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

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Motivation

Industrial Standard in Big Data Era

Apache Hadoop Ecosystem

Limits to growth in HDFS

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

Hops-HDFS and Its Limitation

Distributed NameNode Architecture
Maintain HDFS Strong Consistency Semantics
Concurrency Restricted

Problem Statement

HDFS

System-level Lock

Hops-HDFS v1

System-level Lock

Hops-HDFS v2

Row-level Lock

MySQL Cluster

Read Committed / Anomalies

Contribution

Architectures and Namespace Concurrency Control

GFS, HDFS, Hops-HDFS and MySQL Cluster

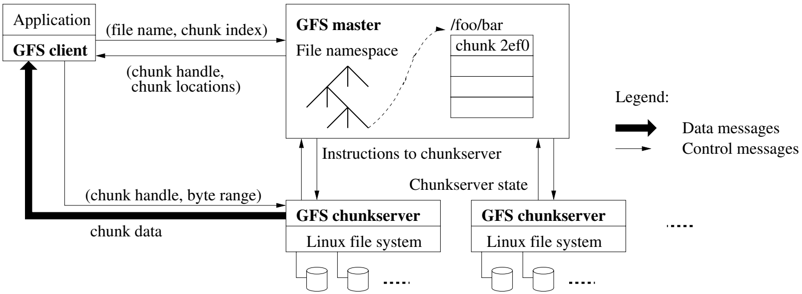
Performance Accessment and Limitation Analysis

HDFS v.s. Hops-HDFS v2 (PCC version)

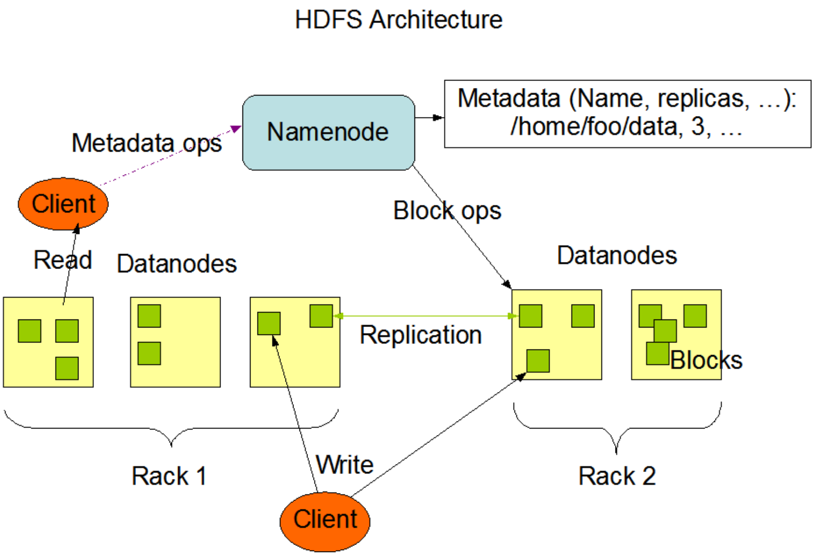
Solution for Hops-HDFS

- Optimistic Concurrency Control with Snapshot Isolation on Semantic Related Group
- Performance Increase Up to 70 %
- Ensured by Passing 300+ Apache HDFS Unit Tests

GFS Architecture



HDFS Architecture



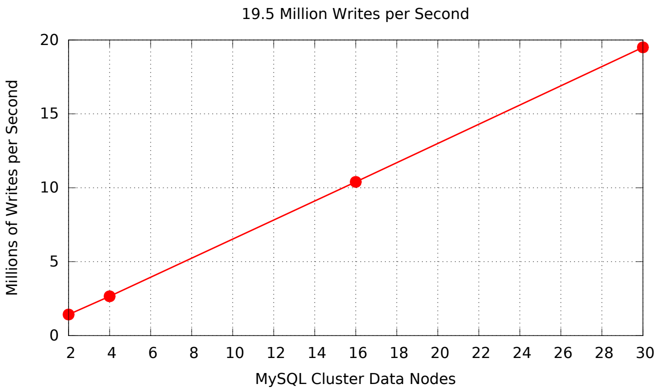
Isolation Level

Berenson, Hal, et al. "A Critique of ANSI SQL Isolation Levels." ACM SIGMOD Record 24.2 (1995): 1-10.

Isolation Level	**Lost Update**	**Fuzzy Read**	**Phantom**	**Read Skew**	**Write Skew**
Read Uncommitted	✓	✓	✓	✓	✓
Read Committed	✓	✓	✓	✓	✓
Cursor Stability	sometimes	sometimes	✓	✓	sometimes
Repeatable Read	X	X	✓	X	X
Snapshot	X	X	sometimes	X	✓
Serializable	X	X	X	X	X

MySQL Cluster

- Distributed, in-memory, replicated database
- Supports only **Read Committed**
- High throughput:

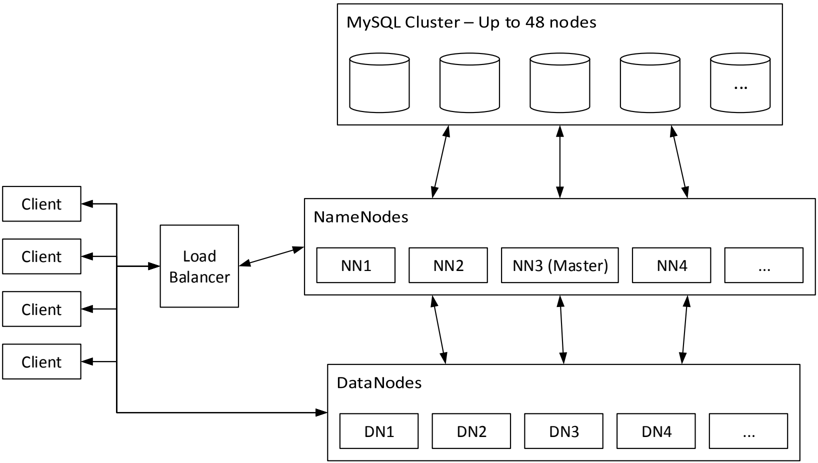


Hops-HDFS

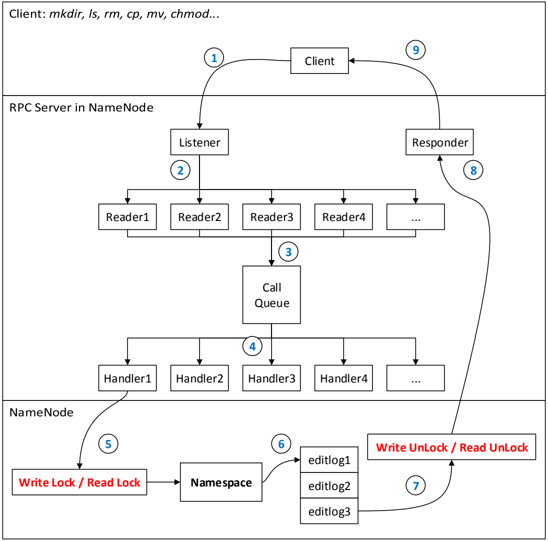
Overcome Limitations in HDFS NameNode

- Scalability of the Namespace
- Throughput Problem
- Failure Recovery

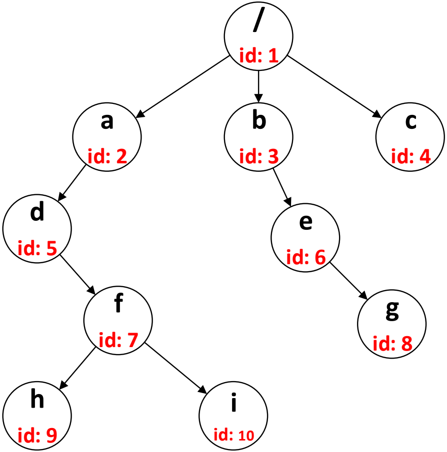
Hops-HDFS Architecture



Limitations in HDFS Namespace Concurrency Control



Hops-HDFS Namespace Structure



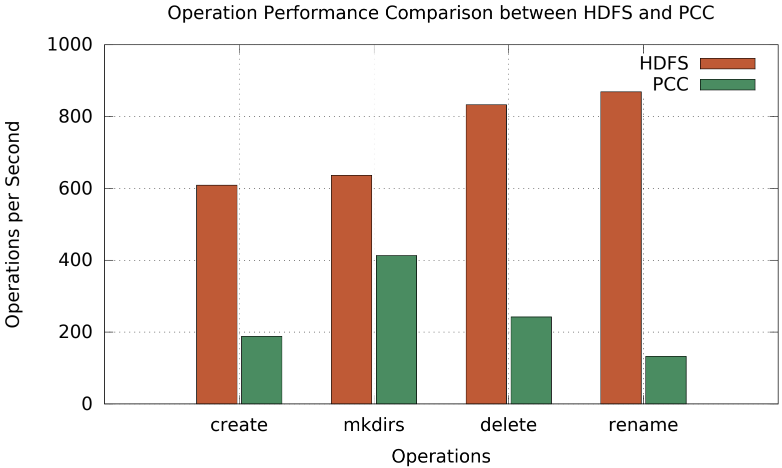
id	parent_id	name
1	0	/
2	1	a
3	1	b
4	1	c
5	2	d
6	3	e
7	5	f
8	6	g
9	7	h
10	7	i

Limitations in Hops-HDFS Namespace Concurrency Control

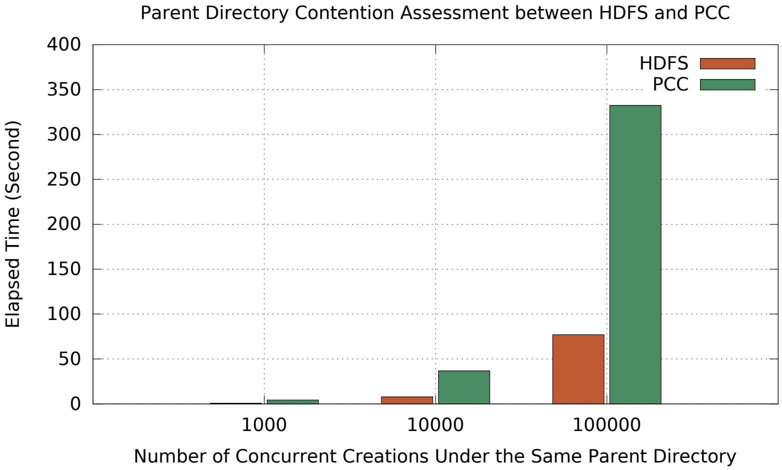
- Duplicated Round Trips
- Implicit Parent Locks:

id	parent_id	name	Locks by Tx1	Locks by Tx2
1	0	/	R	R
2	1	a	R	R
3	1	b		
4	1	c		
5	2	d	R	R
6	3	e		
7	5	f	W	W **(Block)**
8	6	g		
9	7	h (Tx1)	W (Implicit)	W (Implicit) **(Block)**
10	7	i (Tx2)	W (Implicit)	W (Implicit) **(Block)**

NameNode Throughput Benchmark



Parent Directory Contention Assessment



Resolving the Semantic Related Group

Path: /a/d/f/h

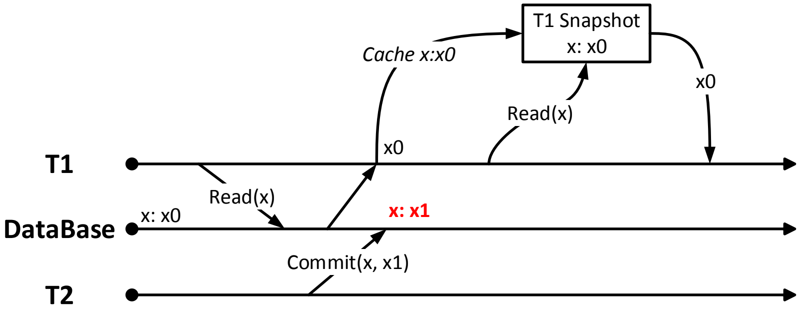
h: {/->a->d->f}

	id	parent_id	name	other parameters...
Related *	1	0	/	...
Related *	2	1	a	...
	3	1	b	...
	4	1	c	...
Related *	5	2	d	...
	6	3	e	...
Related *	7	5	f	...
	8	6	g	...
Selected ✓	9	7	h	...
	10	7	i	...

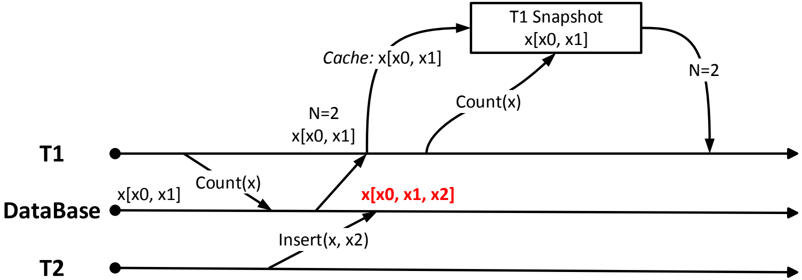
Per-Transaction Snapshot Isolation

- Snapshot the whole Semantic Related Group
- Transaction performs on its own snapshot
- Preclude: *Fuzzy Read & Phantom Read*

Snapshot Isolation Precludes Fuzzy Read



Snapshot Isolation with Semantic Related Group Precludes Phantom Read



Lock Mode in MySQL Cluster

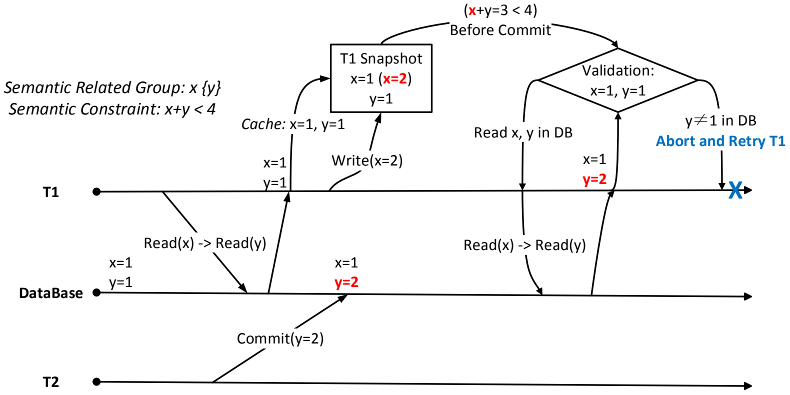
Read_Committed: Consistent nonlocking reads (based on MVCC)

Lock Type	Shared	Exclusive	Read_Committed
Shared	✓	Block	✓
Exclusive	Block	Block	✓
Read_Committed	✓	✓	✓

Optimistic Concurrency Control

- Read Phase: *Read_Committed* on snapshot
- Validation Phase: *Shared* on related Rows, *Exclusive* on modified rows / Compare versions / Abort and retry
- Preclude: *Write Skew*

OCC with Snapshot Isolation on Semantic Related Group Precludes Write Skew



Total Order Update, Abort & Retry, and Version Increase

- Total order update modified rows by *ids*
- Abort and retry transactions if "new" rows already exists
- Increase versions for successful update

Four Phases in Algorithm

- Read Phase
- Execution Phase
- Validation Phase
- Update Phase

Experimental Testbed

MySQL Cluster

6 data nodes, 1 Gbps LAN, Intel Xeon X5660 CPU @ 2.80GHz, 6*6=36 GB RAM, 2 data replicas

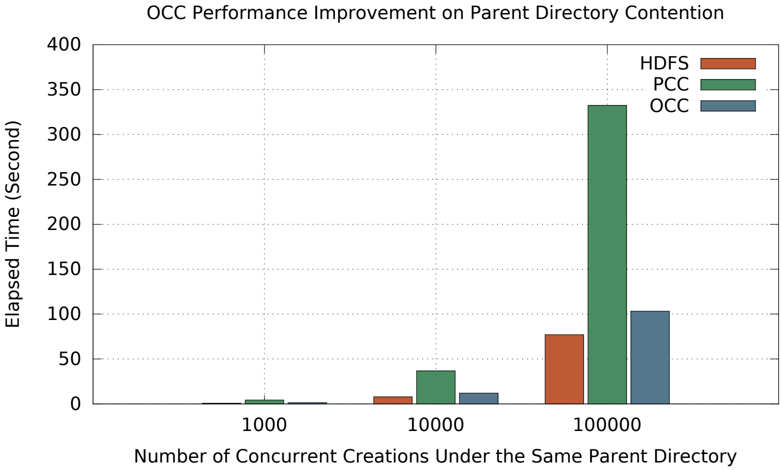
NameNode and Clients

Intel i7-4770T CPU @ 2.50GHz and 16 GB RAM

MySQL Cluster and NameNode

100 Mbps LAN

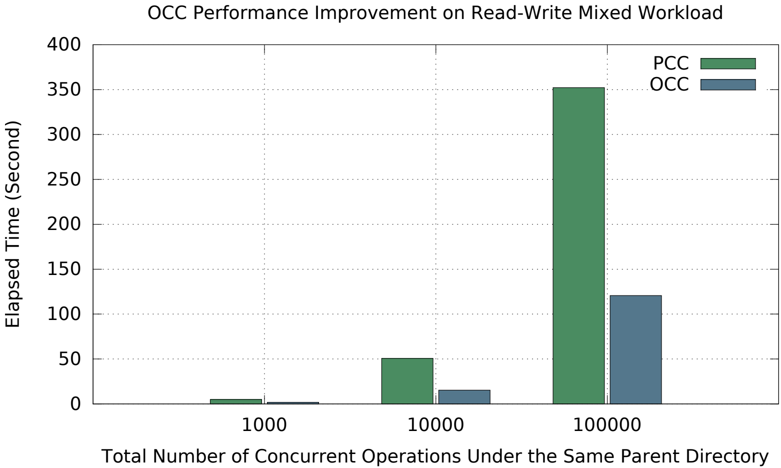
Parent Directory Contention Assessment



Parent Directory Contention Assessment

Num. of Concurrent Creation	**1000**	**10000**	**100000**
HDFS	0.82s	7.83s	77.13s
PCC	4.35s	36.74s	332.36s
OCC	1.36s	12.01s	103.23s
PCC / HDFS	530.5%	469.2%	430.9%
OCC / HDFS	165.9%	153.4%	133.8%
OCC Improvement: (PCC-OCC) / PCC	**68.7%**	**67.3%**	**68.9%**

Read-Write Mixed Workload



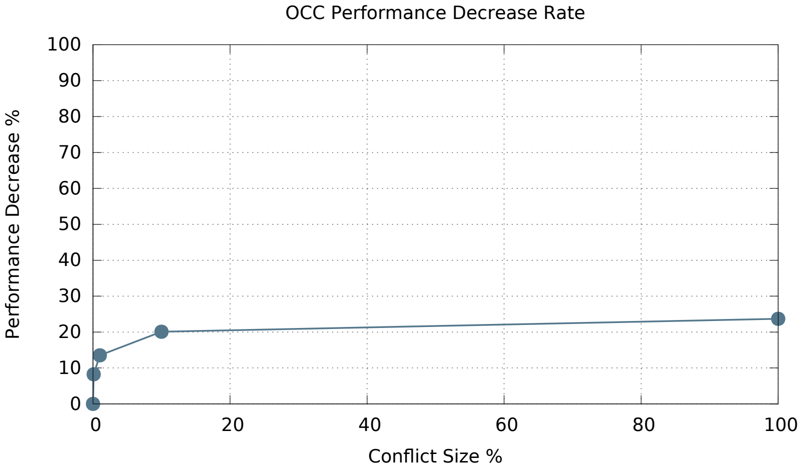
Read-Write Mixed Workload

Concurrent Read+Creation	**1000**	**10000**	**100000**
PCC	4.92s	50.69s	352.25s
OCC	1.78s	15.31s	120.64s
OCC Improvement: (PCC-OCC) / PCC	**63.8%**	**69.8%**	**65.8%**

OCC Performance with Different Size of Conflicts

Creations for 10000 Operations	Conflict Size	Elapsed Time (Second)	Performance Decrease
1	100%	14.53	23.7%
10	10%	14.11	20.1%
100	1%	13.51	15.0%
1000	0.1%	12.72	8.23%
10000	0%	11.75	0%

OCC Performance Decrease Rate



Implementation Correctness Assessment

Ensured by passing 300+ Apache HDFS Unit Tests

Conclusion & Future Work

Conclusion

- Increase Performance up to 70 %
- Maintain HDFS Strong Consistency Semantics

Future Work

- OCC implementation on other operations
- OCC evaluation on multiple NameNodes

Thank you!