INSTITUTO SUPERIOR TÉCNICO
Universidade Técnica de Lisboa

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Author's Name

Dissertação para obtenção do Grau de Mestre em
Engenharia Informática e de Computadores

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Lisboa, August 5, 2014

Author's Name

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Abstract

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1 Apache Hadoop

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– Cerico

1.1 Introduction

Apache Hadoop (White 2009) is an open-source software framework for large-scale data processing. It includes a distributed file system called the Hadoop Distributed File System (HDFS) and a framework for MapReduce. Many data analysis, data warehousing and machine learning solutions have been built on top of it. The most commonly known extensions of Hadoop are Apache Pig (Foundation c), Apache Hive (A.Thusoo et al. 2009), Apache HBase (Foundation a), Apache Zookeeper (Foundation d) and Apache Mahout (Foundation b). Recent version of Hadoop also include a resource negotiator called Yet-Another- Resource-Negotiator (YARN), often also referred to as NextGen MapReduce or short MRv2. YARN is, inter alia, used to execute MapReduce jobs. The design and concepts used by Hadoop are inspired by the Google papers about GFS and MapReduce (White 2009, p. 9). Similar to MapReduce on GFS, Hadoop is exploiting data locality for MapReduce jobs by trying to execute map jobs on a DataNode which hosts the data. If not possible, the framework will attempt to execute the job on a node close to the location of data, for instance on the same rack. This can greatly improve the overall performance [28] and reduces the network bandwidth requirements.

1.2 Hadoop File System(HDFS)

HDFS is Hadoop's distributed file system which has been designed after Google File System.It was initially created to be used in a Map-Reduce computational framework of Hadoop by Apache though later on it started to be used for other big data applications as a storage which can support massive amount of data on commodity machines.Hadoop File System were intended to be distributed for being accessed and used inside by distributed processing machines of Hadoop with a short response time and maximum parallel streaming factor. On the other hand, in order for HDFS to be used as a storage of immutable data for applications like Facebook, the high availability is a key requirement besides the throughput and response time.Moreover, as a file system to be compliant to the common file system standard, it provides posix like interface in terms of operations, however it has a weaker consistency model than posix which is being discussed later on in this section.

1.2.1 HDFS Architecture

HDFS splits up each file into smaller blocks and replicates each block on a different random machine. Machines storing replicas of the blocks called DataNode. On the other hand since it needs to have namespace metadata accessible altogether, there is a dedicated metadata machine called NameNode. For having fast access to metadata, NameNode stores metadata in memory. Accessing to HDFS happens through its clients, each client asks NameNode about namespace information, or location of blocks to be read or written, then it connects to DataNodes for reading or writing file data. Figure1.1 shows the deployment of different nodes in HDFS.

1.2.2 HDFS NameNode

NameNode is known as metadata server of HDFS. Its multithreaded server in which size of the thread pool is configurable. It keeps all metadata information in memory which is described in the next section. The way NameNode protects race condition for metadata modification is based on read/write lock. It splits all operations into read or write operations.Its procedure is shown in alogithm 1.In this way multiple read operations could be run in parallel though they are serialized with each single write operation. Other than serving client's requests, NameNode has been serving part for DataNodes, via this service. DataNodes notice NameNode about receiving or deletion of blocks or they send over list of their replicas periodically. Moreover, NameNode has one still running thread namely ReplicationMonitor to get under-replication and over-replication under its radar and plans for deletion/replication accordingly. Moreover, LeaseMonitor controls the time limit that each client holds the write operation of files. So it walks through all leases and inspect their soft-limit/hard-limit and decides to recover or revoke an expired lease.

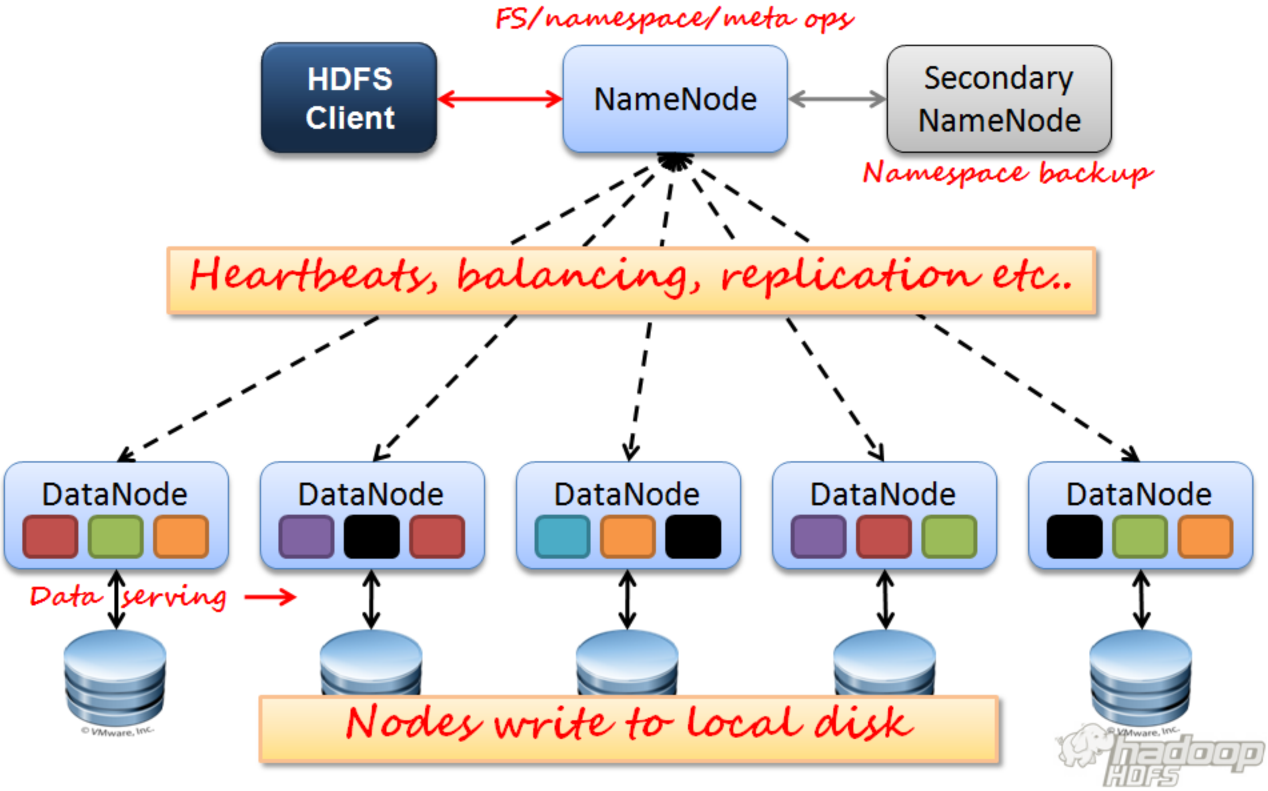

Figure 1.1: HDFS Architecture.

1.2.3 HDFS consistency model

1. **FileSystem Operations**

   In general most of the distributed file systems like GFS and HDFS have a relaxed version of consistency because of the impossibility result of CAP theorem (Gilbert & Lynch 2002) which limits scalability of file system. Even though some works refer to HDFS as sequential consistent file system for data and from filesystem operations point of view, it does not certainly have sequential consistency due to nonatomic write operation. HDFS serializes read/write operations just at the primitive operations' level not the files blockdata. As each write operations consists of multiple micro addBlock operations which makes it unsortable when multiple parallel reads are being performed with one write. Though it protects multiple writes by means of a persistable mechanism called lease.

2. **Primitive NameNode Operations**

   From primitive operations point of view, HDFS is strongly consistent in both data and metadata level. From data level it is strongly consistent because each file's block is not

Algorithm 1 System-Level locking schema in HDFS

```
Operation lock
if op.type = write then
    ns.acquireWriteLock()
else
    ns.acquireReadLock()
end if

Operation perform Task
//Operation body

Operation unlock
if op.type = write then
    ns.releaseWriteLock()
else
    ns.releaseReadLock()
end if
```

available for read unless it gets completely replicated. It means write operation should be completely finished first, then readers will all get the same version of that block and there is not case of version mismatch in the replicas read by two different readers. From meta-data level, as already been mentioned, system level lock serializes all the write operations which results in mutated state of all writes bing available for all readers.

1.2.4 POSIX compliant filesystem

POSIXfs is file system part of POSIX operating system. It has been being a standard for designing filesystems. It is about naming, hardlinks, access control, time stamping and standard folder hierarchy. Under POSIX standards, almost all file operations shall be linearized. Specifically all read operations should have effects of all previous write operations. HDFS is not fully POSIX compliant, because the requirements for a POSIX file system differ from the target goals for a Hadoop application. The tradeoff of not having a fully POSIXcompliant file system is increased performance for data throughput and support for nonPOSIX operations such as Append. Moreover, HDFS consistency model is weaker than POSIX. HDFS is strongly consistent from primitive HDFS operations while from filesystem operations it has a relaxed version of consistency, on the other hand, POSIX filesystem operations are linearizable which is the highest level of consistency.

2 Hadoop Open Platform as a service-HOP

2.1 Introduction

Hadoop Open Platform as a service (HOP) (HopStart) is a Hadoop distribution based on Apache Hadoop . It provides namespace scalability through the support of multiple NameNodes, platform as a service support for creating and managing clusters, and a dashboard for simplified administration. HOP is developed in cooperation of KTH and SICS (SICS)

2.2 HOP-HDFS

HOP-HDFS(Malik 2012) (Sajjad 2013) is a fork of HDFS and part of HOP. It aims on providing high availability and scalability for HDFS. This is achieved by making the NameNode stateless and thereby adding support for the use of multiple NameNodes at the same time. Instead of storing any state in the NameNode, the state is stored in a distributed database offering high-availability and high-redundancy. Therefore, the current implementation uses MySQL Cluster (Oracle), which utilizes NDB Cluster as an underlying storage engine. HOP-HDFS is a promising approach that could make HDFS similar to Colos-sus, while overcoming the scalability and availability limitations of the current Hadoop implementation. Through its support for larger amounts of metadata, it could also make the use of block sizes smaller than 64 megabytes efficient, what might be useful for many applications.

2.2.1 HOP-HDFS Architecture

The persistent data structures of HOP-HDFS (here after referred as HDFS) are defined as 11 database tables. These tables contain all the information about namespace,metadata,block locations and many other information that name-node in HDFS stores in FSImage and keeps in memory.

1. **inodes:** The table representing inode data structure in HDFS which contains the namespace and metadata of the files and directories. inodes are related together by their parent_ id and resembles a hierarchical namespace as in the HDFS. Each row has a unique id which is the primary key.

2. **block_ inofs:** Block is a primitive of HDFS storing a chunk of a file, block-info is its metadata keeping a reference to its file-inode, the list of block's replica which are scattered among multiple data-nodes.

3. **leases:** Basically each file in HDFS is either underconstruction or completed. All underconstruction files are assigned a sort of write lock to them, this lock is persisted in database. Each lease corresponds to just one client machine, each client could be writing multiple files at a time.

4. **lease_ path:** Each lease path represents an underconstruction file, it holds full path of that file and points to the lease as its holder.

5. **replicas:** A copy of a Block which is persisted in one datanode, sometime we refer to replicas as blocks. All the replicas of the same block points to the same blockinfo.

6. **corrupted_ replicas:** A replica become corrupted in the copy operations or due to the storage damages. Namenode realizes this by comparing checksum in the report of the replica's datanode with the checksum of the original block.

7. **excess_ replicas:** A block could become over replicated because of an already dead datanode coming alive again and contain some replicas which has been removed meanwhile from namenode. So distinguishing that, namenode marks marks some replicas to be removed later on.

8. **invalidated_ blocks:** For every datanode keeps a list of blocks that are going to be invalidated(removed) on that datanode due to any reason.

9. **replicas_ under_ construction:** Replications of a block which are being streamed by client into datanodes.

10. **under_ replicated_ blocks:** Keeps track of the blocks which has been under replicated, it realizes the priority of under replications as follow. Priority 0 is the highest priority.

Blocks having only one replica or having only decommissioned replicas are assigned priority 0. Blocks having expected number of replicas but not enough racks are assigned with priority 3. If the number of replicas of a block are 3 times less than expected number of replicas then the priority is assigned to 1. The rest of low replication cases are assigned priority 2. Blocks having zero number of replicas but also zero number of decommissioned replicas are assigned priority 4 as corrupted blocks.

11. **pending_ blocks:** Represents a blocks that are being replicated.

The figure 2.1 illustrates the relation between tables. The figure 2.2 gives the columns stored in each table.

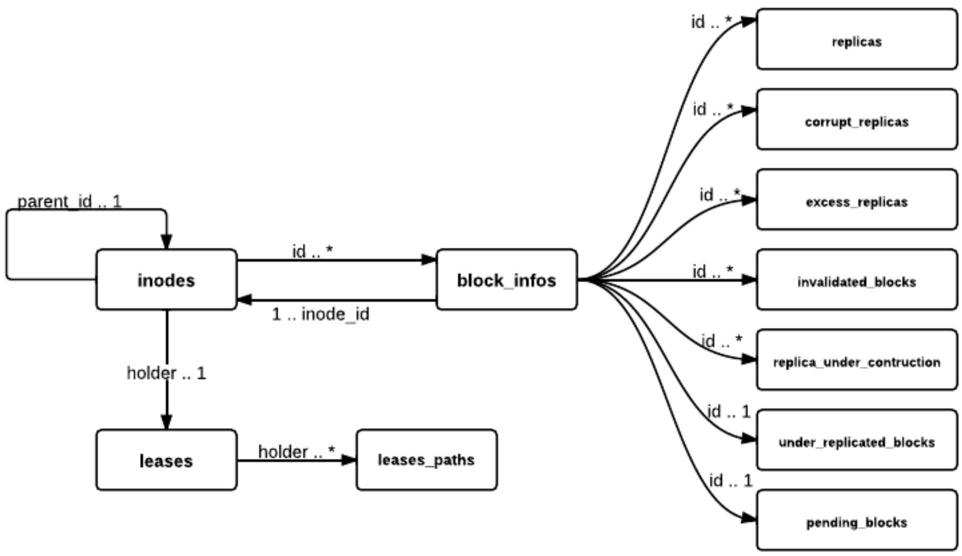

Figure 2.1: HOP-HDFS Table relations.

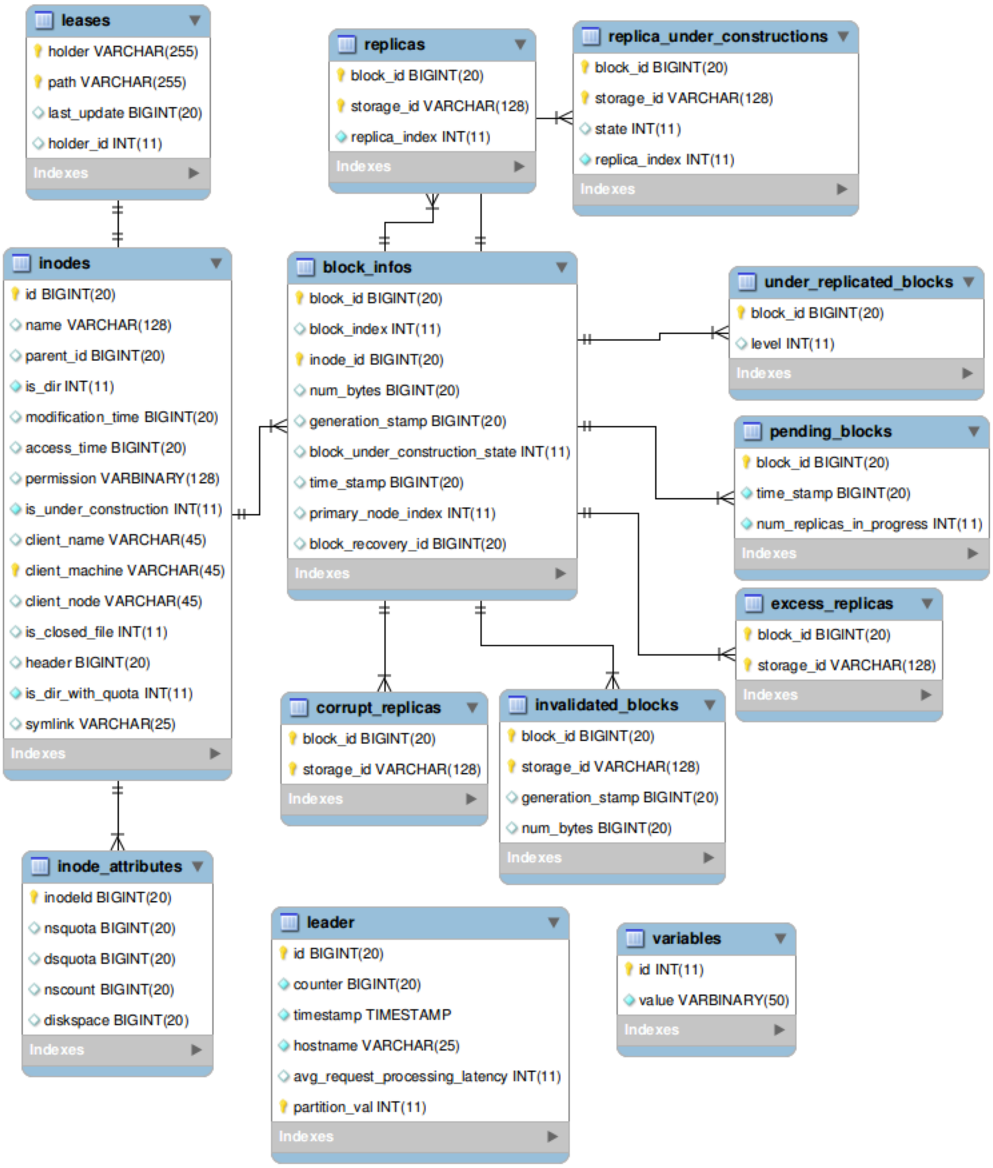

Figure 2.2: HOP-HDFS Schema

2.2.2 NameNode Operations

Every operation defined in the HDFS client API (such as createFile, open, etc) maps onto one or more of the following primitive HDFS operations. Each operation defined in the primitive HDFS API maps onto a protocol message (where each protocol message contains request, reply, and exception parts) sent between the NameNode, client, and DataNodes. Some common primitive operations are shown in the table 2.1. The full list of the primitive operations can be found in Thesis report (Sajjad 2013) Appendix section.

OPERATION	SUMMARY
MKDIR	Creates a directory recursively, it requires a no lock on all the existing components of the path but write lock on the last existing.
START_ FILE	1. If file does not exist, It creates inodes for all the nonexistent directories and new file, writes owner of the lease and creates new leasepath. 2. If file already exists first removes the file, its blocks and dependencies, lease and lease path, then it does the first scenario.
GET_ ADDITIONAL_ BLOCK	In the middle of writing a file, this is the client's mean of noticing namenode that the already being written block is finished while it is asking for the locations of next block. NameNode removes all the replicaunderconstructions of last block, it also changes type of blockinfo from underconstruction to completed one.
COMPLETE	Like get_ additional_ block, it happens for last block of the file, NameNode just removes the replicaunderconstructions and changes type of blockinfo from underconstruction to completed.
GET_ BLOCK_ LOCATIONS	Given path of the file, it returns location if its blocks and updates accesstime of the fileinode.
DELETE	Delete the given file or directory from the file system.
RENAME	Renames gives SRC to DST. Without OVERWRITE option, rename fails if the dst already exists. With OVERWRITE option, rename overwrites the dst, if it is a file or an empty directory. Rename fails if dst is a non-empty directory. The rename opeartion is atomic.
APPEND	Append to the end of the file.It retuns the partially completed last block if any.

Table 2.1: NameNode's Operations

2.2.3 HOP-HDFS Implementation

n HOP-HDFS each HDFS opeartion is implemented as a single transaction,where after transaction began, read and write the necessary meta-data from NDB , and then either commit the transaction, or in case of failure, the transaction was aborted and then possibly retried. However, the default isolation level of NDB is read committed, which allows the results of write operations in transactions to be exposed to read operations in different concurrent transactions. This means that a relatively long running read transaction could read two different versions of data within the same transaction, known as a fuzzy read, or it could get different sets of results if the same query is issued twice within the same transaction this is known as a phantom read. In report(Sajjad 2013) and paper (Hakimzadeh et al. 2014) they proposed and implemented the snapshot-isolation method 2 which pessimistically locks the rows of data preventing other transactions from accessing.

Algorithm 2 Snapshotting taking locks in a total order

```
snapshot.clear

Operation doOperation

tx.begin
create-snapshot()
performTask()
tx.commit

Operation create-snapshot

S = total_ order_ sort(op.X)
for all x in S do
    if x is a parent then
        level = x.parent_ level_ lock
    else
        level = x.strongest_ lock_ type
        tx.lockLevel(level)
        snapshot <- tx.find(x.query)
    end if
end for

Operation performTask
//Operation Body,referring to transaction cache for data
```

2.3 MySQL Cluster

Mysql Cluster is a Database Management System (DBMS) that integrates the standard Mysql Server with an inmemory clustered storage engine called NDB Cluster (which stands for "Network DataBase") . It provides a sharednothing system with no single point of failure.

Mysql Cluster is a compound of different processes called **nodes**. The main nodes are Mysql Servers (mysqld, for accessing NDB data), data nodes (ndbd, as the data storage), one or more management servers (ndb_ mgmd). The relationship between these nodes are shown in figure 2.3. The data in Mysql Cluster is replicated over multiple ndbds so this makes the database to be available in case of node failures. Ndbds are divided into **node groups**. Each unit of data stored by ndbd is called a **partition**. The partitions of data are replicated into ndbds of the same node group while node groups are calculated indirectly as following:

$$NumberofNodegroups = \frac{numberofdatanodes}{numberofreplicas}$$

A simple cluster of 4 datanodes with replication factor of 2 and consequently 2 node groups are shown in figure 8. As it can be seen, the data stored in the database are divided into 4 partitions. There are two replicas of each partition into ndbds of the same node group. So even if one of the ndbds in each of the node groups are failed, the whole data in the cluster will be available. However, if both ndbs in a node group become unavailable then those partitions stored by the failed ndbs also will become unavailable. According to a white paper published by Oracle , Mysql Cluster can handle 4.3 billion fully consistent reads and 1.2 fully transactional writes per minute. They used an open source benchmark called flexAsynch and a Mysql Cluster of 30 data nodes, comprised 15 node groups. The detail of their system configuration is available in the referenced white paper. The results for write operations are shown in figure 2.3. The 72 million reads and 19.5 million write operations per second of Mysql Cluster shows that it has a high throughput for simple read and write operations.

2.3.1 Concurrency Control in NDBCluster

NDB supports pessimistic concurrency control based on locking. It supports row level locking. NDB throws a timeout error if a requested lock cannot be acquired within a specified time (MySql). Concurrent transactions, requested by parallel threads or applications, reaching the same row could end up with deadlock. So, it is up to applications to handle deadlocks gracefully. This means that the timed out transaction should be rolled back and restarted. Transactions in NDB are expected to complete within a short period of time, by default 2 seconds. This enables NDB to support realtime services, that are, operations expected to complete in bounded time. As such, NDB enables the construction of services that can failover, on node failures, within a few seconds ongoing transactions on the node that dies timeout within a couple of seconds, and its transactions can be restarted on another node in the system.

2.3.2 ClusterJ

Clusterj is Java connector implementation of NDB Cluster, Mysql Cluster's storage engine, (Oracle). Clusterj uses a JNI bridge to the NDB API to have a direct access to NDB Cluster. The NDB API is an application programming interface for Mysql Cluster that implements indexes, scans, transactions and event handling. Clusterj connects directly to NDB Clusters instead of connecting to mysqld. It is a persistence framework in the style of Java Persistence API. It provides a data mapper mapping java classes to database tables which separates the data from business logic.

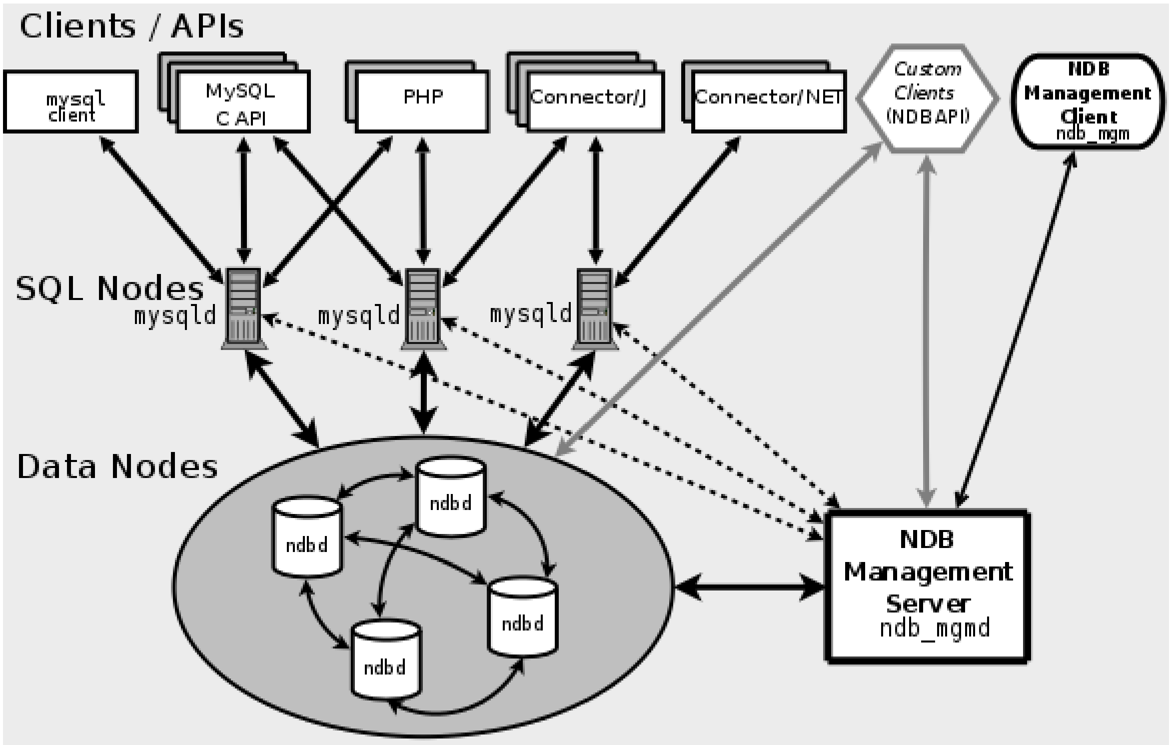

Figure 2.3: MySQL cluster

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3 Read-Only Nested Snapshots

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3.1 Architecture

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4 Read-Only Root Level Single Snapshot

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4.1 Architecture

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III
Cumque Nihil Impedit

Laborum et Dolorum

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5 Read-Only Nested Snapshots

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– Cerico

5.1 Architecture

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6 Read-Only Root Level Single Snapshot

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6.1 Modifications to the Schema

Following columns need to be added to the Inodes table described in the schema of HOP File System.

6.2 Roll Back

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IV

Expedita Distinctio

Omnis voluptas

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7 Omnis Voluptas

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8 Magna Aliqua

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V
Appendices

Figure A.1: Soluta nobis est eligendi optio.