 100 completed
2014-10-20 10:48:53 [ndbd] INFO -- Start phase 101 completed
2014-10-20 10:48:53 [ndbd] INFO -- Node started
2014-10-20 10:48:54 [ndbd] INFO -- Prepare arbitrator node 1 [ticket=6bcd00010ef206a4]
alloc_chunk(1492 16) -
2014-10-20 13:41:58 [ndbd] WARNING -- Time moved forward with 2387 ms
2014-10-20 13:41:58 [ndbd] WARNING -- timerHandlingLab, expected 10ms sleep, not scheduled for: 2389 (ms)
2014-10-20 13:41:58 [ndbd] INFO -- Watchdog: User time: 2908 System time: 3960
2014-10-20 13:41:58 [ndbd] WARNING -- Watchdog: Warning overslept 2482 ms, expected 100 ms.
prepare to takeover bucket: 0
35115/0 (35114/4294967295) switchover complete bucket 0 state: 200 shutdown takeover
2014-10-20 14:37:44 [ndbd] INFO -- findNeighbours from: 4882 old (left: 5 right: 6) new (5 6)
Finished with handling node-failure
```

Administration

- Data nodes – designed for zero maintenance.
 - Logs
 - Writes error logs and trace files in its data directory.
 - Configurable how many error messages/trace files that should be saved
 - Memory Fragmentation
 - Free pages are reclaimed and can be reused
 - If you do a lot of insert/delete on VAR* attributes (of different sizes) you can get fragmentation
 - OPTIMIZE TABLE / Rolling restart of data nodes can help reduce fragmentation
- Management servers
 - Writes cluster log (rotating, size configurable) in its data directory
 - Cluster logs can be sent to Syslog if desired

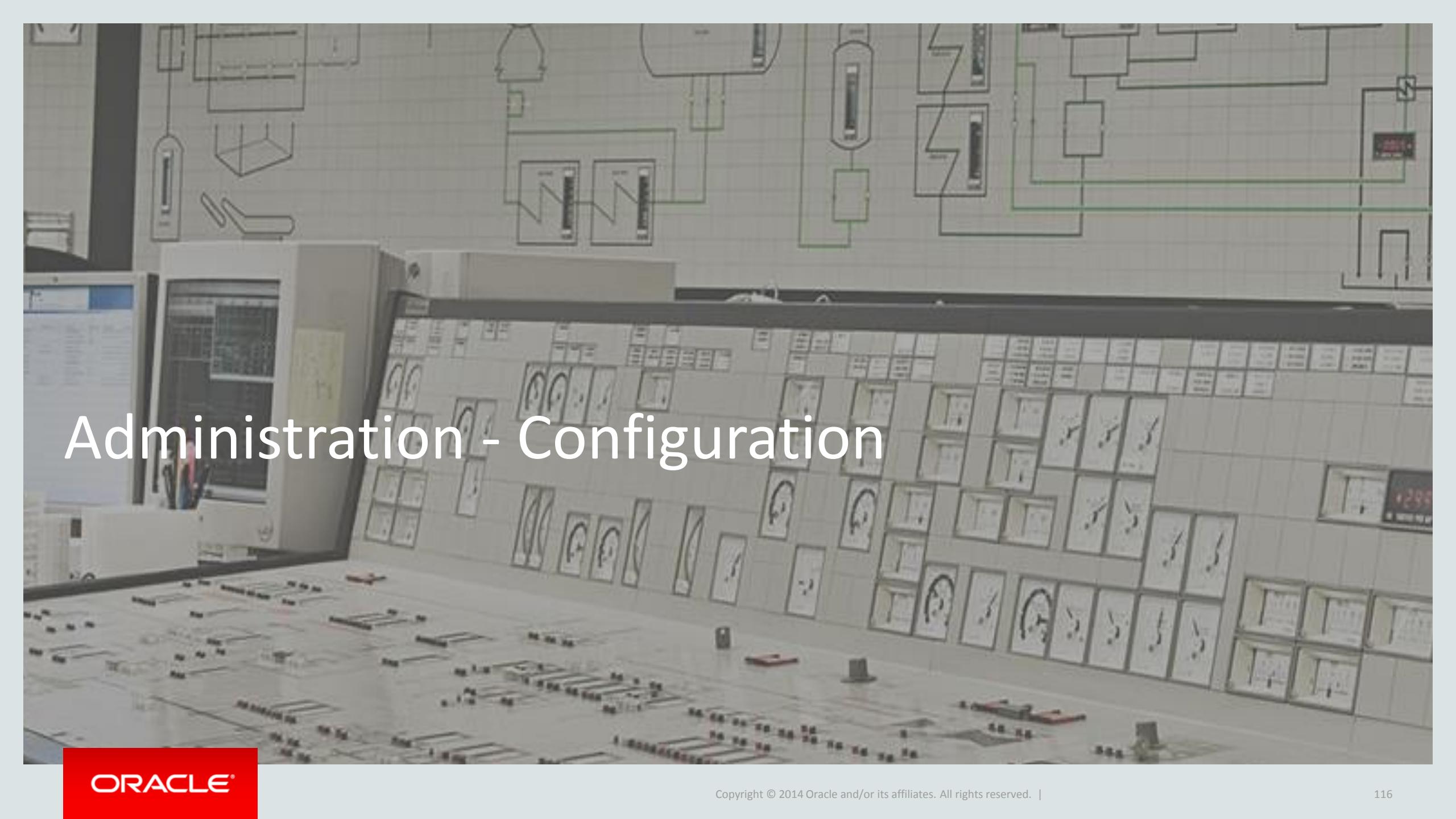
Administration

- MySQL Servers
 - Binary logs - (if enabled) normally removed manually, can be done with -- expire_logs_days but are you sure they have all been applied on the slave?
 - General log / error log / slow log - does not rotate automatically. A script called mysql_log_rotate can help.
 - Or move/cp log manually (or scripted) and do FLUSH LOGS
 - For MySQL Cluster it is also good to have a MySQL Server for administration purposes.
 - Perform offline ALTER TABLE (like change data type etc)
 - Export all non-NDB objects & procedures.

Administration

debugging

- `ndbmtd --nodaemon / --foreground` so it doesn't become a bg process, displaying output to the console.
- `ndb_node_id_trace.log.trace_id` is the trace file generated after an error.
- `ndb_mgm> clusterlog on debug`



Administration - Configuration

Configuration

Users & permissions

- Ensure all sqlnodes / mysqld's have the same user grant tables
 - share/ndb_dist_priv.sql
 - Run from 1 sqlnode
 - Propagates to all other sqlnodes, the same mysql.user contents.
 - Converts user table from MYISAM to NDBCLUSTER.
 - Standard procedures convert existing users to every other sqlnode.
 - Changes storage engine for mysql.user table to NDBCLUSTER.
 - Careful of “Diskless=TRUE” when doing this.

Configuration Network

- [tcp] section for direct connections between nodes.

```
[tcp]  
NodeId1=3  
Hostname=10.0.0.3  
NodeId2=4  
Hostname=10.0.0.4
```

- Other options [sci] & [shm].
- Use `ndbmtd --bind-address=192.168.56.18` to bind to a specific network interface.

Datanodes

- NDB - single threaded data node for TELCO platforms
- NDBMTD - multi-threaded data nodes for general use.
- Data nodes are made up several components:
 - LDM (Local Data Manager)
 - LQH, local query handler, local transaction management, local data operations.
 - ACC, Access control, lock manager
 - TUP, tuple manager, manages physical storage of data (read, insert, update, delete, and monitoring changes of tuples)
 - TC (Transaction Coordinator)
 - Keeps track of user transactions
 - Handle native NDB transactions cross the cluster

NDB Threads I

- **LDM threads**
 - Number of LDM threads should be same in all nodes.
 - Changing number of LDM threads is hard and requires rebuild of tables.
 - Up to 32 LDM threads is supported
- **NoOfFragmentLogParts:**
 - Number of REDO log parts for NDB.
 - **Each** LDM need to have at least one dedicated REDO log part.

NDB Threads II

- TC (Transaction Coordinator) threads
 - Normally 25% of LDM threads but up to 100% for write intense applications
- Send threads
 - Handles sending distributed signals, 2-3 is good enough.
- Receive threads
 - Handles reception of distributed signals, 2-3 is good enough.
- IO threads, handles disk IO, depending on disks.
- Main and replication threads, one of each.

NDB Threads III

- Prior to 7.2 only way to configure multiple threads was to use MaxNoOfExecutionThreads
 - MAX value 8 means 1 TC, 1 send/recs, 1 SUMA and 4 LQH thread.
 - With NDB 7.5 we support ranges up to max 72 threads
- With 7.2 and onwards you can use ThreadConfig = main={count=1}, tc={count=2}, ldm={count=4}, recv={count=1}, io={count=1}, send={count=1} ,rep={count=1}
 - Using ThreadConfig we can also pin processes to specific cores by specifying options cpubind like ldm={count=4, cpubind=1-4}

Getting “high-end” 4 BN Reads per minute

- 30 data nodes
 - Hashmap grown from 240 to 3840 virtual partitions
- Locking threads to CPUs (ThreadConfig)
 - LDM/TC/Send/Receive/IO threads
- Jemalloc and sendBufferMemory
- Infiniband/10G (Enet/1G Enet)
- Numactl (Control process use of CPUs)
- NDB API Multi-connect

Configuration

- Any existing errors being reported frequently? (DataMemory or IndexMemory warnings in `ndb_1_cluster.log`)
- “Hot” data set heading towards 3Tb?
 - Replicate cold / historic data to InnoDB.
- RAID 10, read-write or 5, read intensive.
- `MaxNoOfExecutionThreads=16`
- Multi-threading / ThreadConfig
 - for example:
 - `ThreadConfig=ldm={cpubind=0,1,2,3},tc={cpubind=4,20},main={cpubind=5},rep={cpubind=5},io={cpubind=21},send={cpubind=6,23},recv={cpubind=7,23}`

	24 threads	32 threads	40 threads	48 thread
ldm	8	12	16	16
tc	4	6	8	12
recv	3	3	4	5
send	3	3	4	4
rep	1	1	1	1

Security

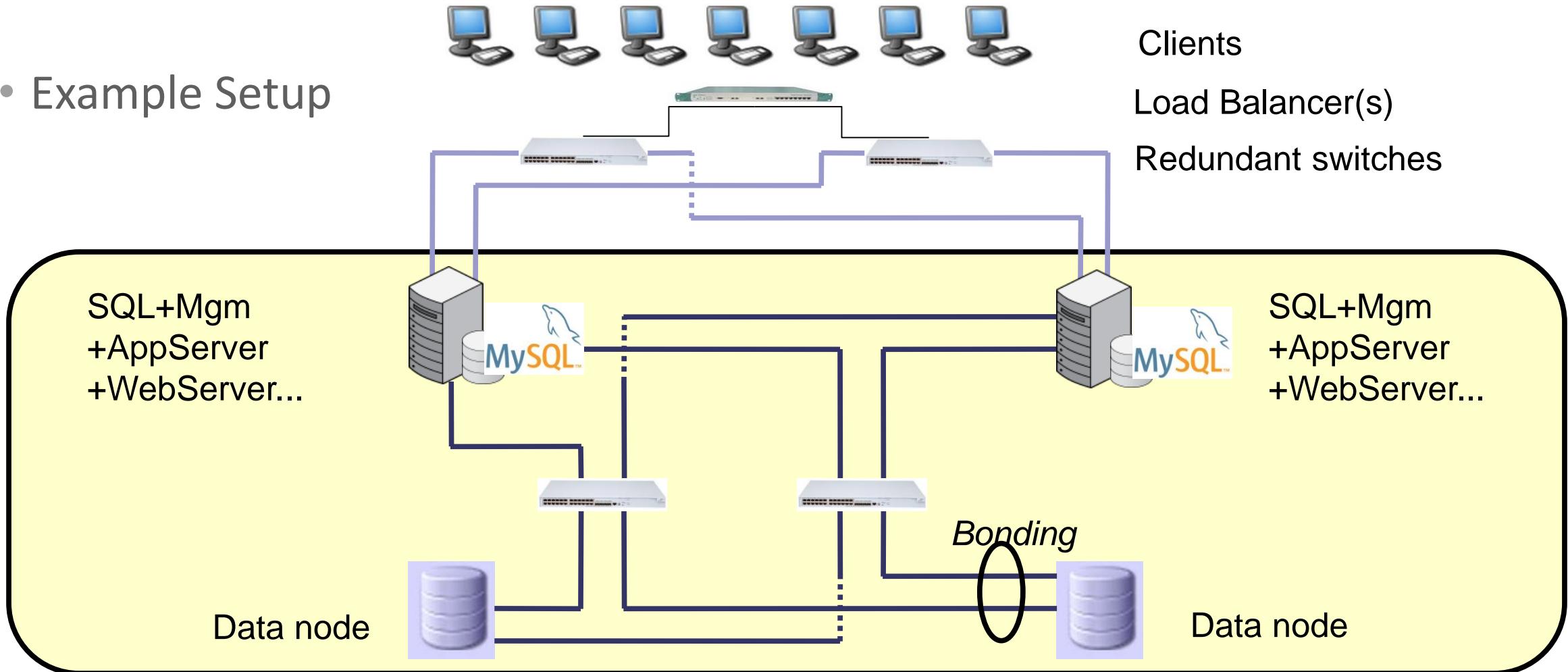
- Basics:
 - Make sure all [api] / [mysqld] entries in config.ini have a hostname assigned.
 - Locally installed firewall rules only allow access from the specific networks & IP's ranges. Port 1186 only accessible from specific nodes.
- Patching Policy
 - Will depend heavily on Development Teams Roadmap & Go-To-Market.
 - Understand Oracle MySQL's policy on Support and Release frequency.

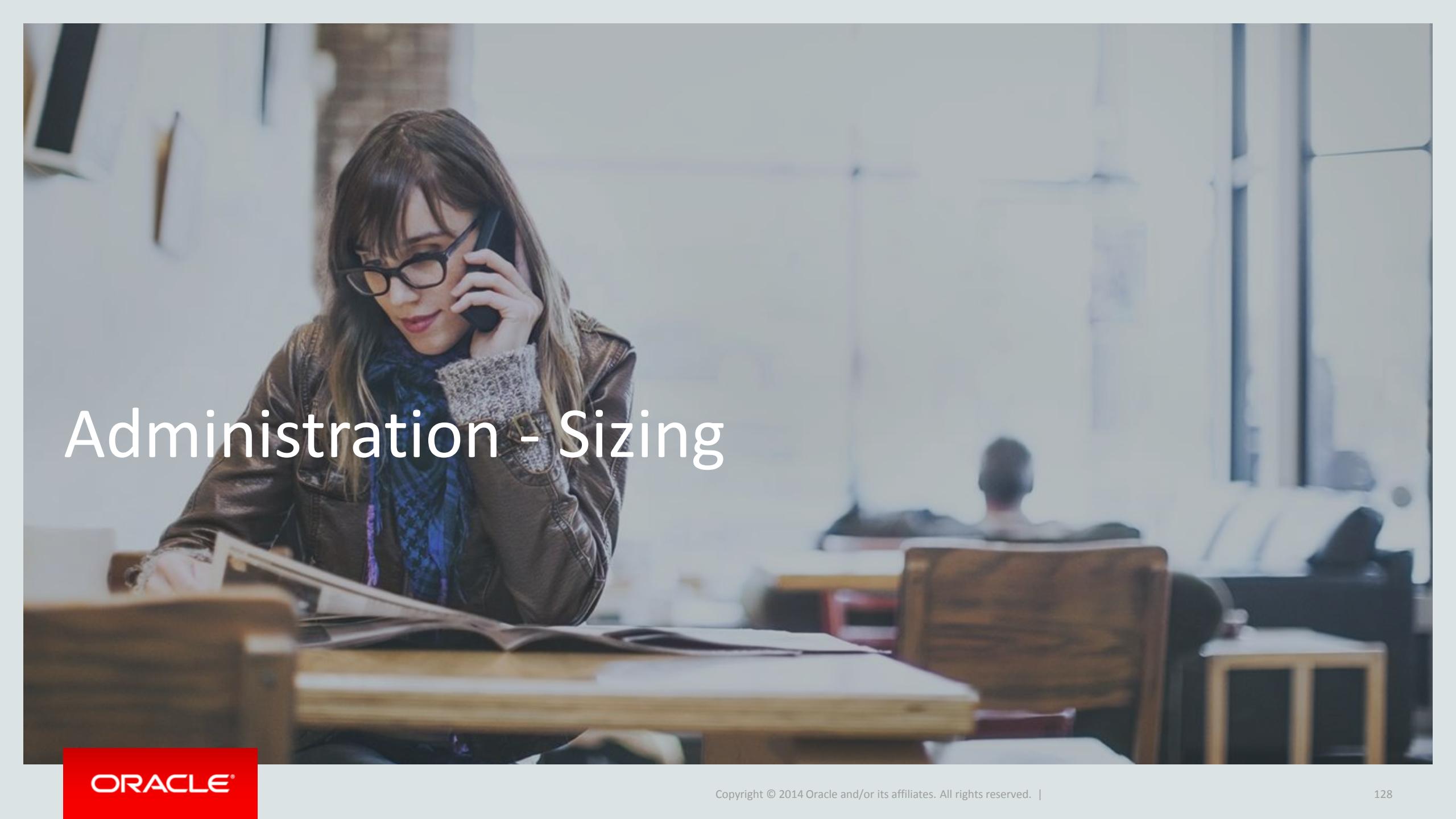
Networking

- NDB API & NDB_MGM don't support IPv6.
 - MUST have all connections originating in IPv4, between ndbd, ndb_mgmd & ndb_mgm plus all API's.
 - MySQL Servers (mysqld) do / can use it to connect to other sqlnodes.
- Transporters
 - Traditional Ethernet or Infiniband (IPoIB)
- Number of NIC's per data node (High Availability):
 - 2 with bonding
- Dedicated Subnet for Datanodes:
 - dual Switches.
- Ports open / default values
 - ServerPort between sqlnodes & datanodes? FW?

Networking

- Example Setup



A photograph of a woman with long brown hair and glasses, wearing a dark leather jacket over a blue patterned scarf. She is sitting at a wooden desk, holding a black cordless phone to her ear with her right hand and looking down at a stack of papers or books on the desk. In the background, there is a window showing a city skyline, and another person is visible sitting at a desk in the distance.

Administration - Sizing

Best Practices - Sizing Tips

Data set

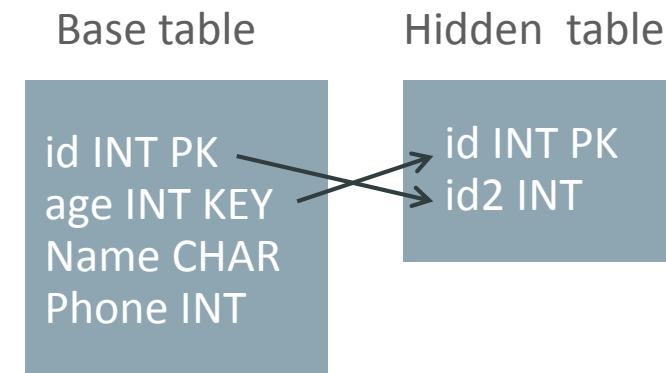
Data Type	Size
VARCHAR(n) and VARBINARY(n)	n + 2 rounded up to next 4 byte boundary
CHAR(n) and BINARY(n)	n rounded up to the next 4 byte boundary
BLOB/TEXT(n)	n < 256 then n, otherwise: 256 + (n-256) rounded up to the next multiple of 2000. For each BLOB column an extra table is used to store the BLOB overflow data in 2000B chunks.
DATE	4
INT	4
BIGINT	8

<http://dev.mysql.com/doc/refman/5.6/en/storage-requirements.html>

Best Practices - Sizing Tips

Data set

- Fixed overhead per row for data memory is 16 bytes.
 - 4 extra bytes if you have any nullable columns in your tables
 - 8 extra bytes for each BLOB column
- Every MySQL cluster table must have a primary key. Every PK creates a hash index (HI) which has a size of 20 bytes
- Every Ordered Index has a size of 16 bytes (resides inside DM)
- Every UK creates a new “hidden” cluster table with the UK column as PK and the originating tables PK as an value column.



Best Practices - Sizing Tips

Data set “example”

```
CREATE TABLE example (
    IDX INT PRIMARY KEY,
    Col1 VARCHAR(13),
    Col2 INT,
    UNIQUE INDEX (Col2)
    /* USING HASH */
) ENGINE=ndbcluster;
```

Column	Size	Size in NDB
IDX	4	4
Col1	13	16
Col2	4	4
Total		24

- PK 20 bytes per row
- Unique key (own table 4+4+20) per row
- Ordered index on Col2 16 bytes (can be avoided)
- DM = $24 + 8 + 16 = 48$ bytes
- IM = $20 + 20 = 40$ bytes
- Total row size $24 + 20 + 28 + 16 = 88$ bytes

Best Practices - Sizing Tips

Memory

- Calculate data set in un-clustered setup, divide by number of datanodes.
 - DataMemory x3 data set (guesstimate)
 - IndexMemory x 0.25 of data set (guesstimate)
- `ndb_mgm> all report memoryusage <- And monitor.`
- `mysql> select * from ndbinfo.memoryusage;`

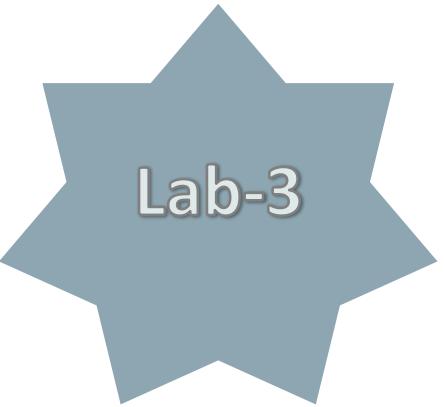
Best Practices - Sizing Tips

Disk

- Datanode `datadir`: local checkpoints, trace files, log files, PID files & error log.
 - LCP: $2 \times \text{sizeof}(\text{used DataMemory})$
- `FileSystemPath`: metadata files, REDO & UNDO logs & Data files. By default, subdirectory in `datadir` “`ndb_NodeID_fs`”.
 - REDO: [4-6] x DataMemory
 - More (6x) REDO log for write intensive
 - Don't have a too short REDO (e.g 2x or 3x)
- `BackupDir`: default = `FileSystemPath`, where backups are placed taken from `ndb_mgm` console.
 - Backups: `sizeof(used DataMemory)`
 - TableSpace (if disk data tables): Must fit dataset.

MCM Hands On Lab

3 Backup and Restore



- Lab-3
 - <https://github.com/wwwted/ndb-cluster-workshop>

Program Agenda

- 1 ➤ Introduction
- 2 ➤ Getting started: configuration/install/start/stop
- 3 ➤ Administration: backup/upgrade/logs/conf/sizing
- 4 ➤ **Monitoring, surveillance and solving problems**
- 5 ➤ Best practices, architectures and case studies
- 6 ➤ Geo-replication

Monitoring Tools

- **ndb_mgm**
 - all status | all report memoryusage | 3 status | 4 report memory
- **ndbinfo schema / ndbinfo_select_all**
- **ndb_desc**
 - View types of indexes created, i.e. if using hash was included with PK.
 - View partitioning information on specific tables
- **ndb_config**
 - --config-info
 - --q NodeId,HostName,NoOfReplicas,DataMemory --type=ndbd
- **ndb_mgmd -print-full-config**

Monitoring Tools continued.

- `ndb_show_tables`
- `ndb_desc -p -d<db> <table>`
- `ndb_select_count` `ndb_delete_all` `ndb_select_all`
– `ndb_select_count -d test city`
- `ndb_index_stat` to view & modify index stats
- MySQL Workbench
- MySQL Enterprise Monitor

Monitoring Tools

ndbinfo / ndbinfo_select_all

```
mysql> show engines;  
mysql> show tables from ndbinfo;  
mysql> SELECT * from ndbinfo.memoryusage;  
mysql> SELECT * from ndbinfo.cluster_transactions;  
mysql> SELECT * from ndbinfo.cluster_operations;
```

- Mapping above to a mysql connection:

```
mysql> SELECT * from performance_schema.threads where  
TYPE="FOREGROUND";  
mysql> SELECT * from ndbinfo.server_operations;
```

- Low level view of what is happening:

```
mysql> SELECT * from ndbinfo.counters;
```

Monitoring Tools

ndb_desc

```
$ ndb_desc -d test City -p
-- City --
Version: 16777218
Fragment type: HashMapPartition
K Value: 6
Min load factor: 78
Max load factor: 80
Temporary table: no
Number of attributes: 5
Number of primary keys: 1
Length of frm data: 369
Row Checksum: 1
Row GCI: 1
SingleUserMode: 0
ForceVarPart: 1
FragmentCount: 4
ExtraRowGciBits: 0
ExtraRowAuthorBits: 0
TableStatus: Retrieved
HashMap: DEFAULT-HASHMAP-3840-4
-- Attributes --
ID Int PRIMARY KEY DISTRIBUTION KEY AT=FIXED ST=MEMORY AUTO_INCR
Name Char(35;latin1_swedish_ci) NULL AT=FIXED ST=MEMORY DEFAULT ""
CountryCode Char(3;latin1_swedish_ci) NOT NULL AT=FIXED ST=MEMORY DEFAULT ""
District Char(20;latin1_swedish_ci) NOT NULL AT=FIXED ST=MEMORY DEFAULT ""
Population Int NOT NULL AT=FIXED ST=MEMORY DEFAULT 0
-- Indexes --
PRIMARY KEY(ID) - UniqueHashIndex
CountryCode(CountryCode) - OrderedIndex
PRIMARY(ID) - OrderedIndex
-- Per partition info --
Partition  Row count  Commit count      Frag fixed memory      Frag varsized memory      Extent_space      Free extent_space
0          3021       3021             360448                  0                   0                   0                   0
2          3032       3032             360448                  0                   0                   0                   0
1          3027       3027             360448                  0                   0                   0                   0
3          3005       3005             360448                  0                   0                   0                   0
```

Monitoring Tools

ndb_mgmd

```
$ ndb_mgmd -f /usr/local/mysql-cluster/conf/config.ini --config-dir=/usr/local/mysql-cluster --print-full-config
```

```
MySQL Cluster Management Server mysql-5.6.17 ndb-7.3.5
[SYSTEM]
Name=MC_20141020173233
PrimaryMGMNode=1
ConfigGenerationNumber=0
[ndb_mgmd (MGM) ]
HostName=khollman-es
DataDir=/opt/mysql/735/mgmd_data
NodeId=1
PortNumber=1186
ArbitrationRank=1
ArbitrationDelay=0
ExtraSendBufferMemory=0
TotalSendBufferMemory=0
HeartbeatIntervalMgmdMgmd=1500
[mysqld (API) ]
HostName=
NodeId=10
ArbitrationRank=0
ArbitrationDelay=0
MaxScanBatchSize=262144
BatchByteSize=16384
BatchSize=256
ExtraSendBufferMemory=0
TotalSendBufferMemory=0
AutoReconnect=1
```

```
DefaultOperationRedoProblemAction=1
DefaultHashmapSize=0
[mysqld (API) ]
HostName=
NodeId=11
ArbitrationRank=0
ArbitrationDelay=0
MaxScanBatchSize=262144
BatchByteSize=16384
BatchSize=256
ExtraSendBufferMemory=0
TotalSendBufferMemory=0
AutoReconnect=1
DefaultOperationRedoProblemAction=1
DefaultHashmapSize=0
[mysqld (API) ]
HostName=
NodeId=12
ArbitrationRank=0
ArbitrationDelay=0
MaxScanBatchSize=262144
BatchByteSize=16384
BatchSize=256
ExtraSendBufferMemory=0
TotalSendBufferMemory=0
AutoReconnect=1
DefaultOperationRedoProblemAction=1
DefaultHashmapSize=0
.....
```

Workbench

MySQL Workbench

MCM_Cluster_mysql50

File Edit View Query Database Server Tools Scripting Help

MANAGEMENT

- Server Status
- Client Connections
- Users and Privileges
- Status and System Variable
- Data Export
- Data Import/Restore

INSTANCE

- Startup / Shutdown
- Server Logs
- Options File

PERFORMANCE

- Dashboard
- Performance Reports
- Performance Schema Setup

MySQL ENTERPRISE

- Online Backup
- Backup Recovery
- Audit Inspector

SCHEMAS

- Filter objects
- information_schema
- ndbinfo
- performance_schema
- test

Query 1 × Administration - Server Status

Connection Name: MCM_Cluster_mysql50

Host: khollman-es
Socket: /tmp/mysql.mycluster.50.sock
Port: 3306
Version: 5.6.17-ndb-7.3.5-cluster-commercial-advanced
MySQL Cluster Server - Advanced Edition (Commercial)
Compiled For: linux-glibc2.5 (x86_64)
Running Since: Mon Nov 17 22:29:13 2014 (0:11)

Refresh

Available Server Features

Performance Schema:	<input checked="" type="radio"/> On	SSL Availability:	<input type="radio"/> Off
Thread Pool:	<input type="radio"/> n/a	PAM Authentication:	<input type="radio"/> Off
Memcached Plugin:	<input type="radio"/> n/a	Password Validation:	<input type="radio"/> n/a
Semisync Replication Plugin:	<input type="radio"/> n/a	Audit Log:	<input type="radio"/> n/a

Server Directories

Base Directory:	/opt/MCM_LAB/cluster-735
Data Directory:	/opt/MCM_LAB/mcm_data/clusters/mycluster/50/data/
Disk Space in Data Dir:	17G of 87G available
Plugins Directory:	/usr/local/mcm_lab/cluster-735/lib/plugin/
Tmp Directory:	/opt/MCM_LAB/mcm_data/clusters/mycluster/50/tmp
Error Log:	<input checked="" type="radio"/> On /opt/MCM_LAB/mcm_data/clusters/mycluster/50/data/mysql50_out.err
General Log:	<input type="radio"/> Off
Slow Query Log:	<input type="radio"/> Off

Replication Slave

this server is not a slave in a replication setup

Management connect for target host enabled successfully

Server Status: Running

Load: 0.71

Connections: 4

Traffic: 12.89 KB/s

Key Efficiency: 85.7%

Queries per Second: 0

InnoDB Buffer Usage: 1.8%

InnoDB Reads per Second: 0

InnoDB Writes per Second: 0

MySQL Enterprise Monitor

ORACLE MySQL Enterprise Monitor

mycluster All Targets

10 3 1 1 1 1 admin Refresh Off Legend

Overview Topology Events

Metrics Queries Replication Backups Configuration Help

mycluster

NDB Management

- mycluster-mgmd1 NDB Version: 7.6.3 Status: CONNECTED
- mycluster-mgmd2 NDB Version: 7.6.3 Status: CONNECTED

NDB API

- NDB API Node 10 NDB Version: N/A
- mycluster-sq17:3306 NDB Version: 7.6.3 Process: mysqld
- mycluster-sq18:3306 NDB Version: 7.6.3 Process: mysqld
- NDB API Node 9 NDB Version: 7.6.3 Process: mysqld

NDB Data

- NDB Data Node Group 0
 - mycluster-ndbmtd3 NDB Version: 7.6.3 Status: STARTED
 - mycluster-ndbmtd4 NDB Version: 7.6.3 Status: STARTED
- NDB Data Node Group 1
 - mycluster-ndbmtd5 NDB Version: 7.6.3 Status: STARTED
 - mycluster-ndbmtd6 NDB Version: 7.6.3 Status: STARTED

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Host: MLEITH-GB2 | Version: 4.0.0.0 | About MEM

Refreshed Sep 26, 2017 9:07:31 am BST | Started 12 minutes ago

Enterprise Monitor cont.

ORACLE MySQL Enterprise Monitor

Dashboards Events Query Analyzer Reports & Graphs Configuration

Advisors

Edit Selected Advisors Disable Selected Advisors Create Advisor Import/Export Select All Expand All Collapse All

Administration Configured: 28 of 28

Agent Configured: 3 of 3

Availability Configured: 6 of 6

Backup Configured: 1 of 1

Cluster Configured: 10 of 10

Item	Info	Coverage	Schedule	Event Handling	Parameters
+ Cluster Data Node Data Memory Getting Low	(?)	100% (9/9)	5m	0 0 0	25 20 ! 10
+ Cluster Data Node Has Been Restarted	(?)	100% (9/9)	5m	0 0 0	600
+ Cluster Data Node Index Memory Getting Low	(?)	100% (9/9)	5m	0 0 0	25 20 ! 10
+ Cluster Data Node Redo Buffer Space Getting Low	(?)	100% (9/9)	5m	0 0 0	35 25 ! 10
+ Cluster Data Node Redo Log Space Getting Low	(?)	100% (9/9)	5m	0 0 0	35 25 ! 10
+ Cluster Data Node Undo Buffer Space Getting Low	(?)	100% (9/9)	5m	0 0 0	35 25 ! 10
+ Cluster Data Node Undo Log Space Getting Low	(?)	100% (9/9)	5m	0 0 0	35 25 ! 10
+ Cluster Data Nodes Not Running	(?)	100% (9/9)	5m	0 0 0	1 ! 2
+ Cluster DiskPageBuffer Hit Ratio Is Low	(?)	100% (9/9)	5m	0 0 0	97 90 ! 80
+ Cluster Has Stopped	(?)	100% (9/9)	2m	0 0 0	0

Graphing Configured: 92 of 92

Memory Usage Configured: 6 of 6

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MCM Hands On Lab

4 Monitoring - NDBINFO



Lab-4

- Lab-4
 - <https://github.com/wwwted/ndb-cluster-workshop>

```
mysql> SELECT * FROM memoryusage;
+-----+-----+-----+-----+-----+-----+
| node_id | memory_type      | used     | used_pages | total    | total_pages |
+-----+-----+-----+-----+-----+-----+
| 1      | Data memory       | 2228224 | 68         | 83886080 | 2560      |
| 1      | Index memory      | 458752  | 56         | 19398656 | 2368      |
| 1      | Long message buffer | 393216 | 1536      | 67108864 | 262144    |
| 2      | Data memory       | 2228224 | 68         | 83886080 | 2560      |
| 2      | Index memory      | 458752  | 56         | 19398656 | 2368      |
| 2      | Long message buffer | 393216 | 1536      | 67108864 | 262144    |
+-----+-----+-----+-----+-----+-----+
```

MCM Hands On Lab

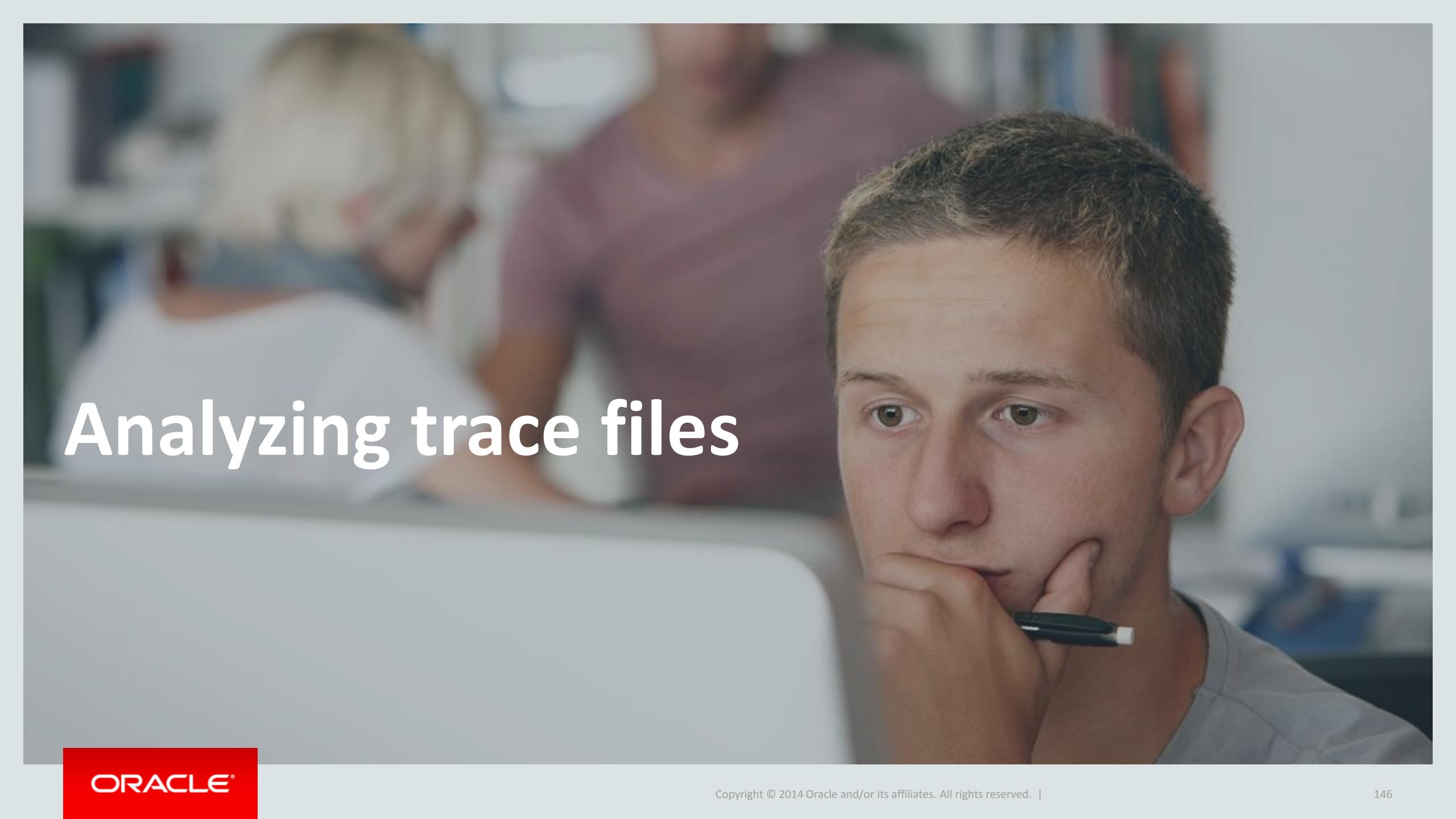
5 Monitoring - Benchmark



Lab-5

- Lab-5
 - <https://github.com/wwwted/ndb-cluster-workshop>

```
mysqlslap -h127.0.0.1 -P3310 -uroot -proot  
    --auto-generate-sql  
    --auto-generate-sql-guid-primary  
    --auto-generate-sql-secondary-indexes=2  
    --auto-generate-sql-load-type=read  
    --auto-generate-sql-write-number=200000  
    --auto-generate-sql-execute-number=100  
    --concurrency=6 --engine=ndbcluster
```

A close-up photograph of a young man with short brown hair, looking directly at the camera with a thoughtful expression. He has his right hand resting against his chin, with a black pen tucked between his fingers. The background is blurred, showing other people in what appears to be a classroom or lecture hall setting.

Analyzing trace files

Crash Investigations and Trace Files

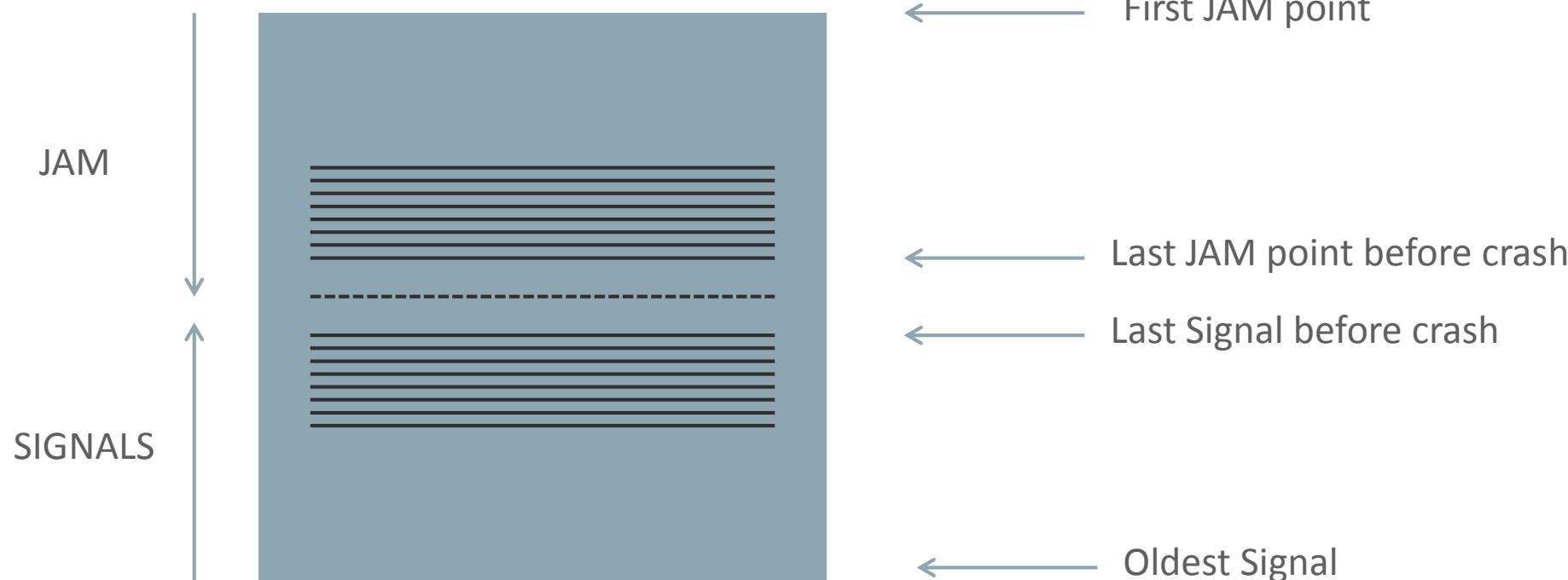
files to Analyze

- During a crash investigation the files collected by the `ndb_error_reporter` script is your best friend.
- If you have problem and cluster created trace files, create a support ticket and attach the trace files.
- If you want to investigate problems yourself;
 - Start om central Cluster log file located on management node
 - Then look in local logs on data nodes (.err and .out)
 - If problem is related to MySQL API nodes, look in error logs for MySQL Server
 - If Trace files have been created by data nodes, they will show you what caused data node to stop.

Crash Investigations and Trace Files

analyzing trace files

- The trace files are the ones containing the most detailed information about the crash. The files is divided into two parts, JAM and Signals.



Crash Investigations and Trace Files

analyzing trace files

- The JAM points are generated by the following two macros in the source code:
 - jam(), inserts the source code line number into the buffer.
 - jamEntry(), additionally inserts a new line and the name of the block before the line number
- MySQL Cluster uses two kinds of signals:
 - asynchronous signals that are added to a queue and processed according to priority and the order they are inserted into the queue
 - synchronous signals that block until they have been processed

Crash Investigations and Trace Files

analyzing trace files JAM()

```
QMGR 004152 004189 004201 004207 004209 004247 004252
QMGR 004273 004287 004287 004287 004287 004287 004287
          004287 004320 005250 006018 006018 006018 006018 006021
          006018 006018 006018 006018 006018 006018 006018 006018
          006018 006018 006018 006018 006018 006018 006018 006018
          006018 006018 006018 006018 006018 006018 006018 006018
          006018 006018 006018 006018 006018 006018 006018 005259
DBDIH 016151 016159 016163 016169 016169 016172 016192
QMGR 005266 005277 005315 005324 005340 005353 005420 005961
          005963 005975
```

```
void
Qmgr::stateArbitCrash(Signal* signal)
{
    jam();
    if (arbitRec.newstate) {
        jam();
        CRASH_INSERTION((UInt32)910 + arbitRec.state);
        arbitRec.setTimestamp();
        ....
```

So the first place to look is the QMGR kernel block. The source code for the kernel blocks is located in storage/ndb/src/kernel/blocks and every block is implemented as a C++ class. Most blocks has its own subdirectory. The file the line number refers to is the <Block>Main.cpp where <Block> should be replaced by the name of the block, e.g. for the QMGR block, the filename is QmgrMain.cpp. Looking up line 5975 in QmgrMain.cpp

Crash Investigations and Trace Files

analyzing trace files Signals

- r.bn – receiver block
- r.proc – node ID of receiver
- gsn – Global Signal Name
- s.bn – sender block
- s.proc – Node ID of sender

----- Signal -----

```
r.bn: 252 "QMGR", r.proc: 4, r.sigId: 2437605 gsn: 343 "PREP_FAILCONF" prio: 0  
s.bn: 252 "QMGR", s.proc: 4, s.sigId: 2437604 length: 2 trace: 8 #sec: 0 fragInf: 0  
H'00000004 H'00000002
```

----- Signal -----

```
r.bn: 252 "QMGR", r.proc: 4, r.sigId: 2437604 gsn: 126 "CLOSE_COMCONF" prio: 0  
s.bn: 266 "TRPMAN", s.proc: 4, s.sigId: 2437603 length: 19 trace: 8 #sec: 0 fragInf: 0  
xxxBlockRef = (252, 4) failNo = 2 noOfNodes = 1
```

Nodes: 3

----- Signal -----

```
r.bn: 266 "TRPMAN", r.proc: 4, r.sigId: 2437603 gsn: 126 "CLOSE_COMCONF" prio: 0  
s.bn: 266 "TRPMAN", s.proc: 4, s.sigId: 2437602 length: 19 trace: 8 #sec: 0 fragInf: 0  
xxxBlockRef = (252, 4) failNo = 2 noOfNodes = 1
```

Nodes: 3

.....

When analyzing the signal list for a multi-threaded data node, in general all but one thread will have the STOP_FOR_CRASH signal as the last one. **The thread not having this signal is the interesting one as it is responsible for the crash.** The STOP_FOR_CRASH signal is sent to the remaining threads to stop them as well

Crash Investigations and Trace Files

introduction to the Source Code

The most important directories and files are:

- storage/ndb/include
 - The shared header files for MySQL Cluster. One directory that may be of particular interest is kernel/signaldta which contains all of the classes implementing the signals.
- storage/ndb/src
 - The source code for the core cluster parts (for example the data nodes and the management server/client, but not high level interaction such as the NDBCluster storage engine, ClusterJ)
- storage/ndb/src/kernel
 - The data nodes.
- storage/ndb/src/kernel/vm
 - Code that is common for the kernel blocks.
- storage/ndb/src/kernel/blocks
 - The code for the actual kernel blocks.

Administration

Adding datanodes online

- Add new datanodes to config.ini.
- Rolling restart of all components (management node, datanodes & sqlnodes).
- Start **new** data nodes with --initial.
- Create new node group via management console.
- `alter online table xxx reorganize partition;` <- 1 online DDL per table.
- `optimize table xxx;`

<https://dev.mysql.com/doc/refman/5.7/en/mysql-cluster-online-add-node-example.html>

MCM Hands On Lab

6 Add more capacity



Lab-6

- Lab-6
 - <https://github.com/wwwted/ndb-cluster-workshop>

```
mcm> show status -r mycluster;
```

NodeId	Process	Host	Status	Nodegroup	Package
49	ndb_mgmd	127.0.0.1	running		cluster758
1	ndbmtd	127.0.0.1	running	0	cluster758
2	ndbmtd	127.0.0.1	running	0	cluster758
3	ndbmtd	127.0.0.1	added	n/a	cluster758
4	ndbmtd	127.0.0.1	added	n/a	cluster758
50	mysqld	127.0.0.1	running		cluster758
51	mysqld	127.0.0.1	running		cluster758
52	ndbapi	*127.0.0.1	added		
53	ndbapi	*127.0.0.1	added		
54	ndbapi	*127.0.0.1	connected		
55	ndbapi	*127.0.0.1	connected		

Program Agenda

- 1 ➤ Introduction
- 2 ➤ Getting started: configuration/install/start/stop
- 3 ➤ Administration: backup/upgrade/logs/conf/sizing
- 4 ➤ Monitoring, surveillance and problem solving
- 5 ➤ Best practices, HW, architectures and case studies
- 6 ➤ Geo-replication

Best Practices

General Design Considerations

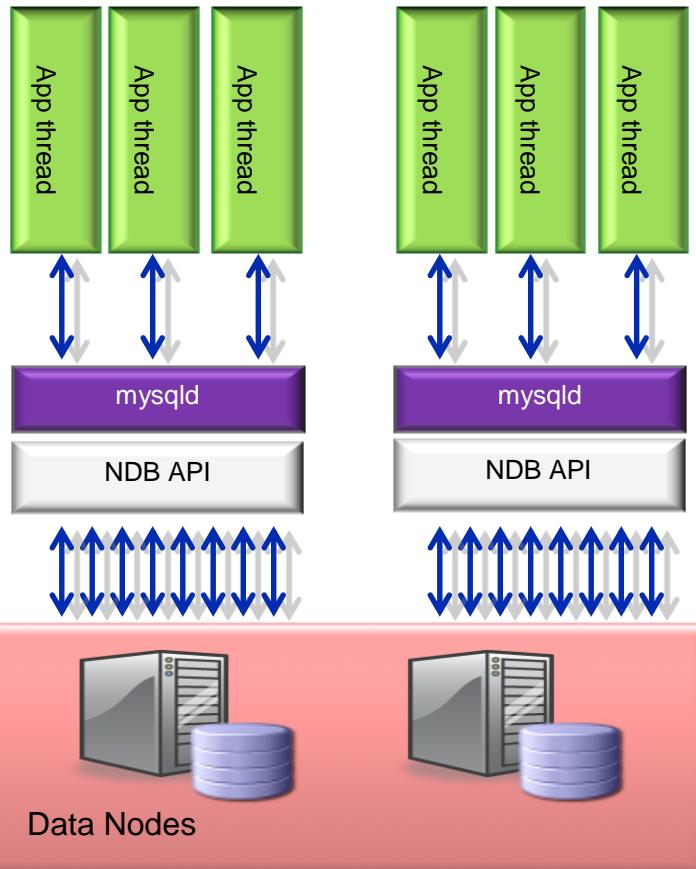
- MySQL Cluster is designed for
 - Short transactions
 - Many parallel transactions
- Utilize Simple access patterns to fetch data
 - Use efficient scans and batching interfaces
- Analyze what your most typical use cases are
 - optimize for those

Overall design goal

*Minimize network roundtrips for your
most important requests!*

Best Practices

Parallel operations for throughput



- Network hops increase latency (e.g. Compared with InnoDB read of cached data)
- Increase throughput by sending in lots of parallel operations
- Multiple client connections (sessions) to each MySQL Server
- Multiple MySQL Servers
- Connection pooling between MySQL Servers and data nodes
- Set `ndb-cluster-connection-pool > 1` in `my.cnf`
- Ensure enough [api] sections in `config.ini`

Best Practices

User defined partitioning

- User defined partitioning is “holy grail” of NDB performance!
- You can choose to partition on any part of PK
 - CREATE TABLE ... PARTITION BY (X)
 - Partition on the correct columns
 - You can only partition on whole or part of PK
 - Try to collocate data that is joined
 - You have the same TC during whole transaction

Best Practices

User defined partitioning II

- PK (a)
 - Data partitioned by hash(a)
 - select * from ptable where a=2
- PK (a,b)
 - Data partitioned by hash(a,b)
 - select * form ptable where b=2?
 - select * from ptable where a=2?
 - select * from ptable where a=2 and b=4?
- create table ptable ... PK(a,b) PARTITION by (b)
 - Data partitioned by hash(b)

Best Practices: Distribution Aware Apps

```
SELECT SUM(population) FROM towns WHERE  
country="UK";
```

Partition Key		
Primary Key		
town	country	population
Maidenhead	UK	78000
Paris	France	2193031
Boston	UK	58124
Boston	USA	617594

```
SELECT SUM(population) FROM towns WHERE  
town="Boston";
```

Partition Key		
Primary Key		
town	country	population
Maidenhead	UK	78000
Paris	France	2193031
Boston	UK	58124
Boston	USA	617594

- Partition selected using hash on Partition Key
 - Primary Key by default
 - User can override in table definition
- MySQL Server (or NDB API) will attempt to send transaction to the correct data node
 - If all data for the transaction are in the same partition, less messaging -> faster
- Aim to have all rows for high-running queries in same partition

Best Practice: Distribution Aware – Multiple Tables

Partition Key		
Primary Key		
sub_id	age	gender
19724	25	male
84539	43	female
19724	16	female
74574	21	female

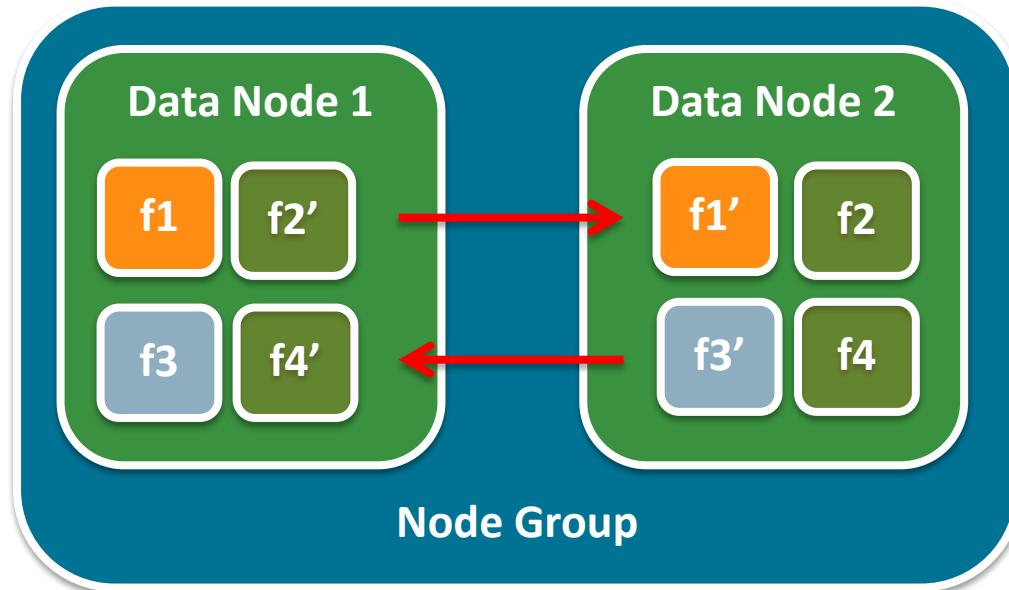
Partition Key		
Primary Key		
service	sub_id	svc_id
twitter	19724	76325732
twitter	84539	67324782
facebook	19724	83753984
facebook	73642	87324793

- Extend partition awareness over multiple tables
- Same rule – aim to have all data for instance of high running transactions in the same partition

```
ALTER TABLE service_ids PARTITION  
BY KEY(sub_id);
```

Best Practices

Improving read/join access – READ_BACKUP (NDB 7.5)



- Reading from backup allows to read from any copy (f1 or f1' (backup))
- Previously all reads were directed towards the primary fragment only

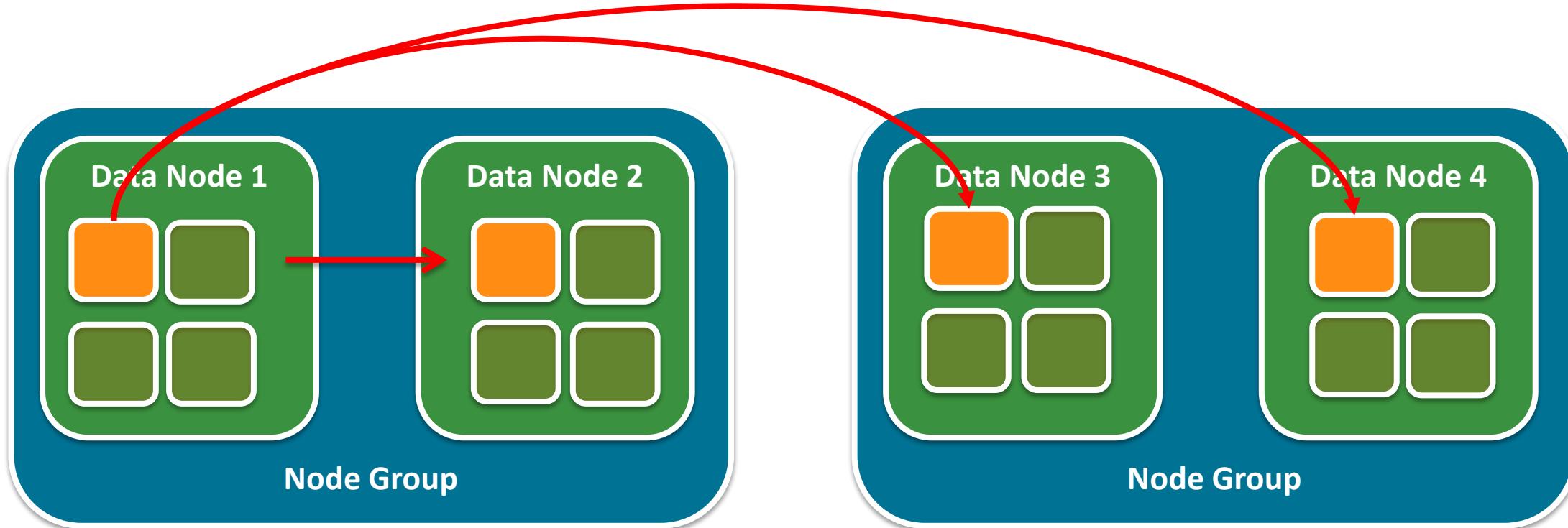
Best Practices

Improving read/join access – READ_BACKUP (NDB 7.5)

- Per default we only read the primary fragment of data, the backup fragment that might be "closer" is not used.
- Read backup can help to avoid network traffic by reading as much data as possible locally, read backup will be most useful in a 2 data node setup where MySQL API nodes are co-located with data nodes.
 - Can be configured when creating table using:
`CREATE TABLE ENGINE=NDB COMMENT="NDB_TABLE=READ_BACKUP=1";`
or by running `ALTER TABLE <table-name> COMMENT="NDB_TABLE=READ_BACKUP=1";`
 - There is also a variable `ndb_read_backup` that can be set in MySQL configuration file that will ensure read backup for all tables created after variable set set.
 - It's important to remember to also set `ndb_data_node_neighbour` if we have co-located MySQL/Data nodes to ensure we read from co-located data node.

Best Practices

Improving read/join access – FULLY_REPLICATED (NDB 7.5)



- Fully replicated allows a table to be read/written locally on any node
- Ideal for static data, faster join performance

Best Practices

Improving read/join access – FULLY_REPLICATED (NDB 7.5)

- All tables in MySQL Cluster are distributed over all data nodes by default, under some circumstances this might not be optimal. One such case is when you want to join data between tables, this will cause lots of network traffic and slow down your queries.
- Fully replicated can help to avoid network traffic by reading as much data as possible locally, this should be considered primary for static tables that are used in join operations with your larger and more frequently updated tables.
 - Fully replicated can be configured when creating table using:
`CREATE TABLE ENGINE=NDB COMMENT="NDB_TABLE=FULLY_REPLICATED=1";`
or by running `ALTER TABLE <table-name> COMMENT="NDB_TABLE=FULLY_REPLICATED=1";`
 - There is also a configuration variable named `ndb_fully_replicated` that can be set in MySQL configuration file that will ensure `fully_replicated` for all tables created after variable is set.
 - It's important to remember to also set `ndb_data_node_neighbour` if we have co-located MySQL/Data nodes to ensure we read from co-located data node.

Hardware

MySQL Cluster Requirements

- TCP/IP or Infiniband
 - Minimum 100Mbps, 1Gbps or higher recommended.
 - MySQL Cluster dedicated network: separate datanodes from sqlnodes.
- Homogeneous environments for each layer, apinodes, sqlnodes & datanodes.
- HW: Supported Linux, Solaris, Windows. x86, 64 bit, SPARC.
 - Compile source code.
 - Min. 1Gb RAM
 - CPU, RAM, DISK: “the more, the better”

MySQL Cluster Hardware Selection

SQL Layer

- 4 - 24 x86-64 bit CPU threads
- Minimum 4GB of RAM
 - Memory not as critical at this layer
 - Requirements influenced by connections and buffers.
- 2 x Network Interface Cards & 2 x PSUs
- Linux, Solaris or Windows operating systems.

MySQL Cluster Hardware Selection

Data Layer

- Up to 64 x86-64 bit CPU threads
 - Use high frequency: enables faster processing of messages
- Calculating RAM per Data Node (in-memory database)
 - Database Size * # Replicas * 1.25 / # data node
 - 50GB database * 2 replicas * 1.25 / 2 data nodes = 64GB of RAM
 - Non-indexed columns can be stored on disk, reduces RAM requirements
- 2 x NICs and 2 x PSUs
- Deep-dive into network best-practices in Ref Archs Guide

MySQL Cluster Hardware Selection: Disk Subsystem for Checkpointing

Entry-Level

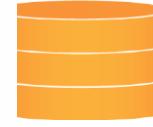


LCP
REDOLOG

SATA/SAS Drives

- For read-mostly
- No redundancy
(but other data node is the mirror)

Mid-Range

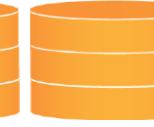


LCP
REDOLOG

SAS/SSD's

- Heavy duty (many MB/s)
- No redundancy
(but other data node is the mirror)

High-End



LCP / REDOLOG



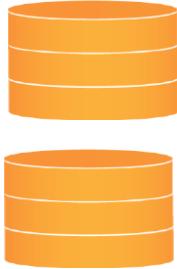
SSDs or NVMe

- Heavy duty (many MB/s)
- Disk redundancy (RAID1+0), hot swap

- REDO, LCP, BACKUP – written sequentially in small chunks (256KB)
- If possible, use ODIRECT = 1

MySQL Cluster Hardware Selection: Disk Data Storage

Recommended Minimum

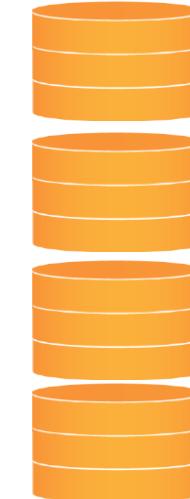


LCP
REDOLOG
UNDOLOG
TABLESPACE

2 x SAS 10K RPM
or 2 x SSD



High-End Recommendation



4 x SAS 10-15K RPM or SSD

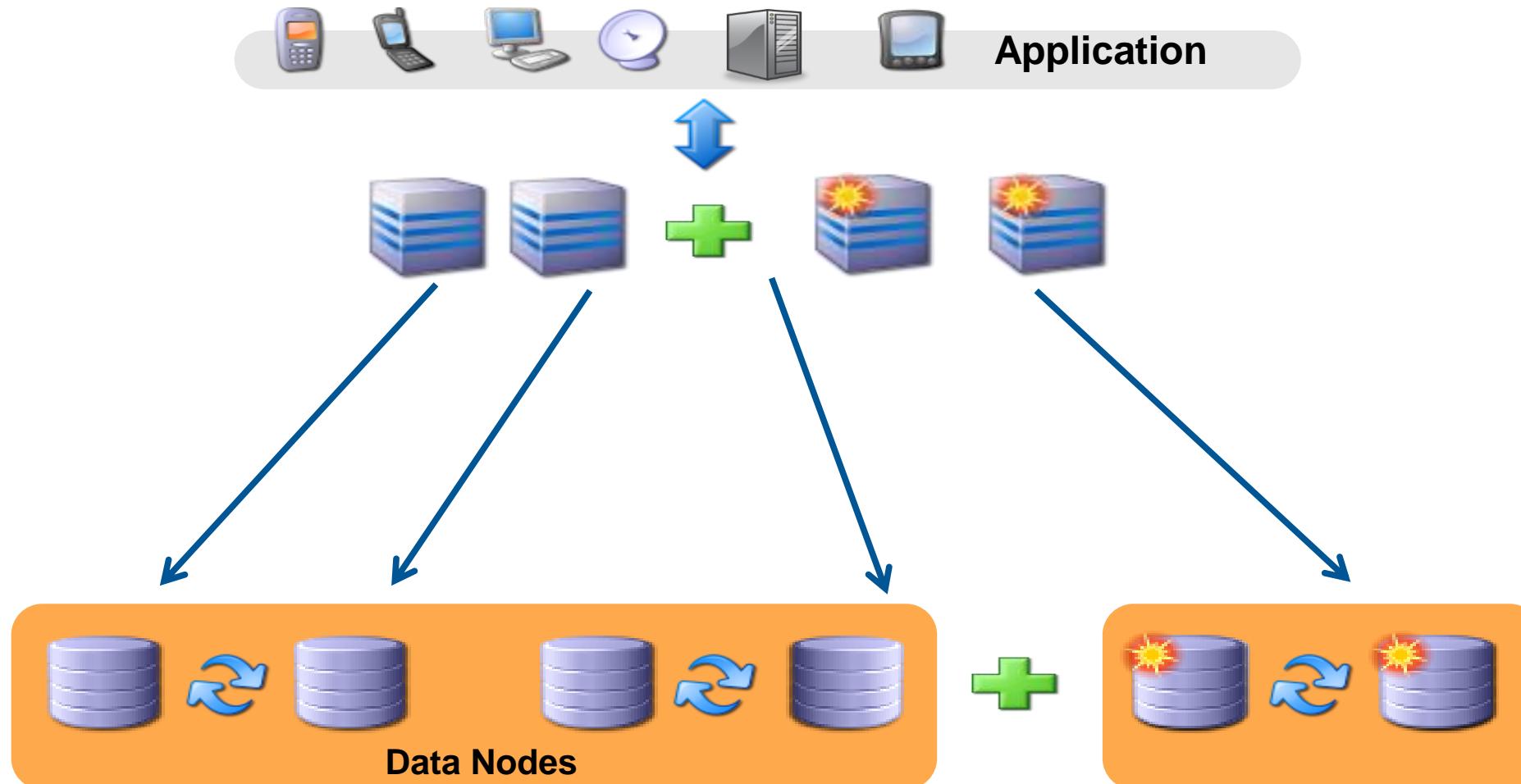
UNDOLOG
(REDO LOG)
TABLESPACE 1
TABLESPACE 2
(REDO LOG / UNDO LOG)
LCP

- Use High-End Recommendation for heavy read / write workloads
 - (1000's of 10KB records per sec) of data (i.e. Content Delivery platforms)
- Having TABLESPACE on separate disk is good for read performance
- Enable WRITE_CACHE on devices

Architecture

Scaleable & Elastic

Increasing capacity in seconds



Basic Deployments

1 Data Node

Front-End
Application Logic
Data Access



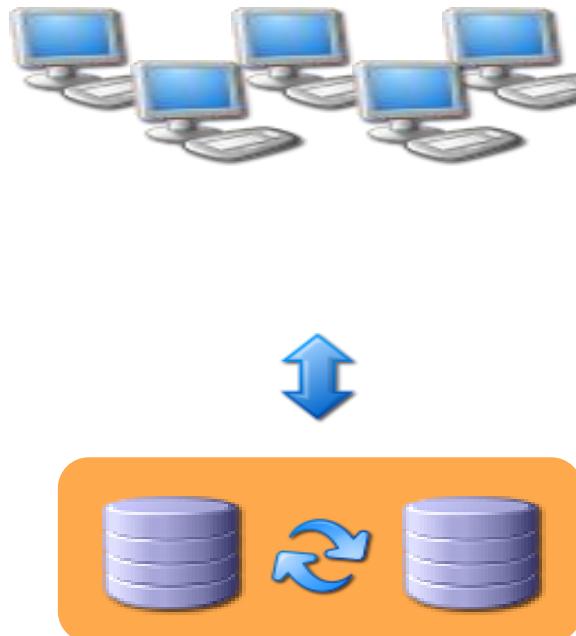
Data
Indexes

Basic Deployments

Start scaling with 2 Data Nodes

Front-End
Application Logic
Data Access

Data
Indexes



- Shared Data View
- Automated Load Balancing

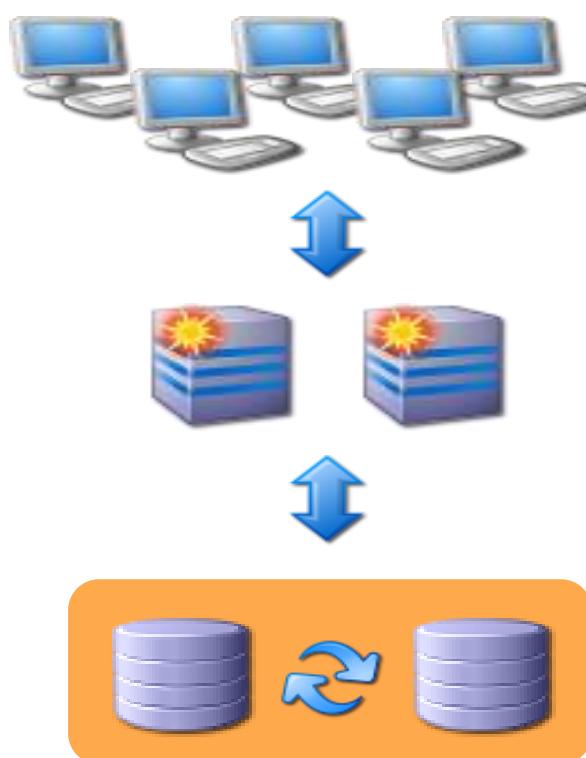
Basic Deployments

Continue Scaling

Front-End
Application Logic

Data access
(e.g. SQL engine)

Data
Indexes



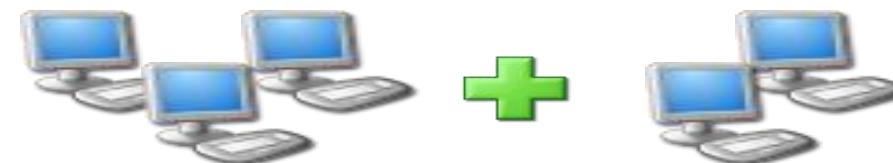
OS, App or
Hardware Load
Balancing

Automated
Load Balancing

Basic Deployments

Scale on 3 levels

Front-End
Application Logic



Data access
(e.g. SQL engine)

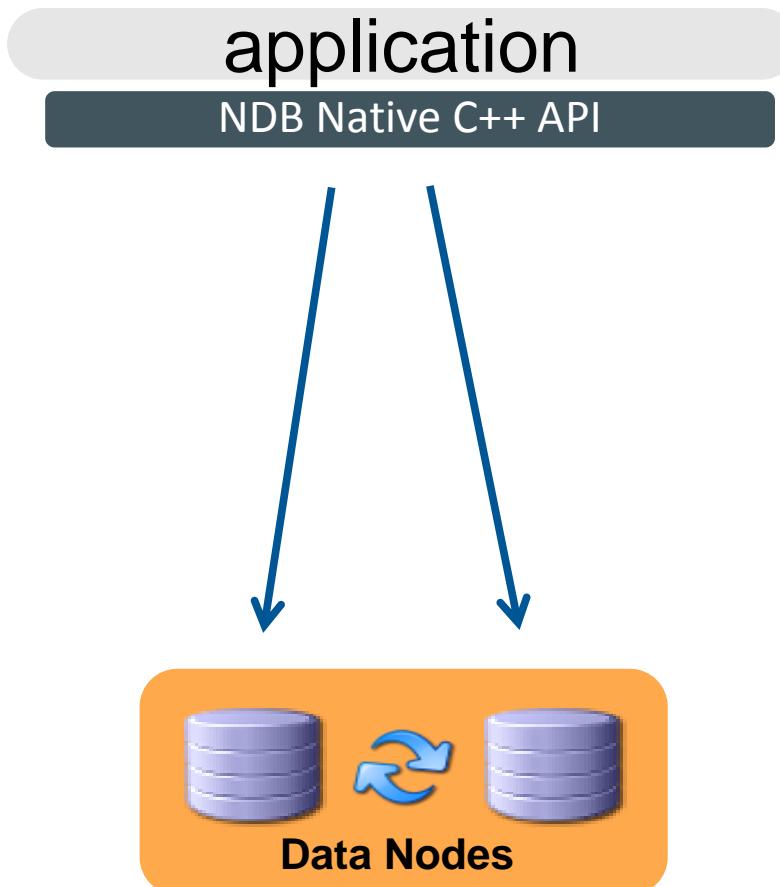


Data
Indexes



Architectures

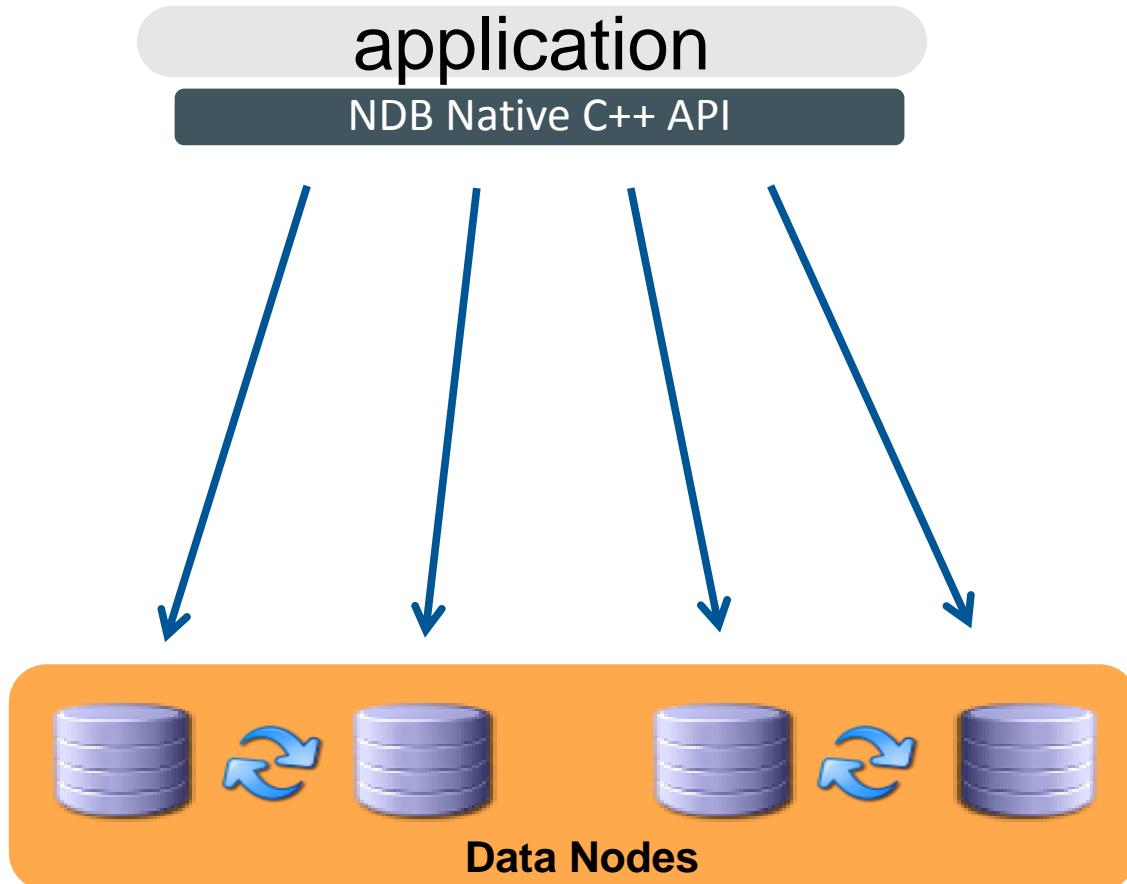
Small applications



- Start small and grow.
- Smaller operators, DNS/DHCP/EMUM services.
- Minimal installation on 3 physical servers due to arbitration.
- Max 200M QPM and 20M UPM.
- Size of database limited by RAM of smallest server.

Architectures

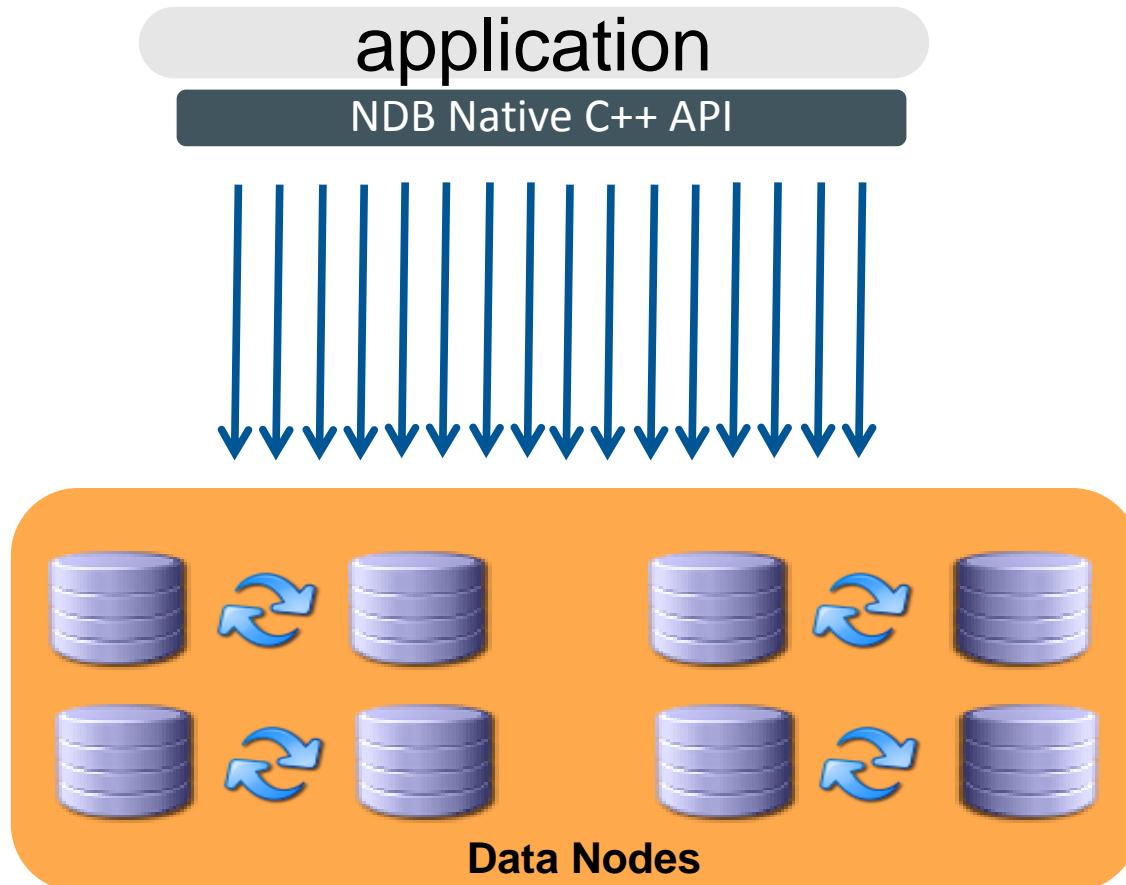
Medium applications



- Most common setup.
- 4 server setup, management nodes can be co-located with data nodes.
- Max 600M QPM and 55M UPM.
- Size of DB limited by 2xRAM (RAM of smallest server).

Architectures

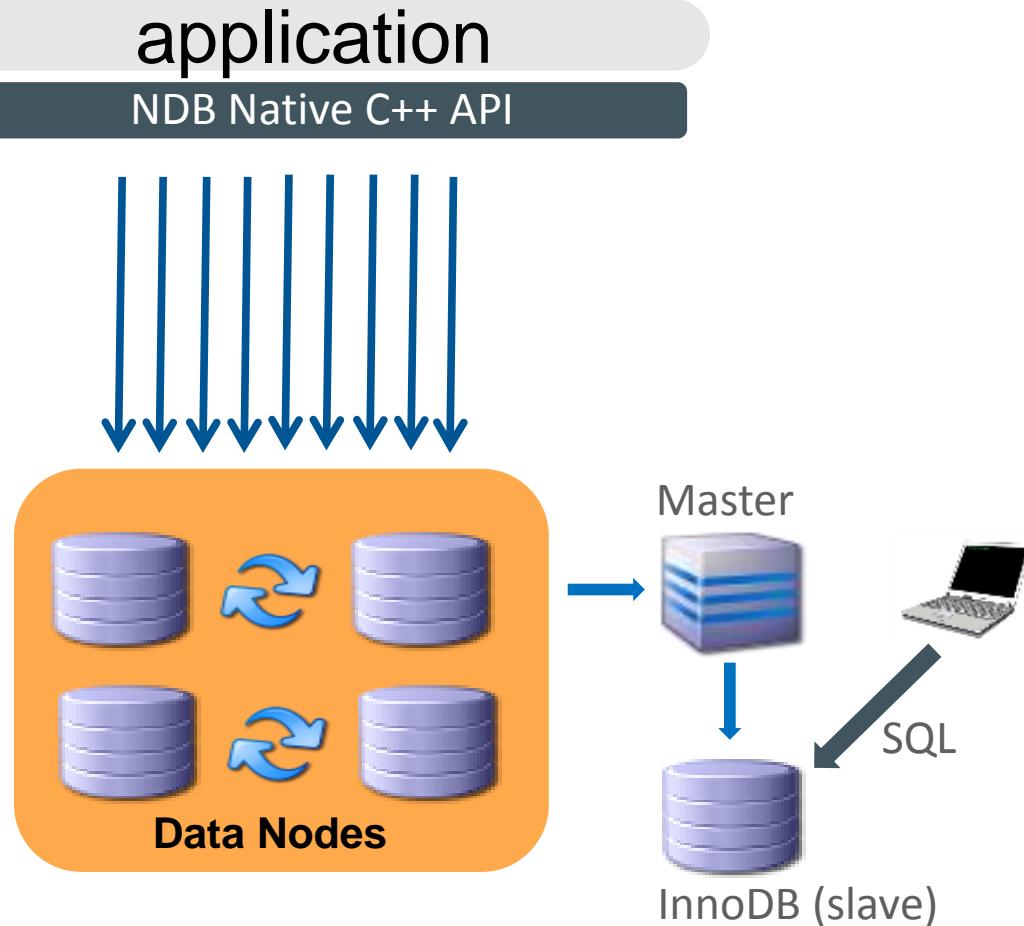
Big applications



- High performance systems.
- 8 server setup
- Max number of data nodes is 48.
- Max 1100M QPM and 110M UPM.
- Size of DB limited by 4xRAM (RAM of smallest server).

Architectures

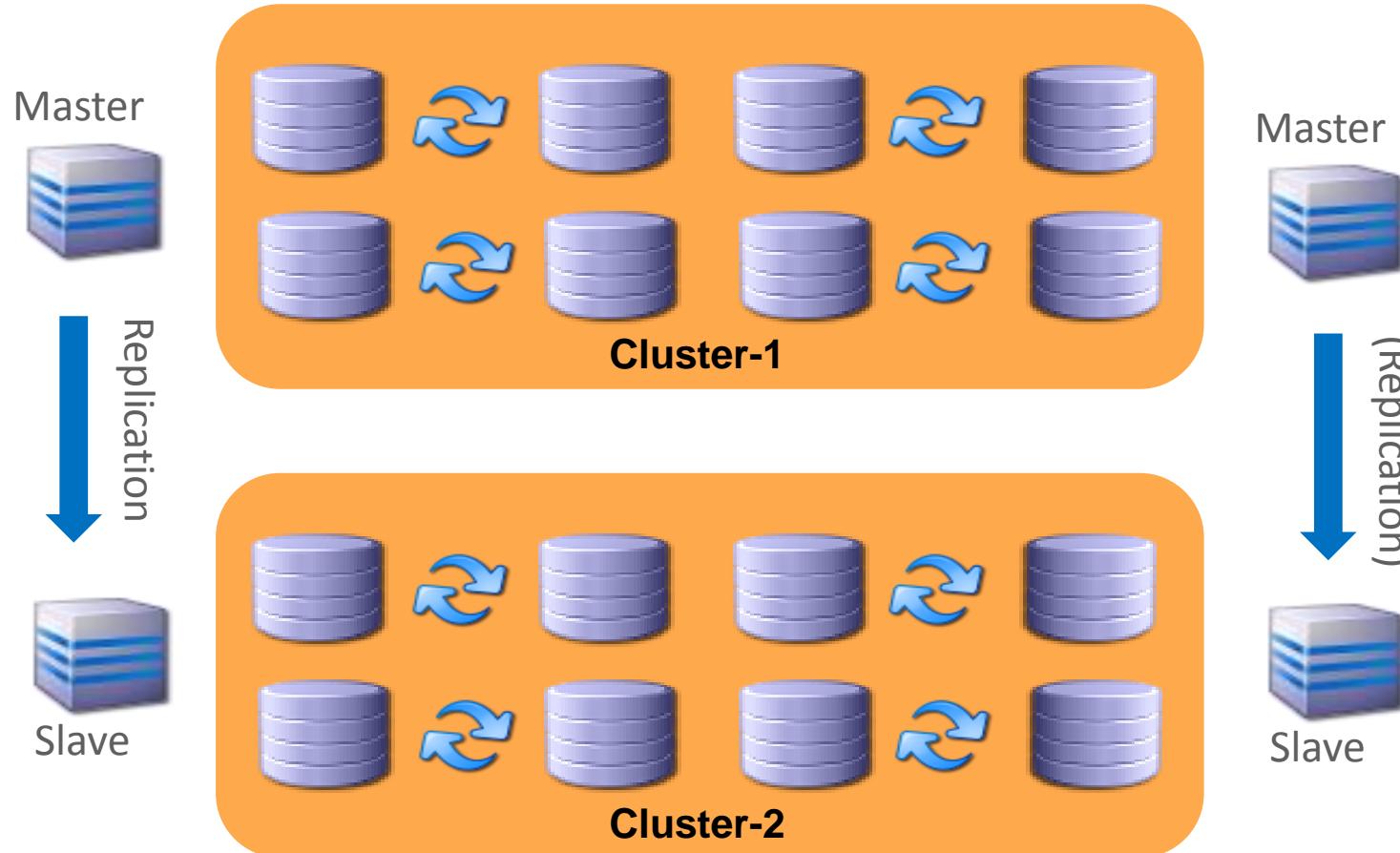
Storing Hot & Cold data



- Replicate to InnoDB for cold data.
- Full dataset in InnoDB (slave).
- Only “HOT” data in cluster low latency operations.
- Run reports/statistics on disk based database InnoDB.
- Cost effective!

Architectures

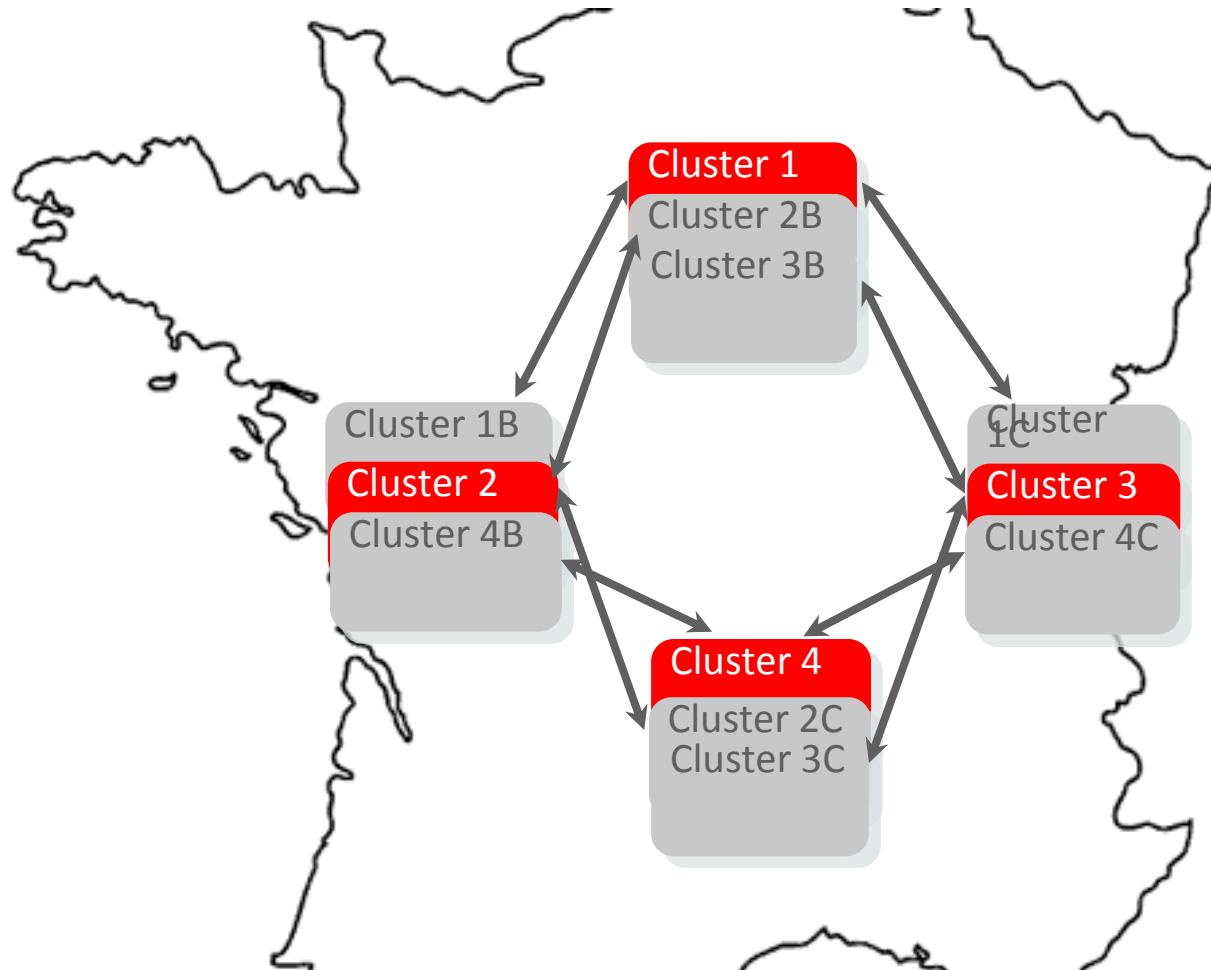
Geo redundancy



- Mission critical high performance applications.
- Geographic redundancy between data centers or continents.
- Active/passive or Active/Active

Architectures

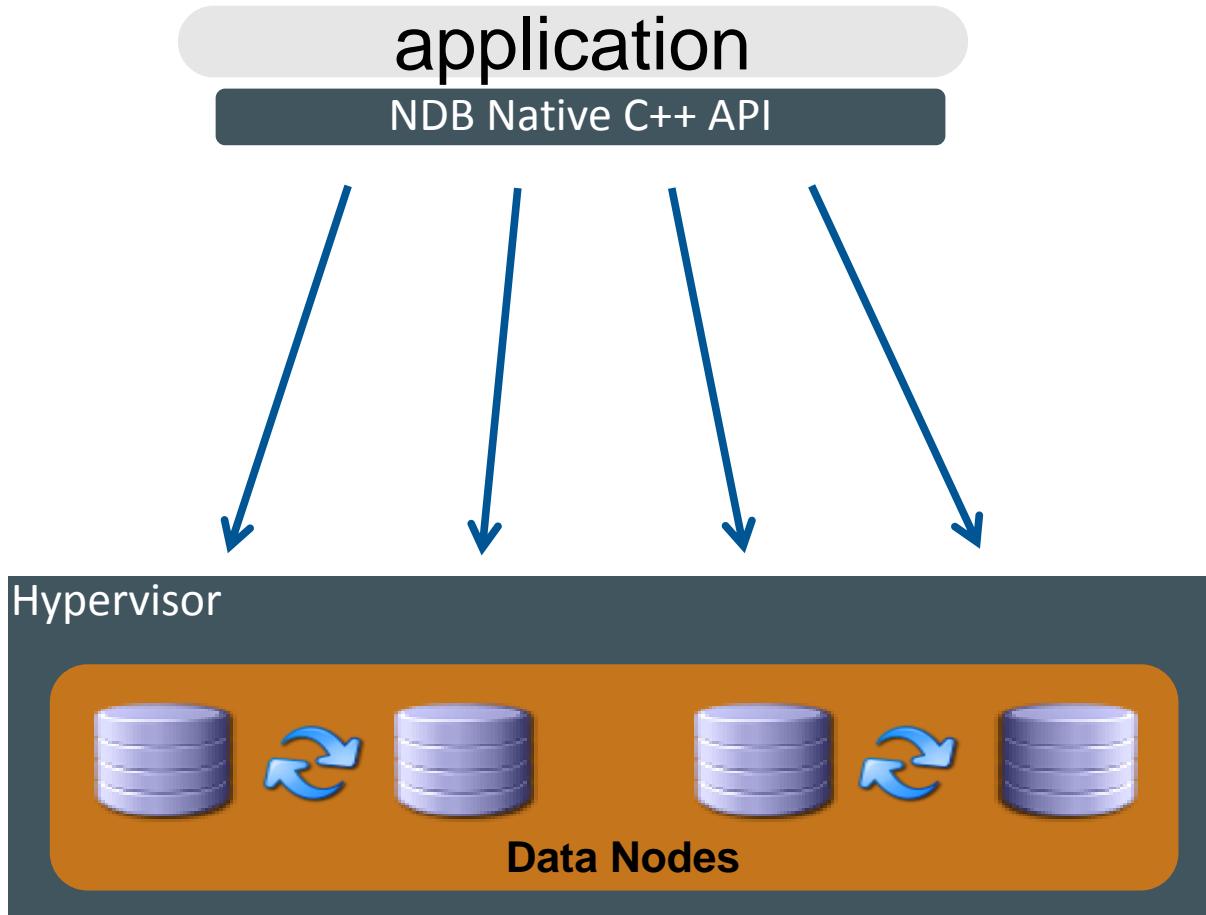
Partition your data for low latency



- Partition the subscribers across multiple clusters, distributed by country/region to optimize low latency access.
- Each sub-cluster is replicated for High Availability.
- Active/passive or Active/Active.

Architectures

Virtual environments



- Supported as of MySQL Cluster 7.2
- Use dedicated resources for data nodes in same node groups.
- Be aware of SPOFs.
- Mostly smaller operators using virtual environments today.

MySQL Cluster – Users & Applications

Telecoms

- Subscriber Databases (HLR / HSS)
- Service Delivery Platforms
- VAS: VoIP, IPTV & VoD
- Mobile Content Delivery
- Mobile Payments
- LTE Access

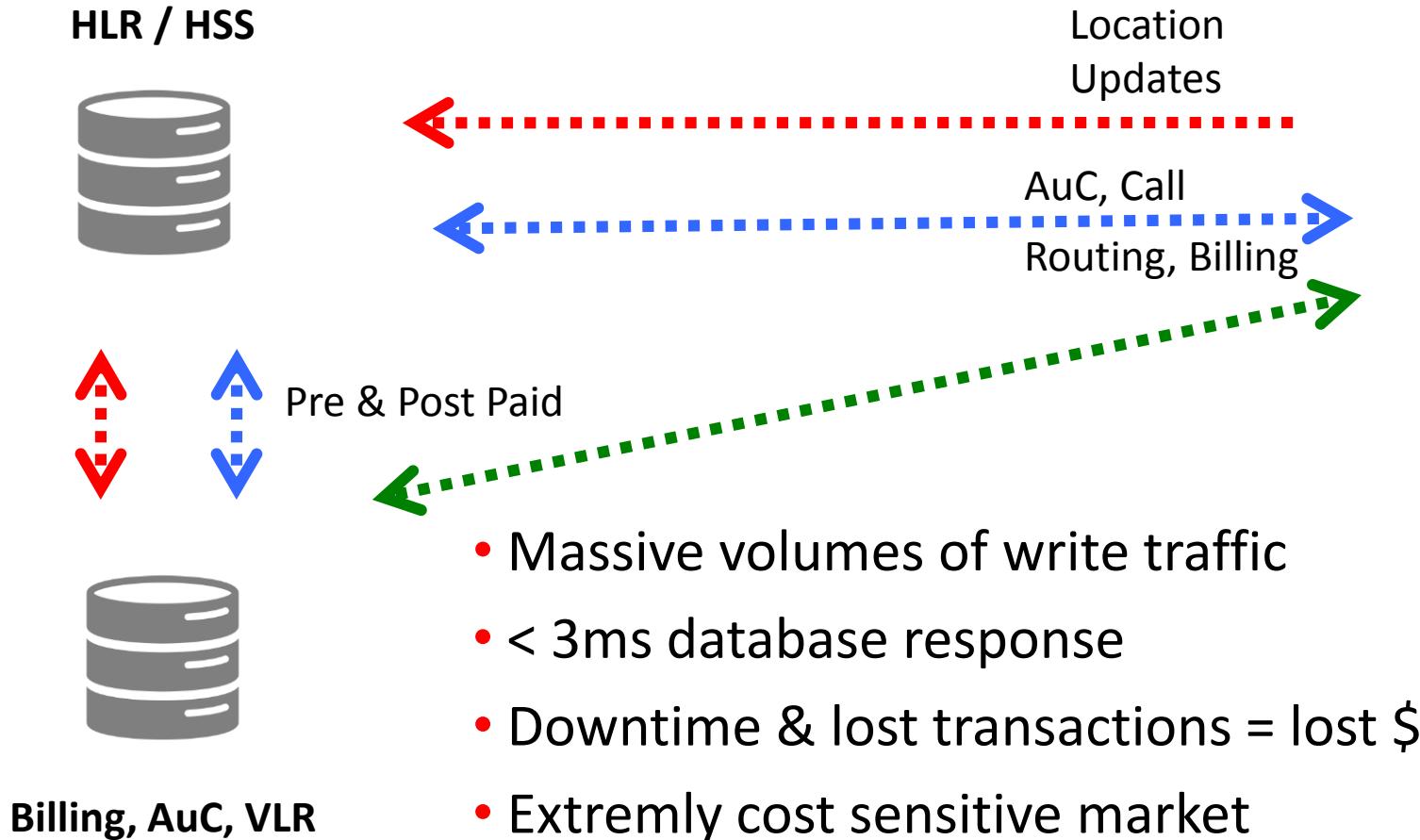
Web & Enterprise

- High volume OLTP
- eCommerce
- User Profile Management
- Session Management & Caching
- Content Management
- On-Line Gaming



<http://www.mysql.com/customers/cluster/>

No Trade-Offs: Cellular Network



MySQL Cluster in Action: <http://bit.ly/oRI5tF>

No Trade-Offs: Massive Parallel Online Games

User Session



Location Updates,
Character movements, ...



Session
management



Session
management

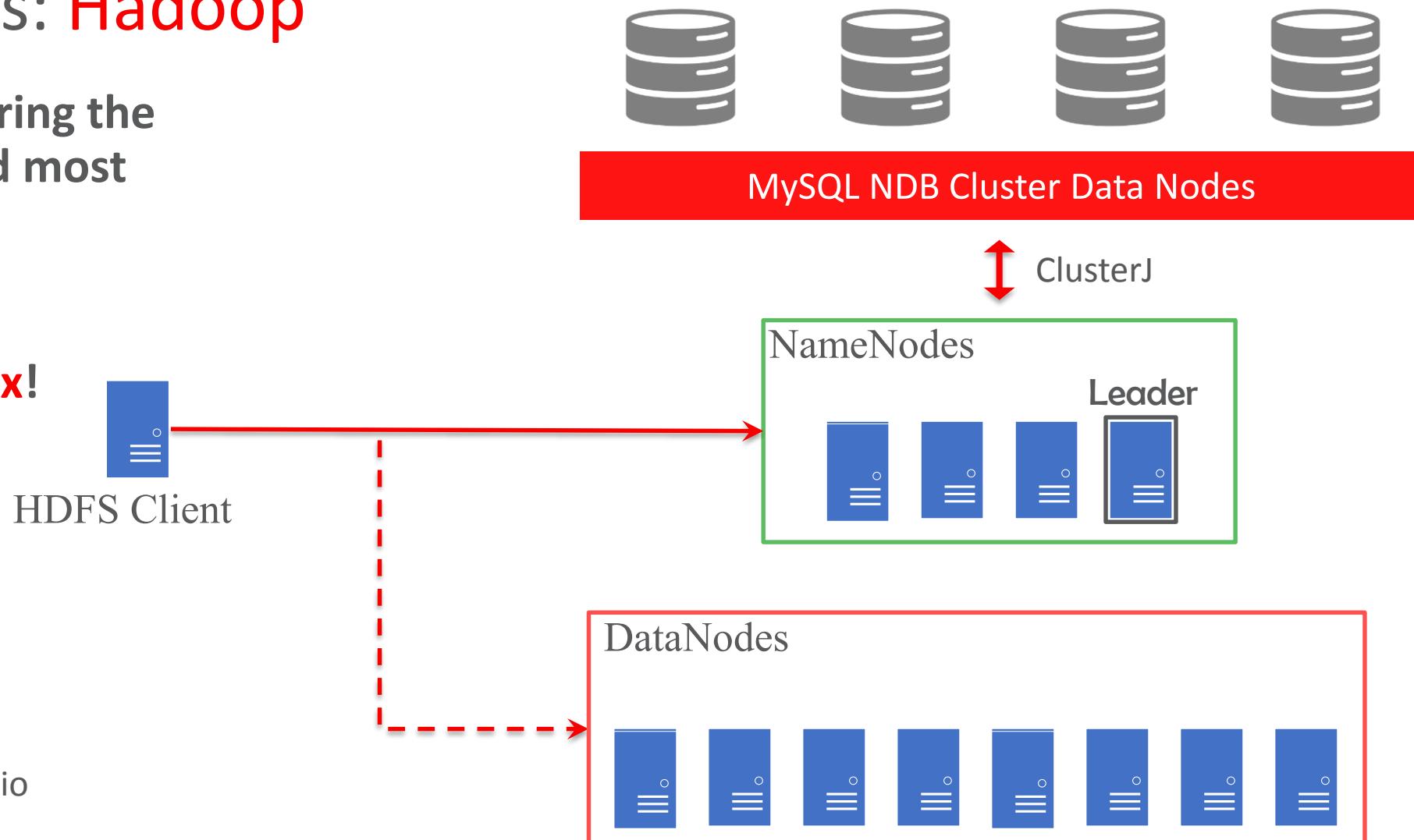
- Massive volumes of write traffic
- < 3ms database response
- Downtime & lost transactions = lost \$
- Extremely sensitive crowd



No Trade-offs: Hadoop

NDB Cluster powering the world's fastest and most scalable Hadoop filesystem.

Scaling Hadoop **20x!**



Program Agenda

- 1 ➤ Introduction
- 2 ➤ Getting started: configuration/install/start/stop
- 3 ➤ Administration: backup/upgrade/logs/conf/sizing
- 4 ➤ Monitoring, surveillance and problem solving
- 5 ➤ Best practices, architectures and case studies
- 6 ➤ Geo-replication



Geo-Replication

MySQL Cluster Replication

Basics

- Asynchronous replication
- External, not Internal.
- Geographical Replication
- MySQL Server / SQL Node – NDB Binlog Injector Thread
- Requirements:
 - 2 SQL nodes per Replication channel.
 - Unique server-id for all SQL nodes, Master & Slave
 - binlog-format=**ROW** or binlog-format=**MIXED** (default)

MySQL Cluster Replication

NDB Binlog Injector Thread

- Binlog Injector Thread receives events directly from NDB storage engine.
- Makes sure all all events that change data are recorded in binlogs &:
 - `mysql.ndb_binlog_index`
 - Every time an NDB tables receives an update a record is inserted.
 - Local to each MySQL Server: Does not participate in clustering.
 - Requires binlogging to be enabled.
 - Uses MyISAM storage engine.
 - epoch column calculated from Master's last --initial restart.
 - Size depends on no. of epochs / binlog and no. of binlog files.

MySQL Cluster Replication

NDB Binlog Injector Thread cont.

- **`mysql.ndb_apply_status`**
 - Keeps record of all operations replicated from Master to Slave.
 - Not bound to any specific node in the cluster.
 - Uses NDB storage engine.
- **`mysql.ndb_schema`**
 - Tracks schema changes made to NDB tables.
 - Invisible table, except for `ndb_show_tables` & `select * from mysql.ndb_schema;`
- **`mysql.ndb_replication`**
 - For conflict resolution.
 - Requires manual creation.

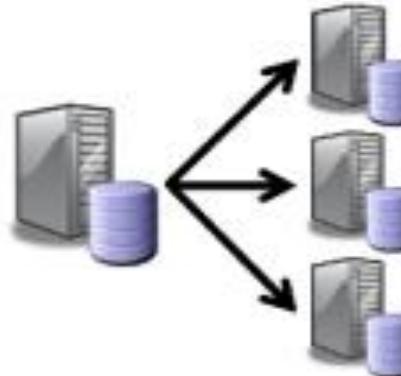
MySQL Cluster Replication

Classic Replication Scenarios

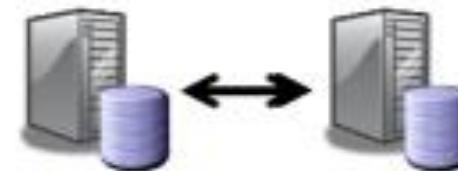
Master to Slave



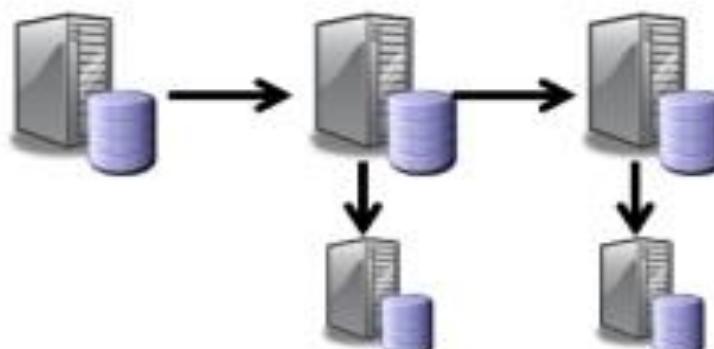
Master to Multiple Slaves



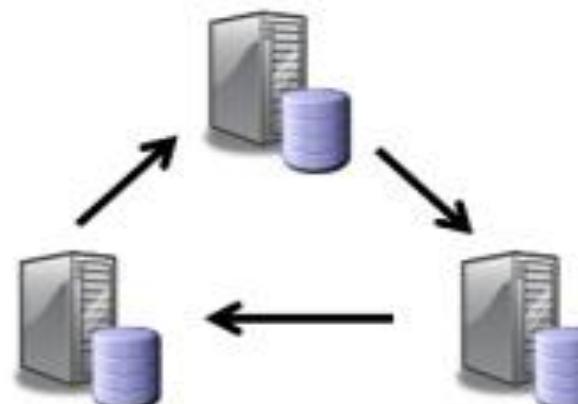
Multi-Master



Master to Slave(s) to Slave(s)

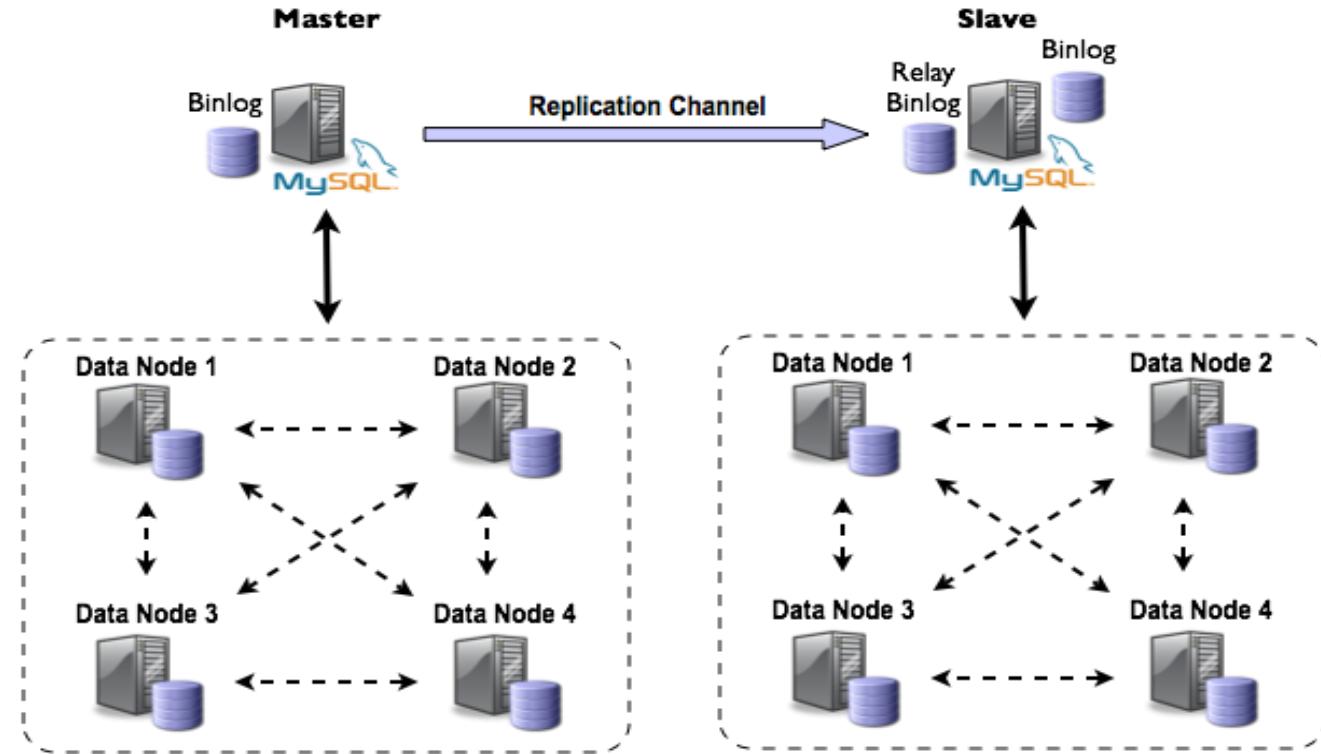


Multi-Master Ring



MySQL Cluster Replication

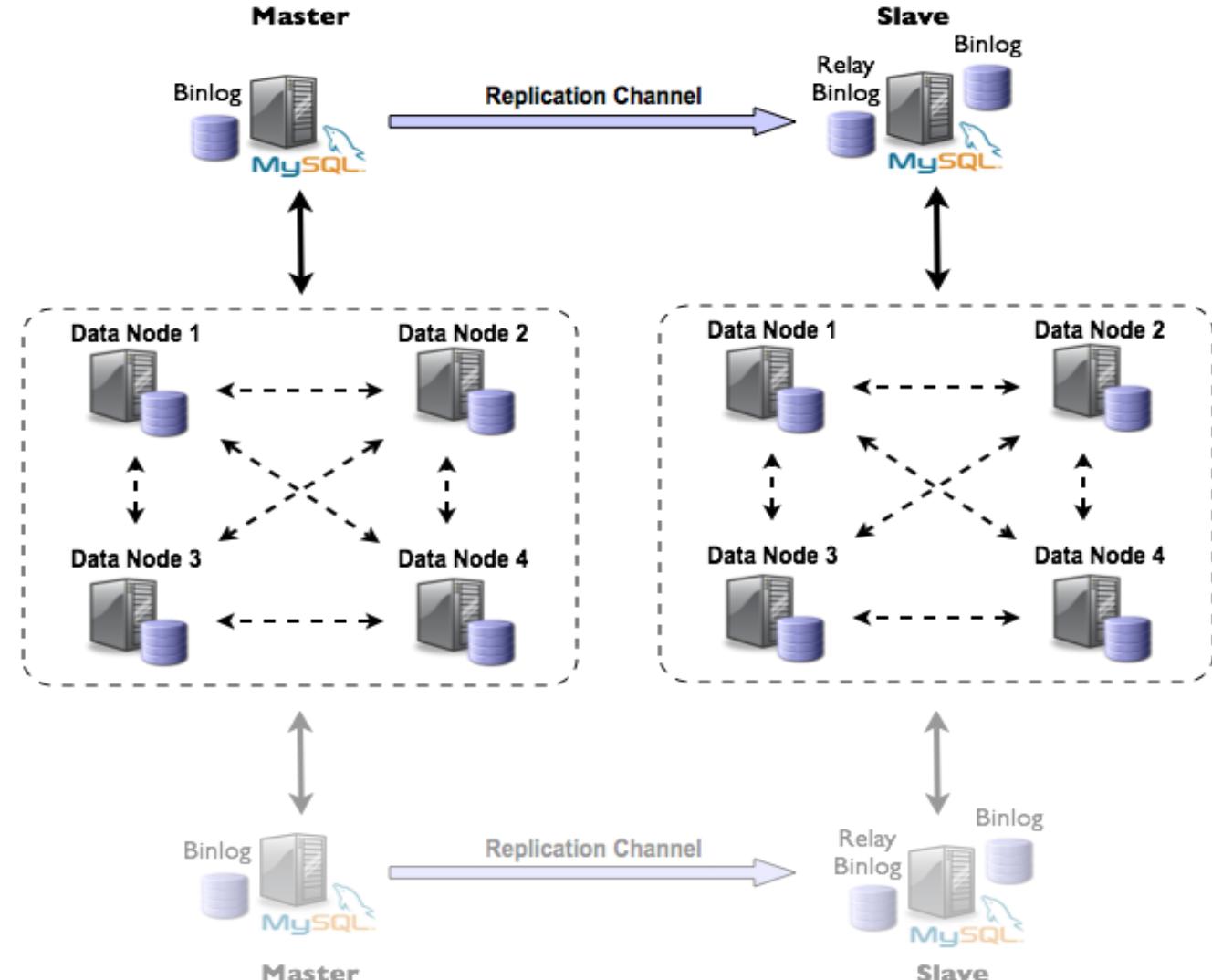
- Geographical Redundancy
 - Across data centers
 - Bring data closer to customers
- Load Balancing across clusters
 - Master cluster for writes
 - Slave cluster for reads
- Asynchronous Replication
 - Micro GCP
 - Slave batching
- Various Topologies
 - Master - Master
 - Master - Slave
 - Circular, ring, hub etc
- Conflict resolution
 - Multi master, ring



MySQL Cluster Replication

Master - Slave

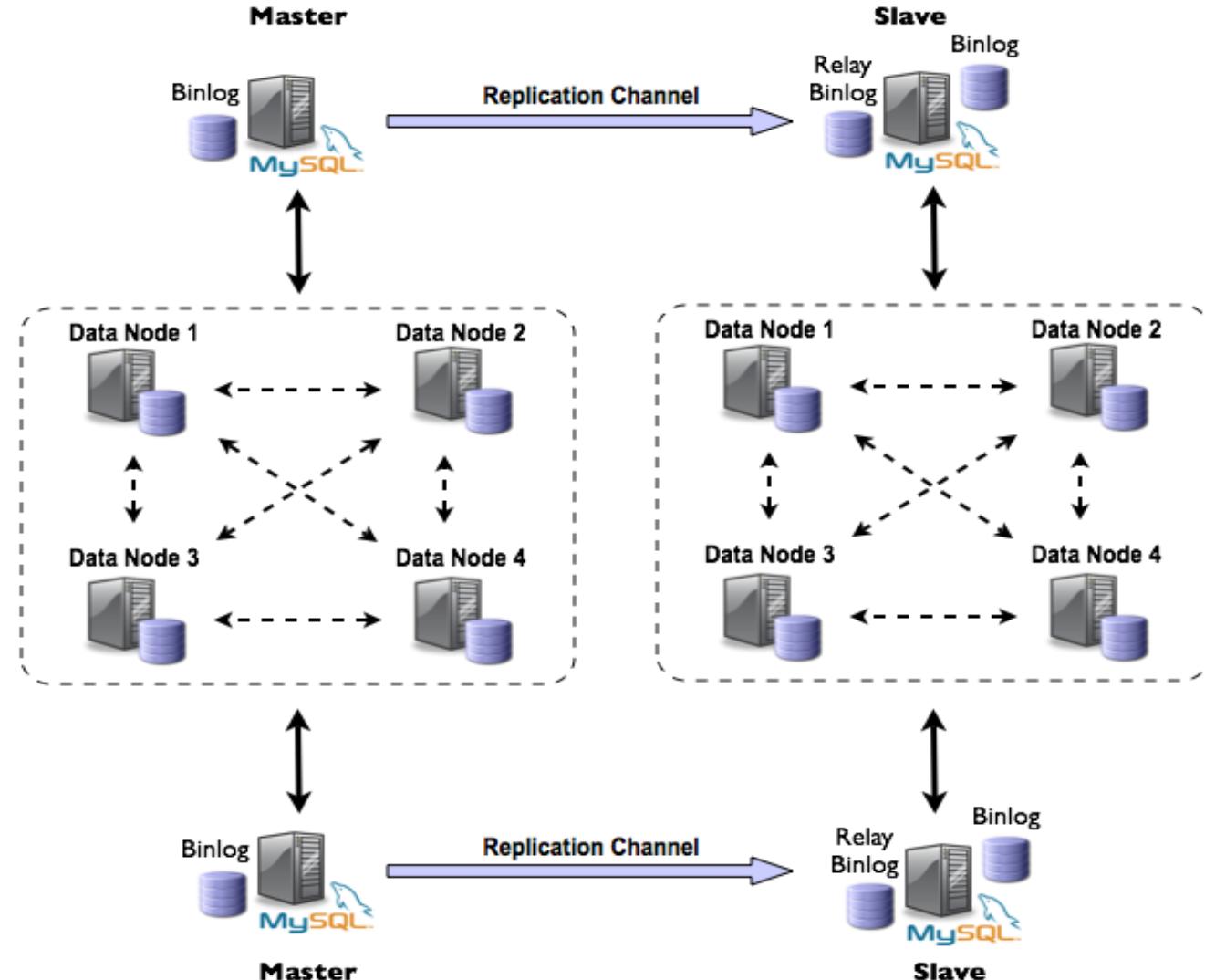
- A SQL Node/MySQL Server is responsible for the replication
 - NDB Binlog injector thread
 - Subscribes to events in MySQL Cluster.
- Injects rows into the Binlog
 - All changes in the cluster.



MySQL Cluster Replication

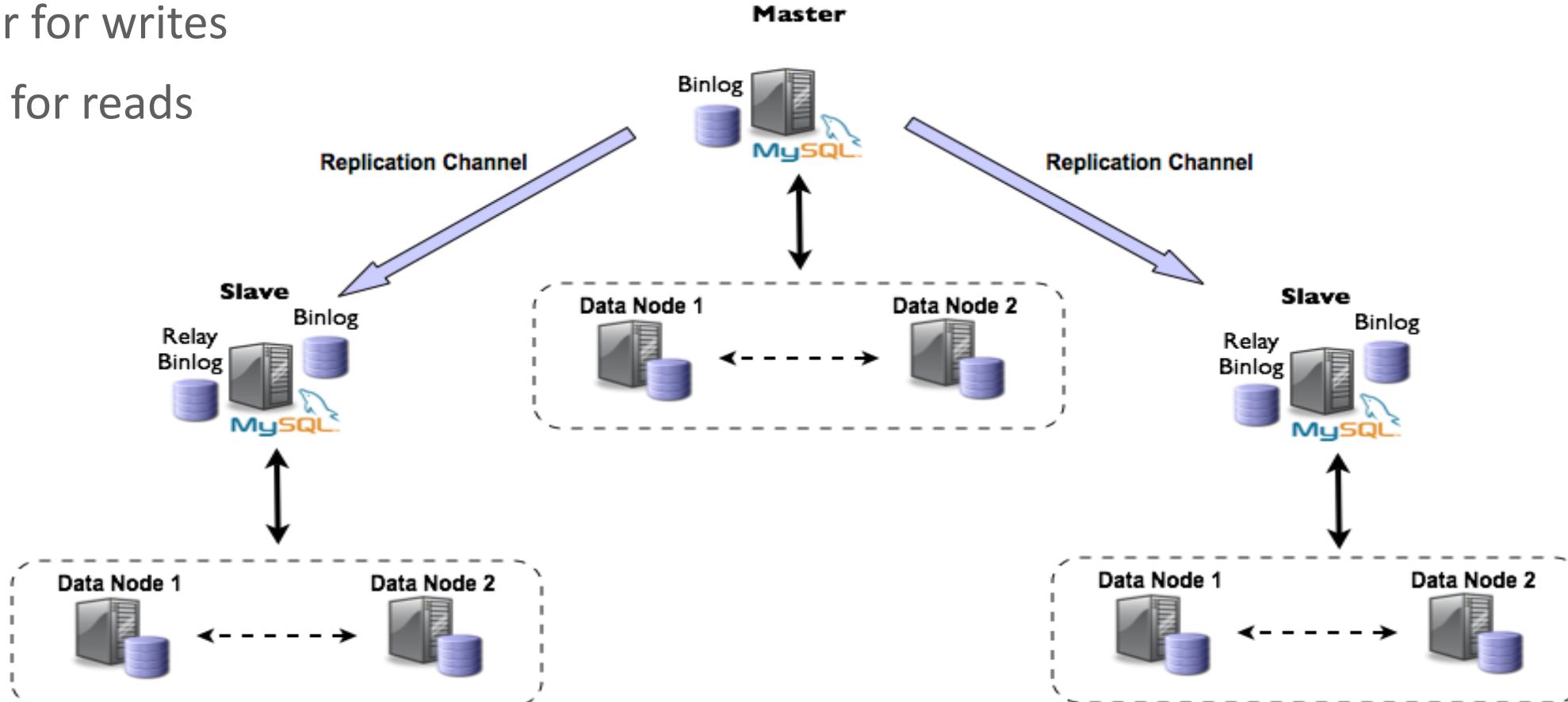
Master - Slave

- A SQL Node/MySQL Server is responsible for the replication
 - NDB Binlog injector thread
 - Subscribes to events in MySQL Cluster.
- Injects rows into the Binlog
 - All changes in the cluster.
- Two replication channels
 - No single point of failure



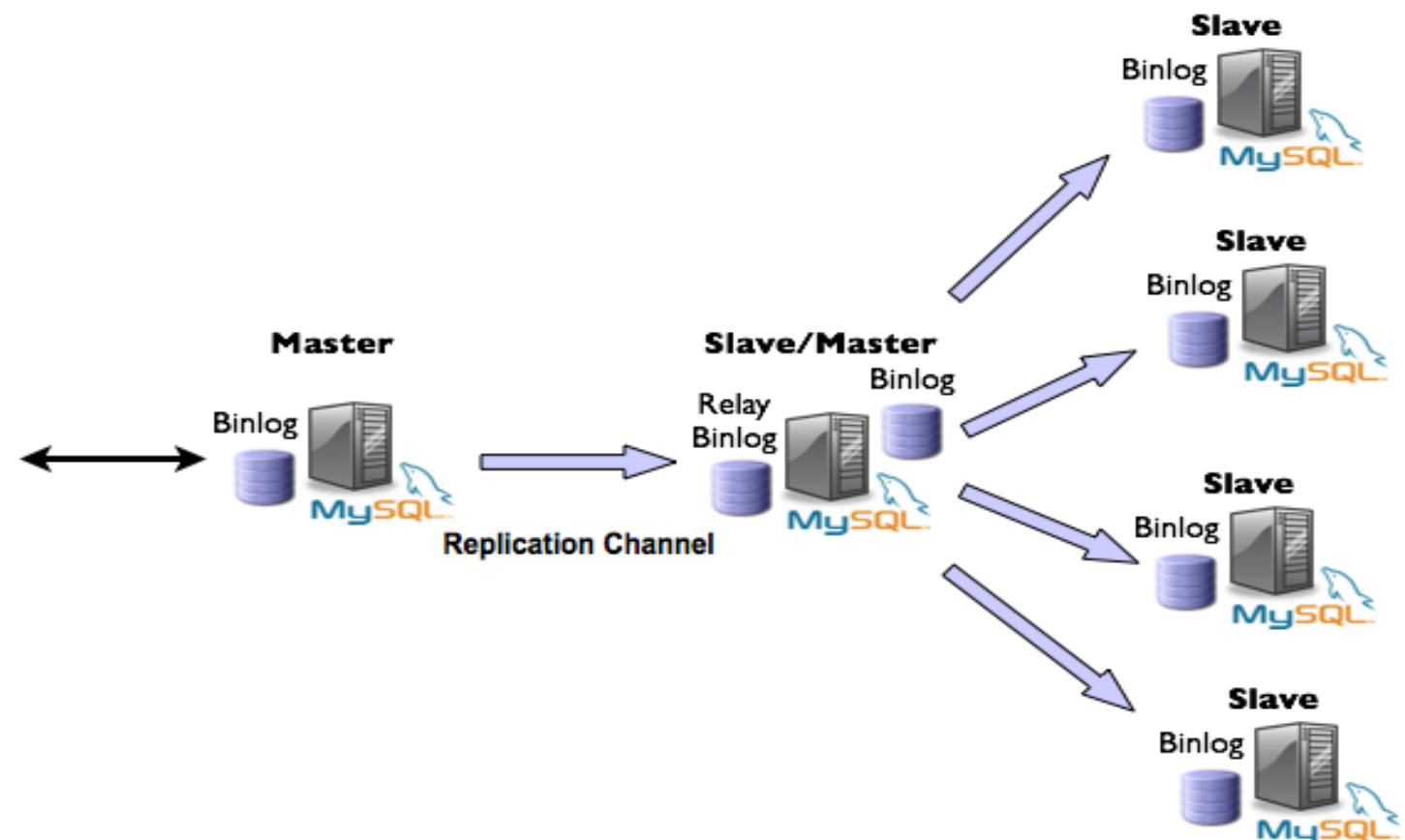
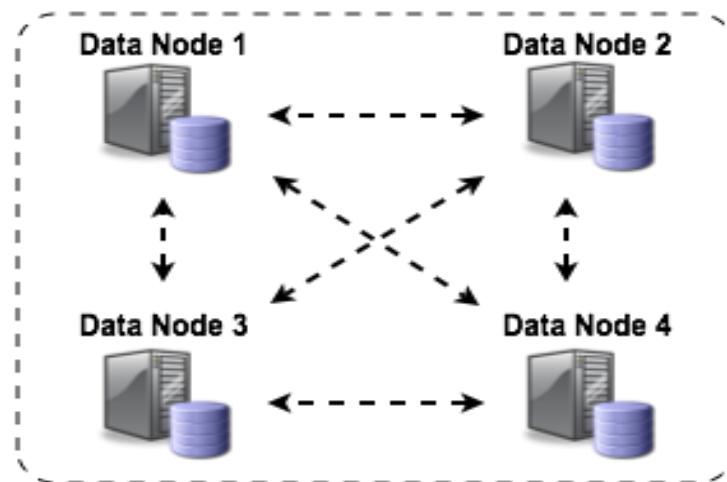
MySQL Cluster Replication Examples

- Master for writes
- Slaves for reads



MySQL Cluster Replication Examples

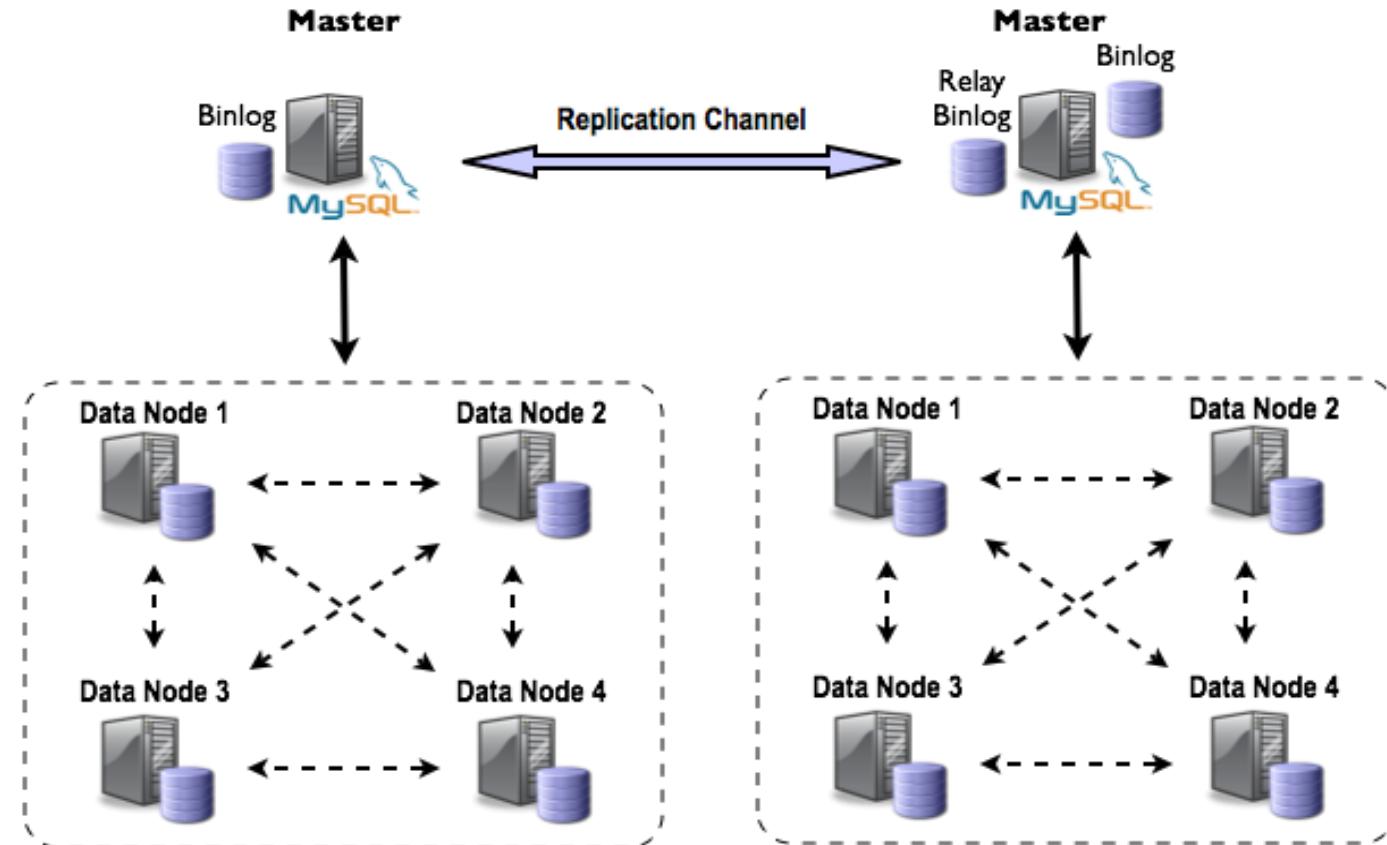
- Migrate MySQL Cluster Data
 - To any storage engine
- To InnoDB tables
 - CRM



MySQL Cluster Replication

Multi-Master

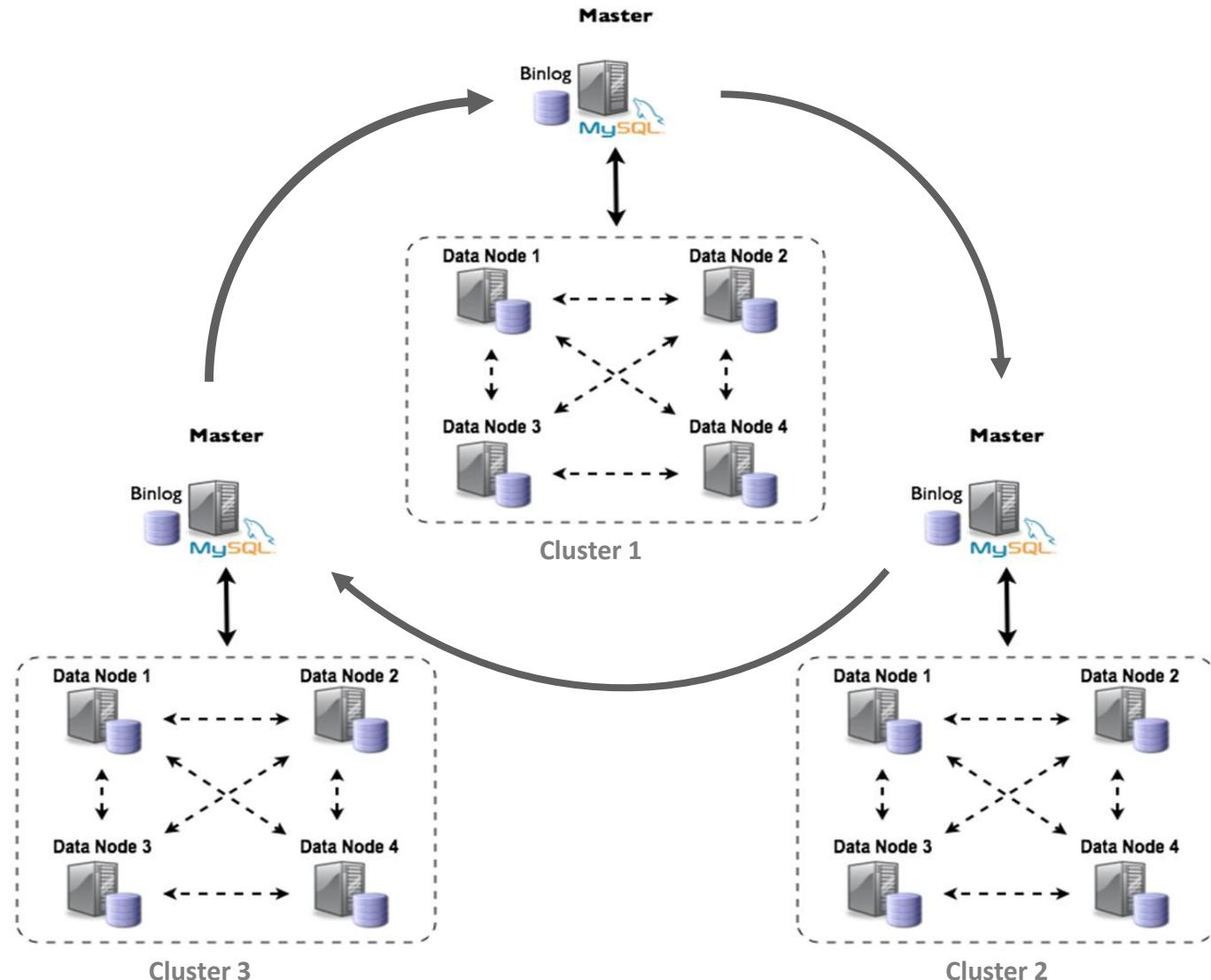
- Multi-Master
- Conflict resolution
 - timestamp
- Requirements:
 - Both Masters are NDB.
 - All SQL Nodes are the same.
 - Slaves need binlogging to be enabled.
 - Start mysqld with --ndb-log-orig=ON



MySQL Cluster Replication

Circular replication

- Cluster 1 is Master for Cluster 2,
 - Cluster 2 is Master for Cluster 3,
 - Cluster 3 is Master for Cluster 1
-
- Requirements:
 - All SQL Nodes are the same.
 - SQL nodes all started with
--log-slave-updates*.
 - All nodes need to be NDB.
 - No need to explicitly set
slave_exec_mode=IDEMPOTENT
- * Unless different SQL nodes are used as replication Masters & Slaves.



Conflict Resolution

2 types

- A user-defined resolution is permitted.
 - Types supported:
 - NDB\$OLD(), NDB\$MAX() & NDB\$MAX_DELETE_WIN(), as a ‘timestamp’ type column.
 - Row-by-row.
 - The Application holds the responsibility to make sure that the resolution column is correctly populated.
- Transaction based, comparing relative order of replication epochs:
 - NDB\$EPOCH() & NDB\$EPOCH_TRANS().
 - Does not make use of timestamps.

Conflict Resolution

User Defined

- Master: determine which columns are sent, all or just the updated ones.
 - --ndb-log-updated-only, MySQL Server wide
 - Per-table basis as per `mysql.ndb_replication`
- Slave: determine which Conflict Resolution to apply:
 - “latest timestamp wins”, “same timestamp wins”, “primary wins, complete transaction” or none.

Conflict Resolution

- Reflecting GCI (Global Checkpoint Index) removes requirement for applications to maintain timestamp field in each potentially conflicting table;
 - One of the two masters acts as the ‘primary’ and monitors all received replication events from the ‘secondary’ (including its own ‘reflected GCI’) to establish when changes not applied in same order on primary and secondary Clusters
 - Primary will then overwrite all conflicting transactions (or optionally just the conflicting rows) on the secondary – as well as subsequent transactions influenced by the conflict
- To use, set the function in **mysql.ndb_replication** to NDB\$EPOCH() or NDB\$EPOCH_TRANS()
- Overview & worked example: <http://clusterdb.com/u/conf>
- Finer details: <http://clusterdb.com/u/actact>

Conflict Resolution

mysql.ndb_replication

- Table required to be created manually:

```
CREATE TABLE mysql.ndb_replication (
    db VARBINARY(63),
    table_name VARBINARY(63),
    server_id INT UNSIGNED,
    binlog_type INT UNSIGNED,
    conflict_fn VARBINARY(128),
    PRIMARY KEY USING HASH (db, table_name, server_id)
) ENGINE=NDB
PARTITION BY KEY(db,table_name);
```

How To:

Master - Slave

Preparation:

1. Check version compatibility.
2. Create Slave account on Master.
3. Configure Slave to use Master.
4. Execute backup and load onto Slave.

Each MySQL Server acting as replication master has:

- Unique server-id
- Binary logging enabled
- Binlog Row format

How To:

Single-channel replication setup

1. If environments are cloned, then all the better, but just in case:

```
mysql -uroot -poracle -e "select version();"  
ndb_mgm -e show
```

2. On master:

```
grant REPLICATION SLAVE on *.* to 'replicant'@'192.168.56.107' identified by 'pkdick' ;  
FLUSH TABLES WITH READ LOCK;  
SHOW MASTER STATUS;
```

+

Make sure both env's have "log-bin=ON", "log-slave-updates=ON".

3. On slave:

\$DATADIR/auto.cnf has a unique server-uuid value for the slave, i.e. when cloned from Master, get new UUID from mysqld:
"select UUID();"

And use this one to replace existing entry.

Also, in my.cnf, set:

```
skip-slave-start = TRUE
```

Test the connection:

```
$ mysql -ureplicant -ppkdick -h192.168.56.106 -P3306 -e status  
mysql> change master to master_host='192.168.56.106', master_port=3306,  
master_user='replicant', master_password='pkdick', master_auto_position=1;
```

How To:

Single-channel replication setup cont.

4. Take a backup On Master:

```
ndb_mgm  
enter single user mode 10  
start backup
```

Wait for "Node 3: Backup 2 started from node 1 completed"

Exit single user mode

Go to backupdir on all Data nodes and copy the resulting backup dir contents to a central dir on the slave.

On slave:

```
mysql> reset slave;  
mysql> DELETE FROM mysql.ndb_apply_status;
```

For first restore, of 1st data node:

```
ndb_restore -c ol63uek04:1186 -n 3 -b 2 -m -r /opt/mysql/cluster/ndbd_data/BACKUP/BACKUP-2
```

For last (in this case, second as well) restore:

```
ndb_restore -c ol63uek04:1186 -n 4 -b 2 -e -r /opt/mysql/cluster/ndbd_data/BACKUP/BACKUP-2
```

On Slave:

Sync slave with master via:

```
change master to master_log_file='', master_log_pos=4;  *  
start slave;  
show slave status\G
```

How To:

Two-channel Replication

- Same as single node, but for between another 2 sql nodes o Master and slave, each using different server-id's.
- MUST: 2nd slave needs to be started with `skip-slave-start` in `my.cnf`.
- `start slave;` is only executed on the primary slave.

How To:

Two-channel Replication Failover

- As we're failing over from the 1st channel to the 2nd, we'll need some info as to where the 1st channel reached:

From any sqlnode on the Master Cluster:

```
select max(epoch) from mysql.ndb_apply_status;
```

From the replication Master sqlnode:

```
SELECT SUBSTRING_INDEX(File, '/', -1), Position  
FROM mysql.ndb_binlog_index  
WHERE epoch > <max_epoch_value_from_previous_sql>  
ORDER BY epoch ASC LIMIT 1;
```

- Sync the 2nd replication channel (2nd sqlnode):

```
CHANGE MASTER TO MASTER_LOG_FILE='<fileSubstringValue>',  
MASTER_LOG_POS=<positionValue>;  
start slave;
```

Replication hints

- Batch Updates:
 - `slave_allow_batching = ON|1` (normally, updates are applied as received, but this batches updates into 32Kb packets)
- Row based log-format.
- If we didn't have a primary key, it's always a good idea to revisit the need.
- High concurrency on the `ndb_binlog_index` table or getting big in size?
Consider additional indexes, located on other disks:
 - `ALTER TABLE mysql.ndb_binlog_index ADD INDEX orig_lookup USING BTREE (orig_server_id, orig_epoch);`

NDB to non-NDB tables

- Slave doesn't have to be NDB.
- Multi-master & circular replication not supported with different storage engines: They need to be NDB.
- Only one replication channel can be configured.
- For a storage engine where no binlogging is generated, requires special handling.
- Non-transactional storage engines for slave tables also require special handling.
- Row-based replication: attribute promotion and demotion & `slave_type_conversions` for lossy & non-lossy type conversions.
- Might need to use `ndb-log-update-as-write=0` to force updates to be logged as writes.



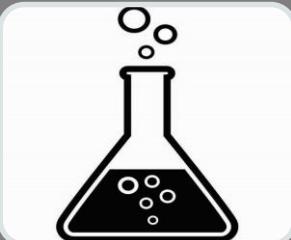
Questions?

Next Steps



Learn More

- www.mysql.com/cluster
- MySQL Curriculum: <http://oracle.com/education/mysql>



Try it Out

- dev.mysql.com/downloads/cluster/



Let us know what you think

- forums.mysql.com/list.php?25
- ted.wenmark@oracle.com
- keith.hollman@oracle.com

Thanks for attending!

