Optimistic Concurrency Control in a Distributed NameNode Architecture for Hadoop Distributed File System

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September 8, 2014, Stockholm

Qi Qi

Dedication

To my father, a man of integrity, who supports all my adventurous decisions so that I can live outside of the box.

Resumo

[To be added] Portuguese Abstract

Abstract

The *Hadoop Distributed File System* (HDFS) is the storage layer for Apache Hadoop ecosystem, persisting large data sets across multiple machines. However, the overall storage capacity is limited since the metadata is stored in-memory on a single server, called the *NameNode*. The heap size of the NameNode restricts the number of data files and addressable blocks persisted in the file system.

The *Hadoop Open Platform-as-a-service* (Hop) is an open platform-as-a-Service (PaaS) support of the Hadoop ecosystem on existing cloud platforms including Amazon Web Service and OpenStack. The storage layer of Hop, called the Hop-HDFS, is a highly available implementation of HDFS, based on storing the metadata in a distributed, in-memory, replicated database, called the *MySQL Cluster*. It aims to overcome the NameNode's limitation while maintaining the strong consistency semantics of HDFS so that applications written for HDFS can run on Hop-HDFS without modifications.

Precedent thesis works have contributed for a transaction model for Hop-HDFS. From system-level coarse grained locking to row-level fine grained locking, the strong consistency semantics have been ensured in Hop-HDFS, but the overall performance is restricted compared to the original HDFS.

In this thesis, we first analyze the limitation of HDFS NameNode implementation and provide an overview of Hop-HDFS illustrating how we overcome those problems. Then we give a systematic assessment on precedent works for Hop-HDFS comparing to HDFS, and also analyze the restriction when using pessimistic locking mechanisms to ensure the strong consistency semantics. Finally, based on the investigation of current shortcomings, we demonstrate how to improve the performance by designing a new model based on optimistic concurrency control with snapshot isolation. As a proof of concept, the evaluation shows the significant improvement of this new model. The correctness of our implementation has been validated by 300+ Apache HDFS unit tests passing.

Palavras Chave
Keywords

Palavras Chave [To be corrected by native Portuguese speaker]

HDFS

MySQL Cluster

Controle de Concorrência

Snapshot Isolation

Transação

Vazão

Keywords

HDFS

MySQL Cluster

Concurrency Control

Snapshot Isolation

Transaction

Throughput

Index

List of Figures

List of Tables

I

Introduction and Background

1 Introduction

1.1 Motivation

1.1.1 The De Facto Industrial Standard in Big Data Era

The *Apache Hadoop* (Apache) ecosystem has become the de facto industrial standard to store, process and analyze large data sets in the big data era (Cloudera). It is widely used as a computational platform for a variety of areas including search engines, data warehousing, behavioral analysis, natural language processing, genomic analysis, image processing, etc (Shvachko 2011).

The *Hadoop Distributed File System* (HDFS) is the storage layer for Apache Hadoop, which enables petabytes of data to be persisted on clusters of commodity hardware at relatively low cost (Borthakur 2008). Inspired by the *Google File System* (GFS) (Ghemawat et al. 2003), the namespace, *metadata*, is decoupled from data and stored in-memory on a single server, called the *NameNode*. The file datasets are stored as sequences of blocks and replicated across potentially thousands of machines for fault tolerance.

1.1.2 Limits to growth in HDFS

Built upon the single namespace server, *the NameNode*, architecture, one well-known limitation of HDFS is the limitation to growth (Shvachko 2010). Since the metadata is kept in-memory for fast operation in NameNode, the number of file objects in the filesystem is limited by the amount of memory of the NameNode.

Approximately, the size of the metadata for a single file object having two blocks (replicated three times by default) is 600 bytes. As a rule of thumb, for one petabyte physical storage, it requires one gigabyte metadata in memory (Shvachko 2010). Table 1.1 gives an estimation of the memory requirement and its related physical storage capacity for different number of files.

Number of Files	Memory Requirement	Physical Storage
1 million	0.6 GB	0.6 PB
100 million	60 GB	60 PB
1 billion	600 GB	600 PB
2 billion	1200 GB	1200 PB

Table 1.1: Memory Requirement for Related Storage Capacity in HDFS

As HDFS runs in the *Java Virtual Machine* (JVM), due to interactive workloads, heap sizes larger than 60 GB is not considered practical (Shvachko 2010). Therefore, 100 million files will be the maximum storage capacity of HDFS.

1.1.3 Hop-HDFS and Its Limitation

The *Hadoop Open Platform-as-a-service* (Hop) (Dowling 2013) is an open platform-as-a-Service (PaaS) support of the Hadoop ecosystem on existing cloud platforms including Amazon Web Service and OpenStack. The storage layer of Hop, called the Hop-HDFS, is a highly available implementation of HDFS, based on storing the metadata in a distributed, in-memory, replicated database, called the *MySQL Cluster*. It aims to overcome the NameNode's limitation while maintaining the strong consistency semantics of HDFS so that applications written for HDFS can run on Hop-HDFS without modifications.

Precedent thesis works have contributed for a transaction model (Wasif 2012) (Peiro Sajjad & Hakimzadeh Harirbaf 2013) as well as a high availability multi-NameNode architecture (D'Souza 2013) for Hop-HDFS. It can store up to 4.1 billion files with 3TB MySQL Cluster support for metadata (Hakimzadeh et al. 2014).

However, in HDFS, the correctness and consistency of the namespace is ensured by atomic metadata mutation (Shvachko et al. 2010). In order to maintain the same level of strong consistency semantics, system-level coarse grained locking (Wasif 2012) and row-level fine grained locking (Peiro Sajjad & Hakimzadeh Harirbaf 2013) are adopted in precedent projects of Hop-HDFS, but the overall performance is heavily restricted compared to the original HDFS. Therefore, efficient locking mechanisms needed to be investigated to achieve better concurrency control.

1.2 Problem Statement

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1.3 Contribution

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1.4 Document Structure

[To be Added]

2 Background and Related Work

2.1 A

AAA

2.2 B

BBB

2.3 C

CCC

2.4 D

DDD

II

Assessment in Hop-HDFS

3 Limitation on Pessimistic Locking Mechanism

3.1 A

AAA

3.2 B

BBB

3.2.1 B1

BBB1

3.2.2 B2

BBB2

3.3 C

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3.4 D

DDD

4 Systematic Assessment of Hop-HDFS Performance

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– Cerico

4.1 A

AAA

4.2 B

BBB

4.2.1 B1

BBB1

4.2.2 B2

BBB2

4.3 C

CCC

4.4 D

DDD

III Solution

5 Design

5.1 A

AAA

5.2 B

BBB

5.2.1 B1

BBB1

5.2.2 B2

BBB2

5.3 C

CCC

5.4 D

DDD

6 Implementation

6.1 A

AAA

6.2 B

BBB

6.2.1 B1

BBB1

6.2.2 B2

BBB2

6.3 C

CCC

6.4 D

DDD

IV

Evaluation and Conclusion

7 Evaluation

7.1 A

AAA

7.2 B

BBB

7.2.1 B1

BBB1

7.2.2 B2

BBB2

7.3 C

CCC

7.4 D

DDD

8
Conclusion

8.1 A

AAA

8.2 B

BBB

8.2.1 B1

BBB1

8.2.2 B2

BBB2

8.3 C

CCC

8.4 D

DDD

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V

Appendices

A

Apache HDFS Unit Tests Passing List