Carnegie Mellon University

Filesystems for Exascale Storage

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And Gary Grider and team, LANL

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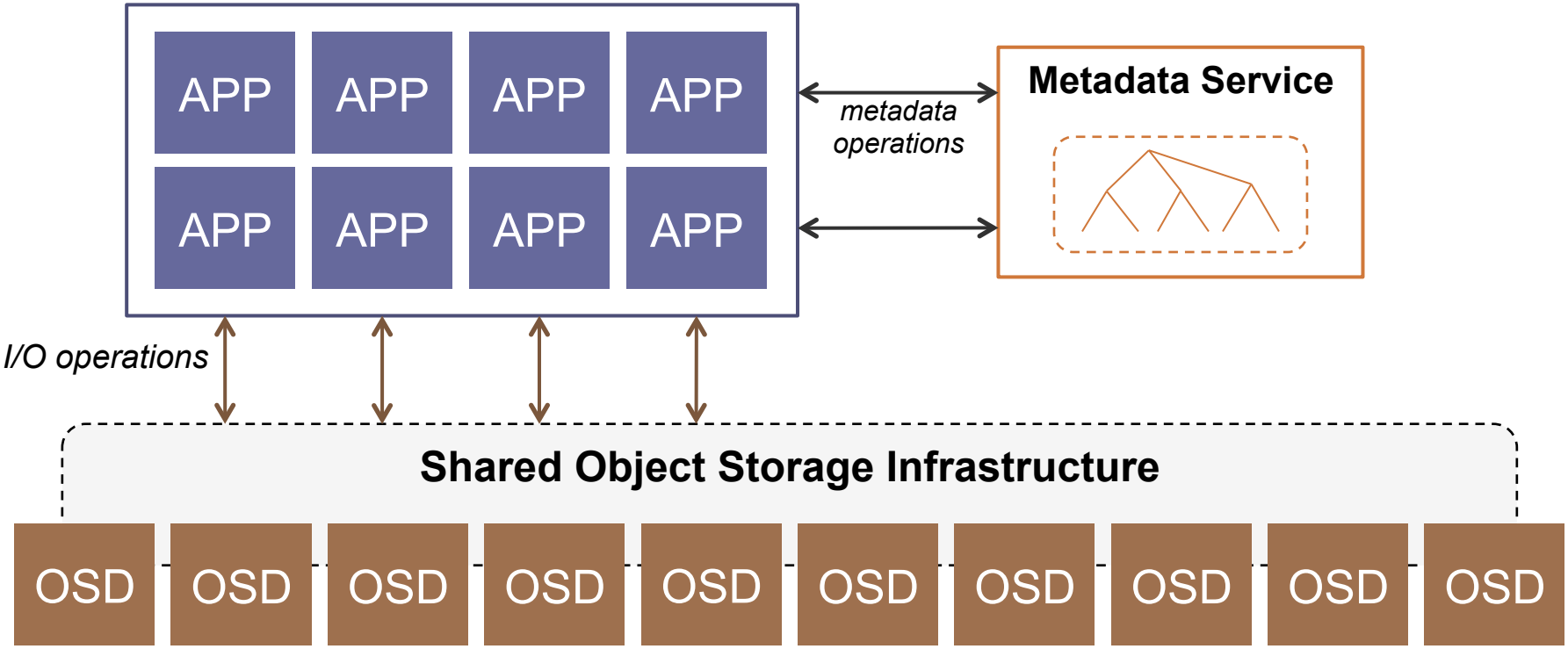
Intel Science & Technology Center for Cloud Computing

Parallel File System Architecture

Object-based scalable storage circa 2000: Data parallel



Data path is loosely coupled, parallel, simple, scalable but ~POSIX metadata path is not necessarily

Scaling Metadata Performance

INDEXFS

Two orders of magnitude faster than Lustre/PVFS [SC14]

BATCHFS

Scale another order of magnitude [PDSW14]

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IndexFS:

Scaling File System Metadata Performance with Stateless Caching and Bulk Insertion

SC14

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Garth Gibson

PARALLEL DATA LABORATORY

Carnegie Mellon University

Carnegie Mellon
Parallel Data Laboratory

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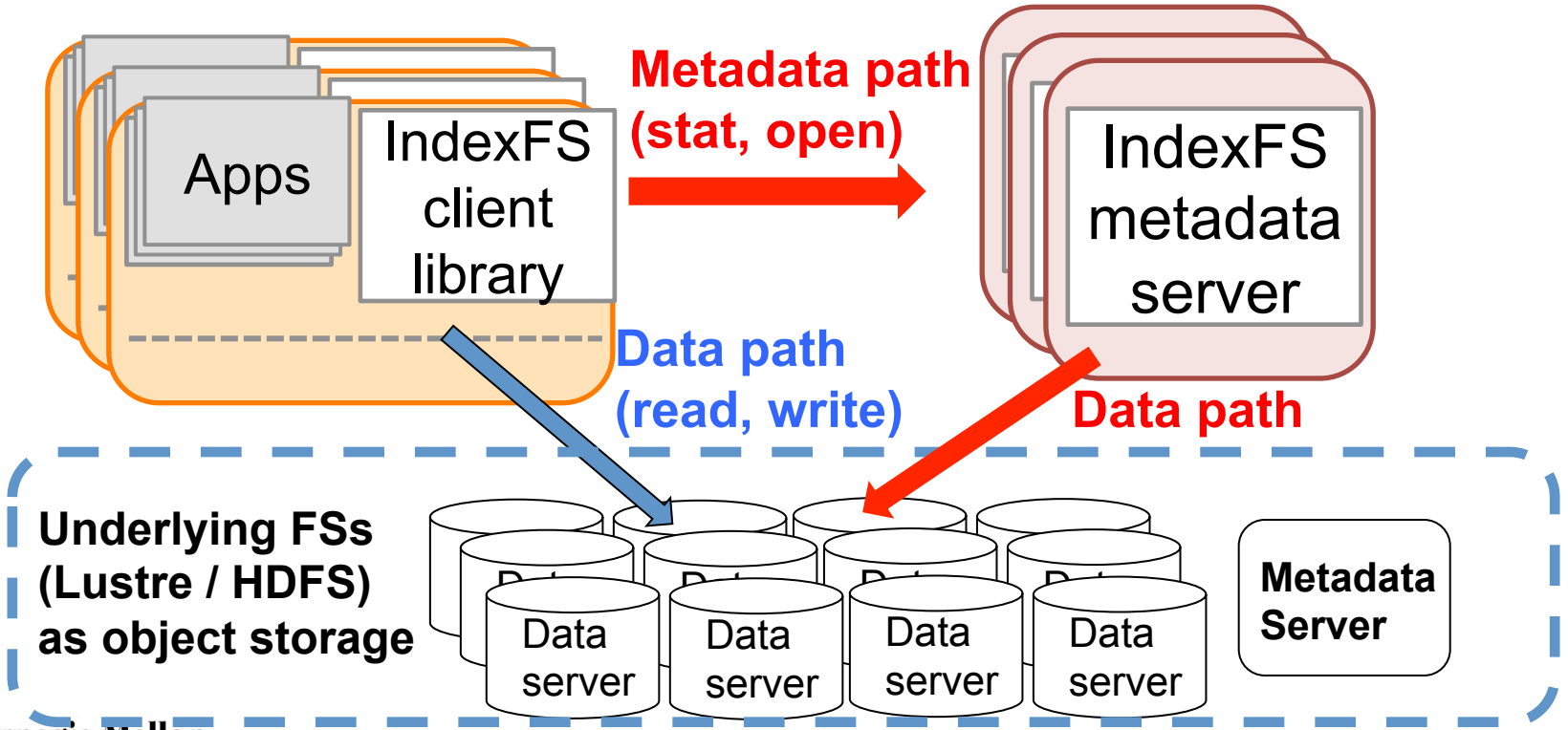
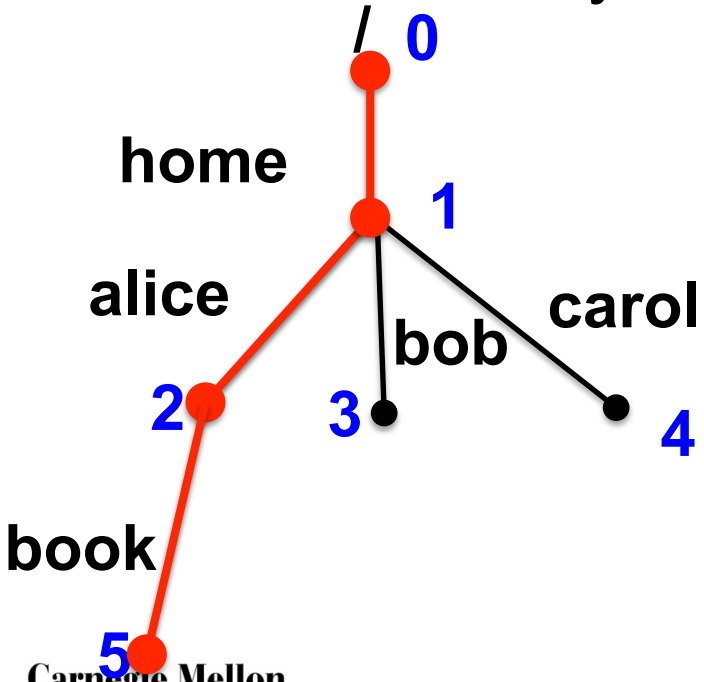
Layered Design

- IndexFS is layered on top of original DFSs
  - Provide a scalable metadata path for existing file systems such as HDFS, PVFS and Lustre



Efficient Per-Node Metadata Table

- Randomly distribute dir partitions over servers
- Key:<parent directory's inode number, filename>
- Value: attributes, file data or file pointer
- Stored in a key value store : LevelDB [Dean11]

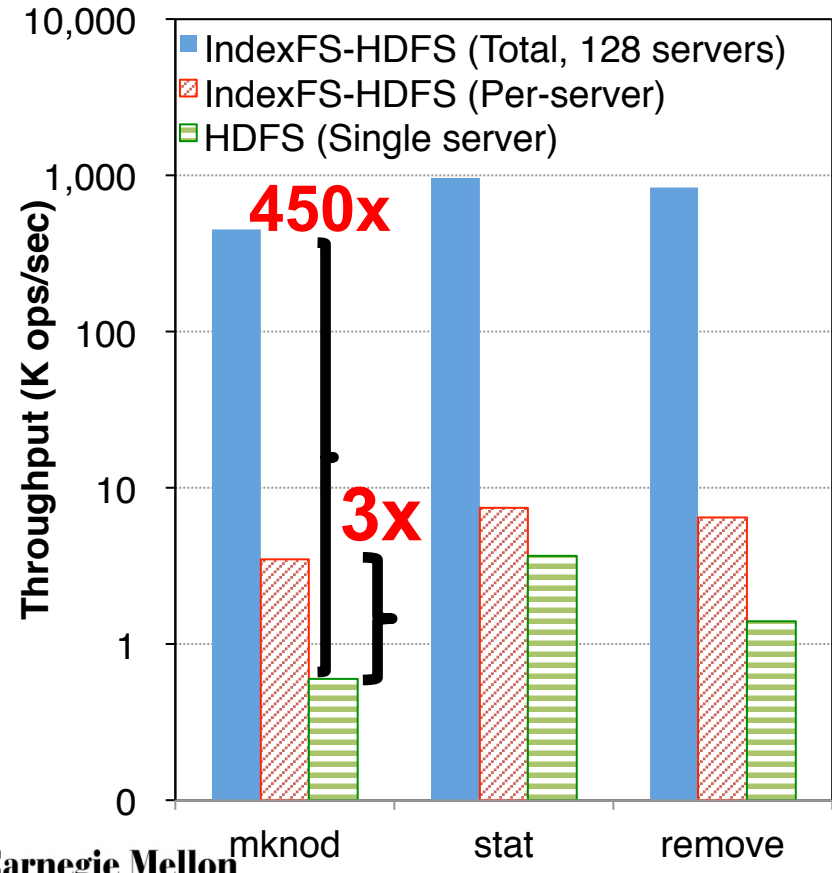


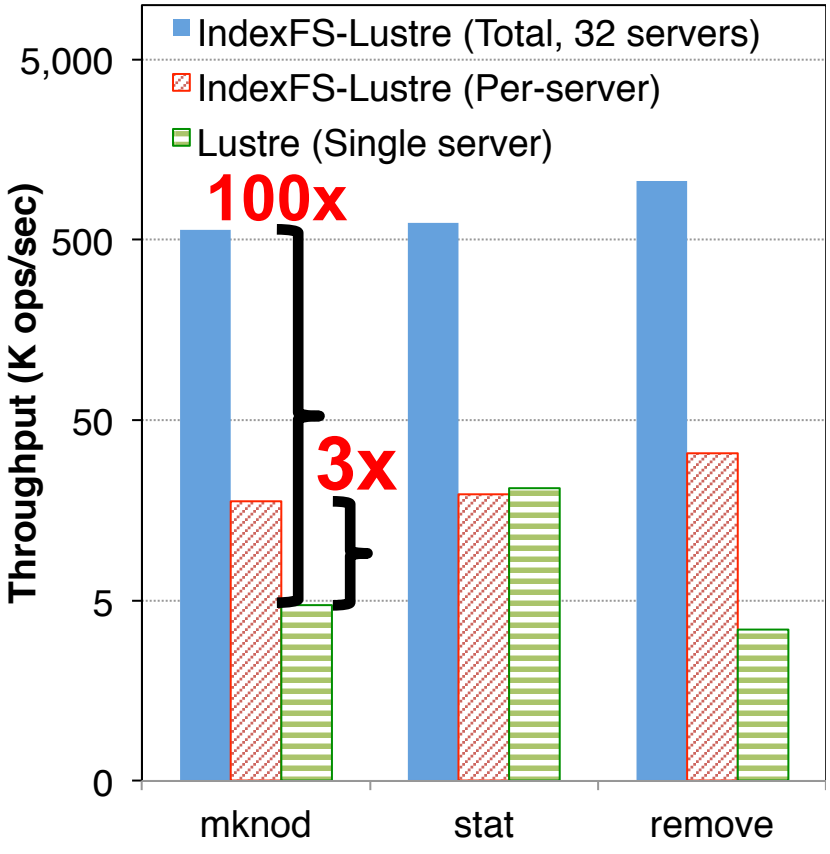
Lexicographic order

Key	Value
<0, *home*>	1, attributes
<1, *alice*>	2, attributes
<1, *bob*>	3, attributes
<1, *carol*>	4, attributes
<2, *book*>	5, attributes, small file data

100-450X Faster For HDFS & Lustre

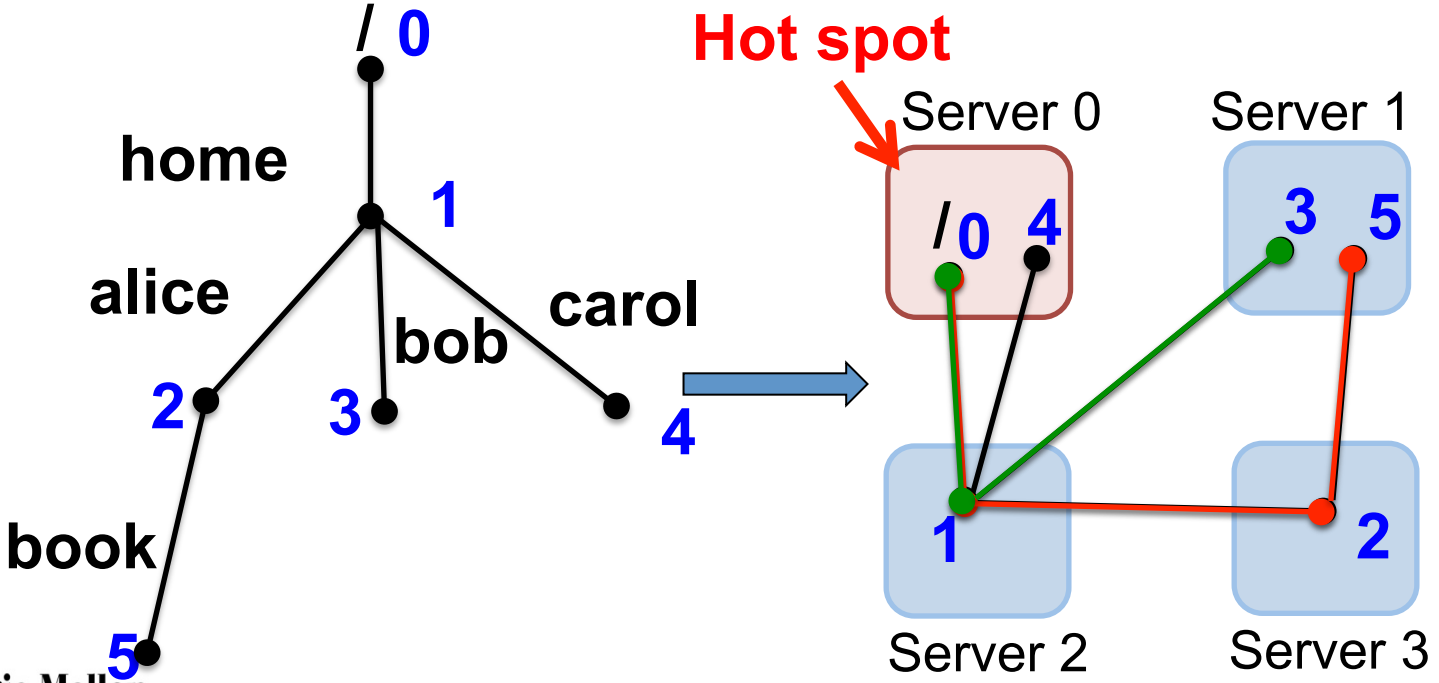
- Run mdtest on IndexFS layered on top of HDFS in PRObE Kodiak and Lustre in LANL Smog clusters





Hot Spot: Server with Root Directories

- Every POSIX lookup starts with root directory
  - Path traversal needs to visit each ancestor
  - Retrieve inode number and access permissions
  - Early IndexFS was defeated by this hot spot



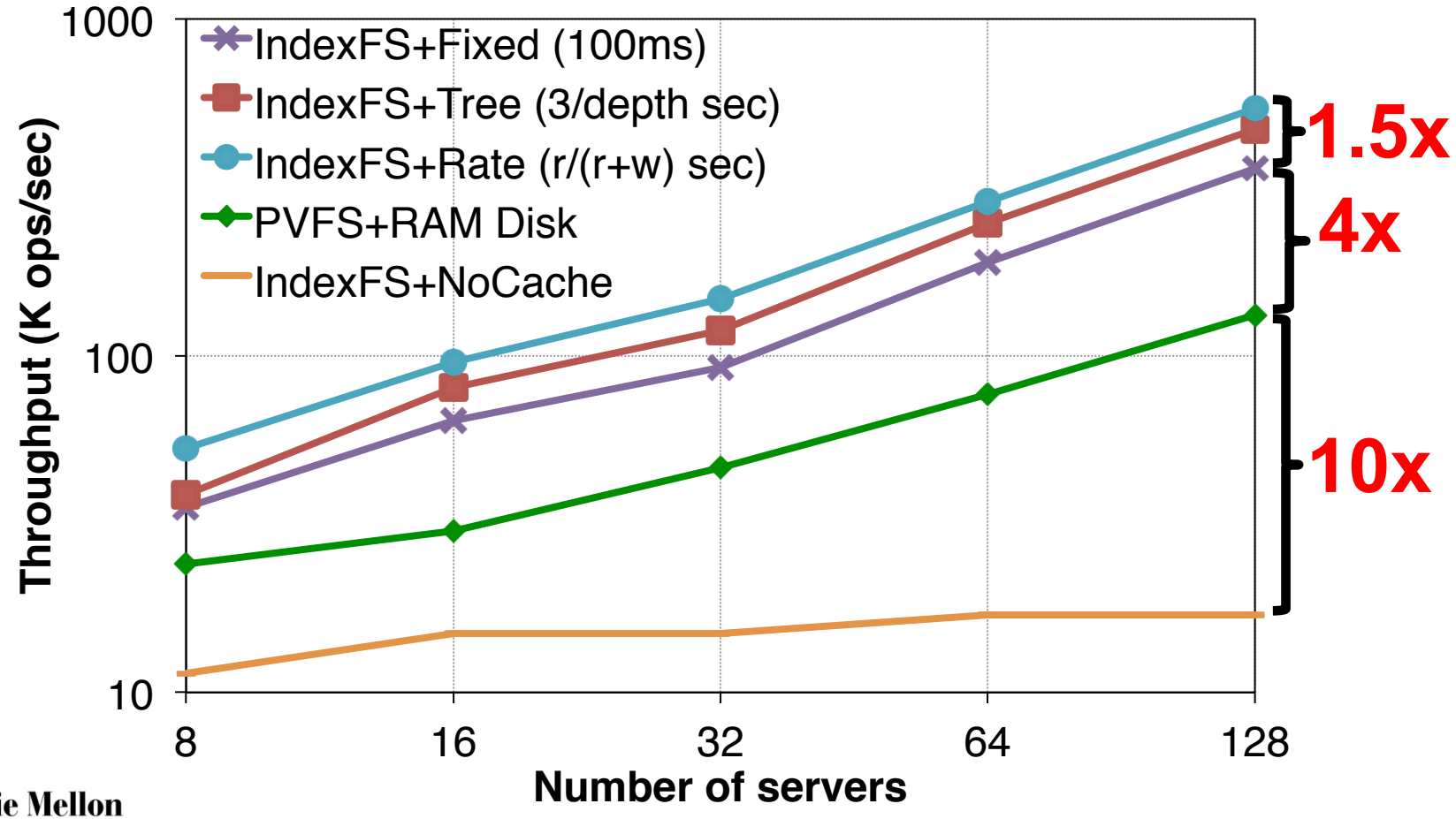
How To Mitigate Hot Spots?

- Client caches directory entry in many FSs
- Problem with invalidation callbacks at scale

- Idea: let the "clock" do the invalidation
  - Clients use ***read-only*** cache for directory entries
  - Servers remember only ***expiration deadline***
  - Assume ***clock synchronization*** within data center
  - Directory mutations wait for expiration
    - *rmdir*, *rename*, *chmod* can be slow

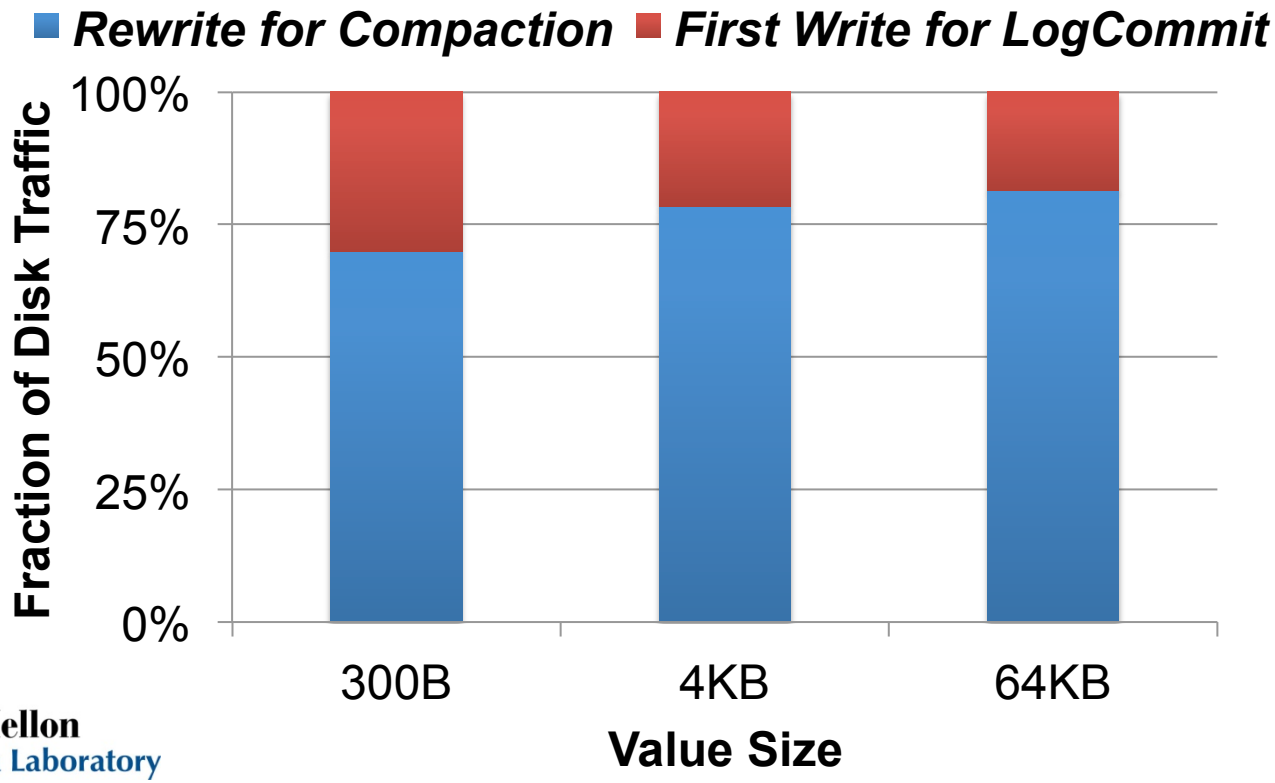
Replay Result: Throughput

- Directory entry cache mitigates hot spots



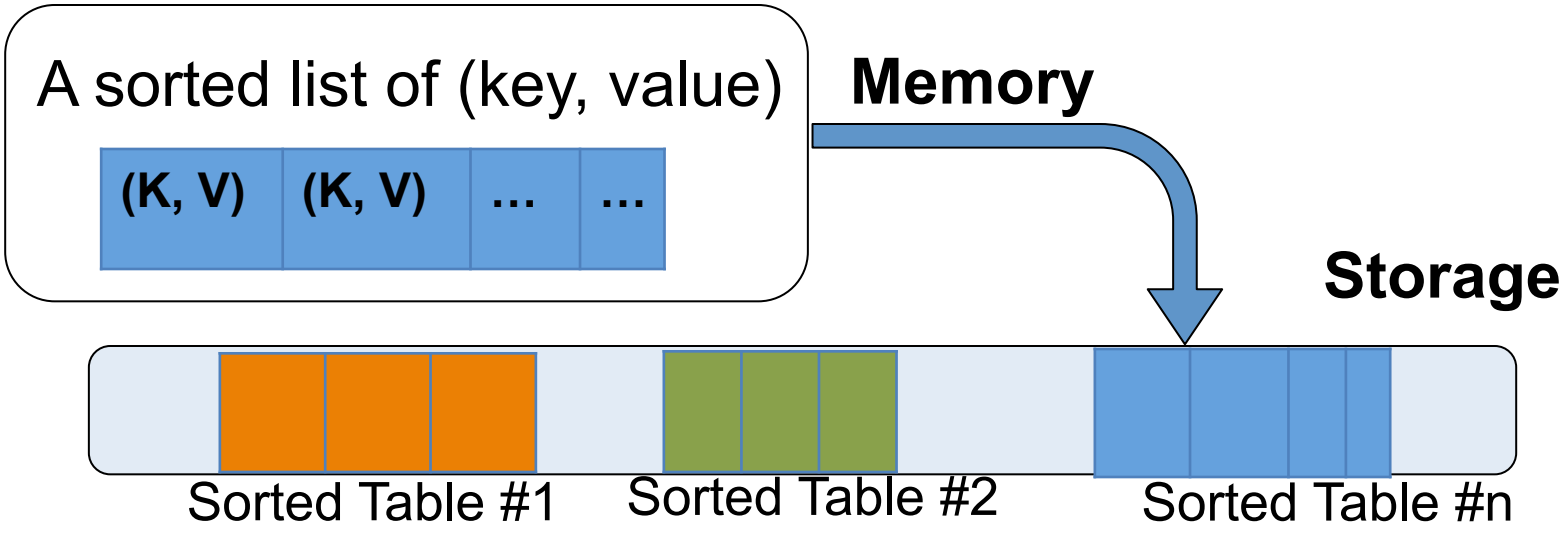
2nd Bottleneck: Compaction in LevelDB

- Slows insertion of user metadata/small files
  - 75% of insertion disk traffic caused by compaction
  - Compaction of larger values wastes more bandwidth



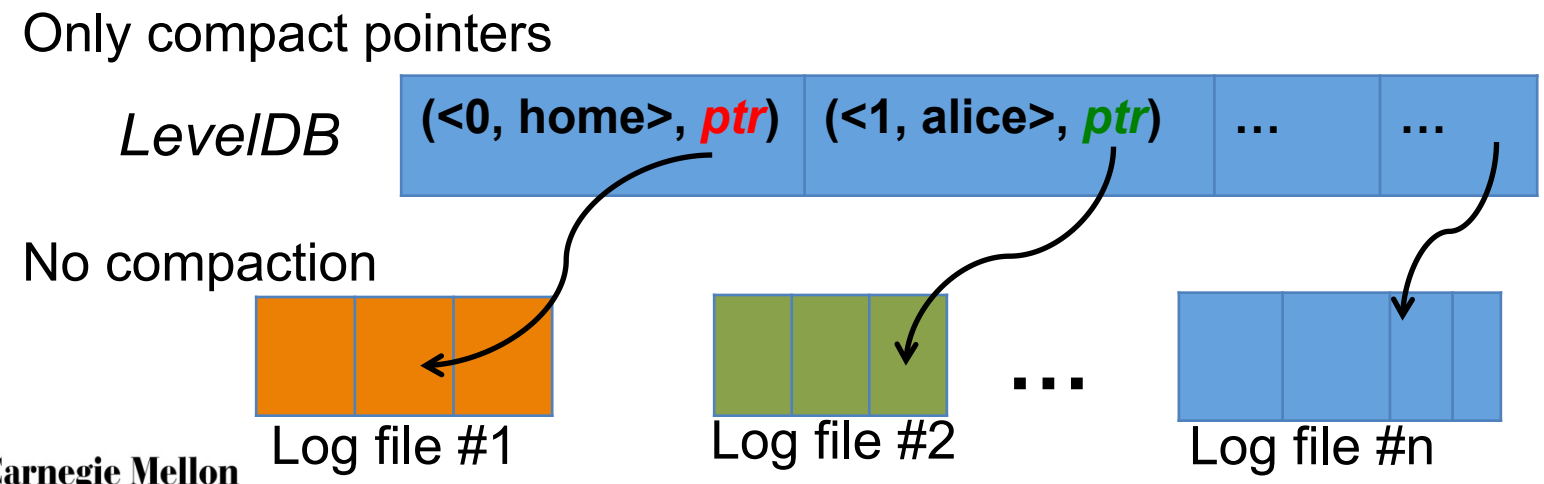
Background: LevelDB Internal

- LevelDB (LSM Tree): Insert and update ops:
  - Buffer and sort recent inserts/updates in memory
  - Flush buffer to generate immutable sorted tables
  - Perform compaction to reduce #tables for searching
- Want to avoid rewrites while having fast lookup



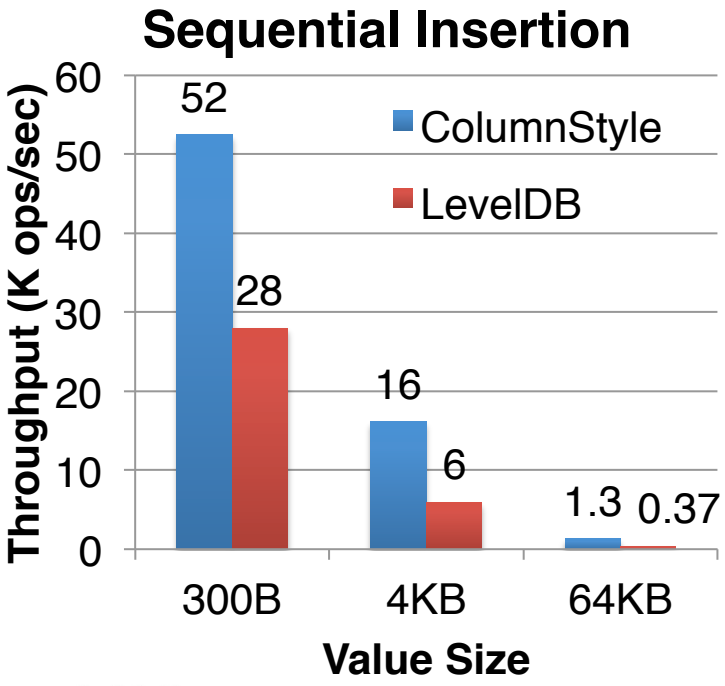
Column-Style Metadata Schema

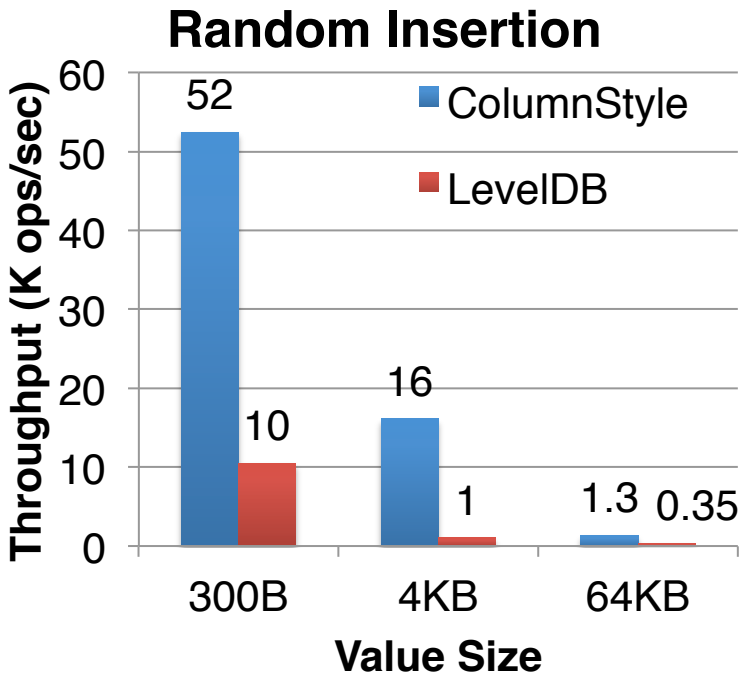
- Column-style approach:
  - Metadata/small files appended to non-LevelDB log files
  - LevelDB stores only pointers to metadata
  - Don't compact the metadata
    - Delay space reclamation for deleted/over-written values since metadata are small



Speed Up Ingestion Rate

- Insert 30M entries sequentially or randomly
  - Limit memory to 350 MB, using single SATA disk
- About 2 to 15 times faster insertion





IndexFS Summary

- IndexFS: a **middleware** approach to scale metadata path, portable to HDFS, Lustre, PVFS
- Scale out: **partition tree on directory basis**
  - File system distribution into server local LSM trees
  - Read-only consistent caching without per-client state
- Scale up: **optimize log-structured merge tree**
  - Column-style schema reduces compaction overhead
- Code available: http://www.pdl.cmu.edu/indexfs

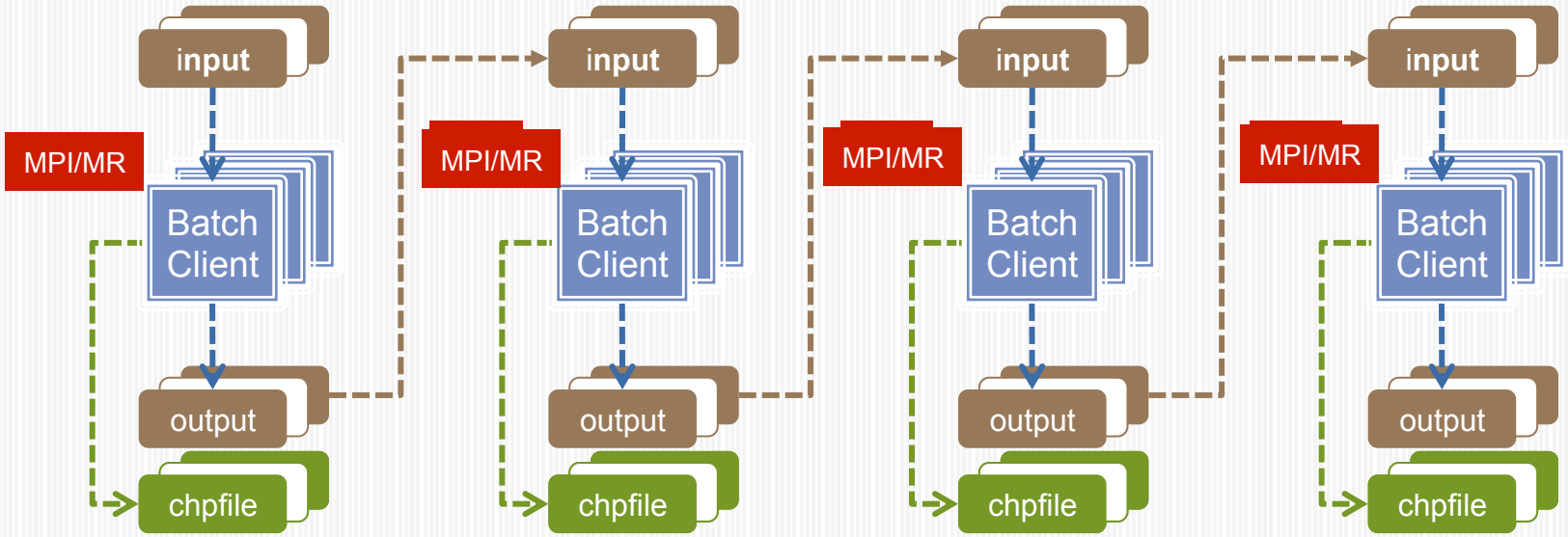
BATCHFS

Scaling the File System Control Plane with Client-Funded Metadata Servers

Qing Zheng, Kai Ren, Garth Gibson
Carnegie Mellon University

9th Parallel Data Storage Workshop (PDSW) 2014

Batch Applications



Batch apps are self-coordinated by framework & workflow engines

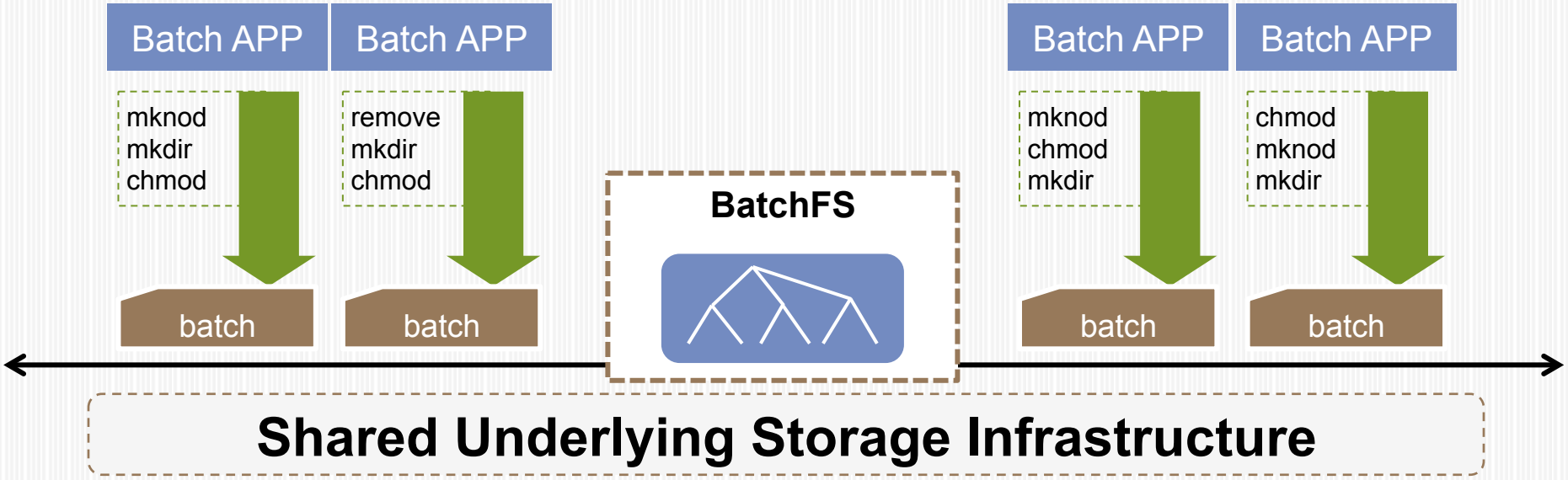
Key Observation

Batch apps **DON'T** need FS to communicate

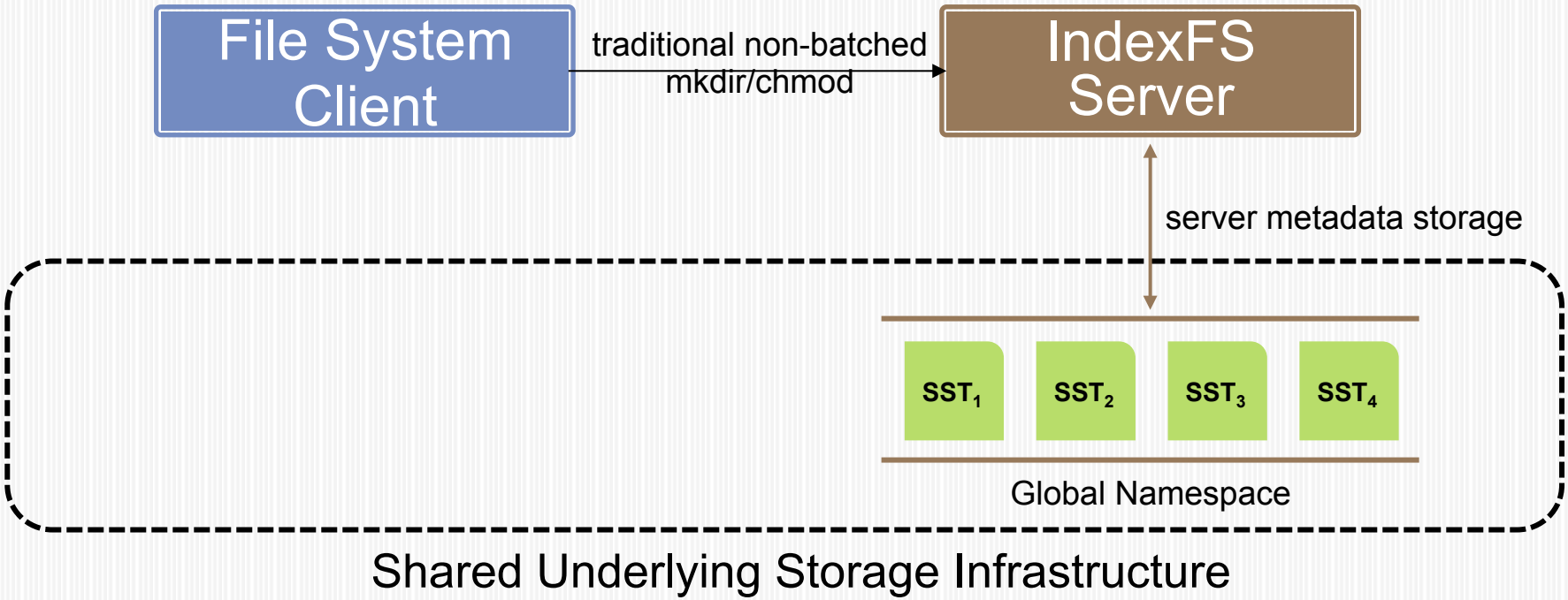
SYNCHRONOUS and SERIALIZED metadata management is **OVERKILL** for batch apps

Introducing BatchFS

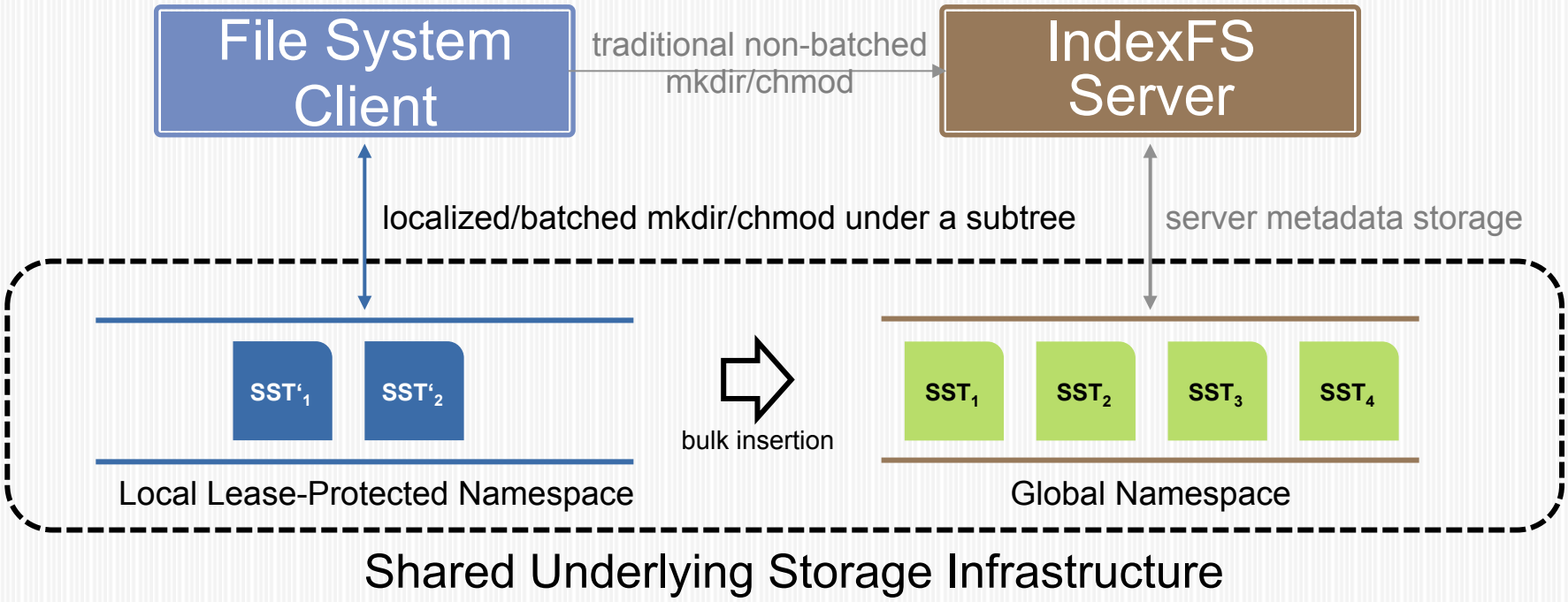
Deep batching for high throughput



Client-Server Interaction



Metadata Bulk Insertion

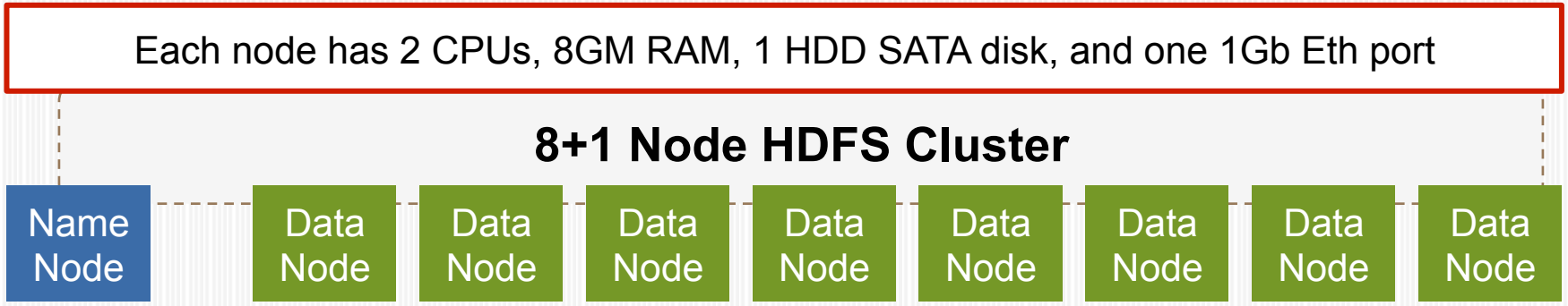


EXPERIMENT PLATFORM

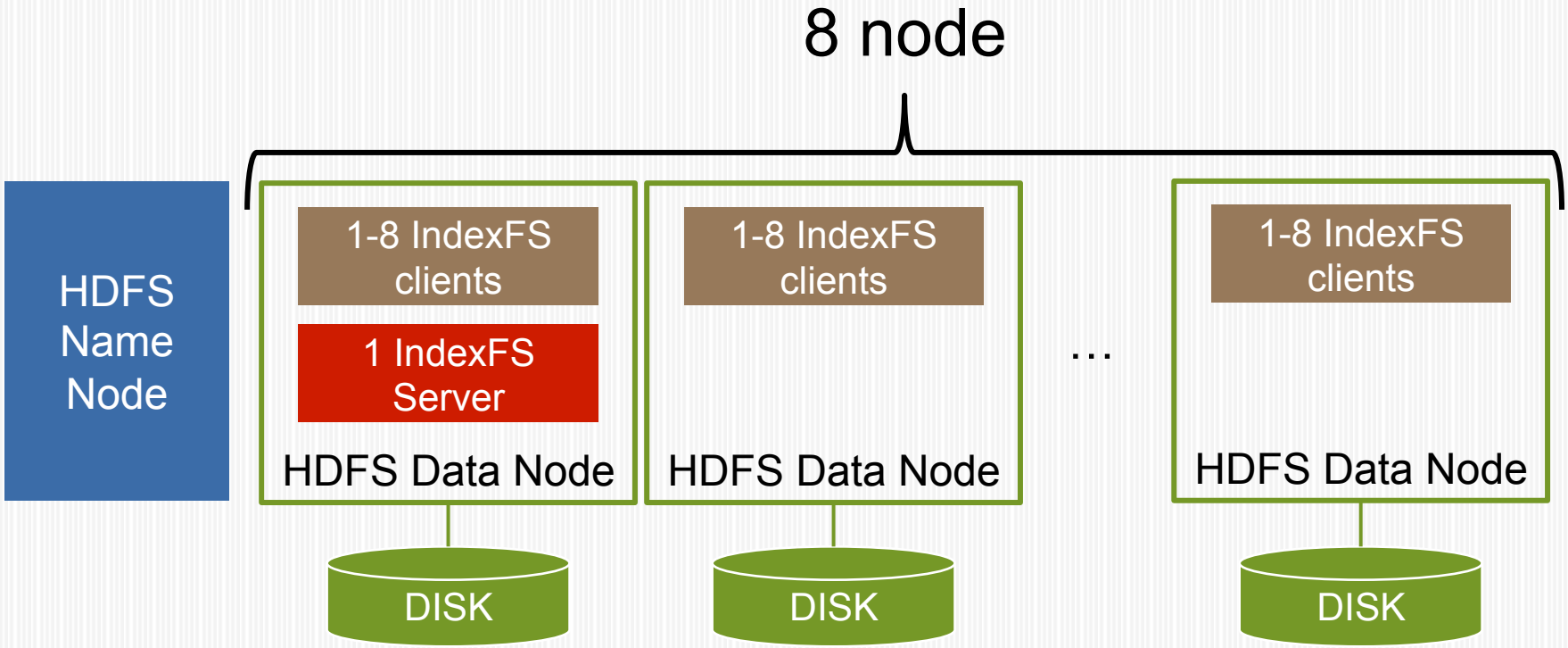
A prototype of BatchFS as an IndexFS feature

metadata bulk insertion (batching)

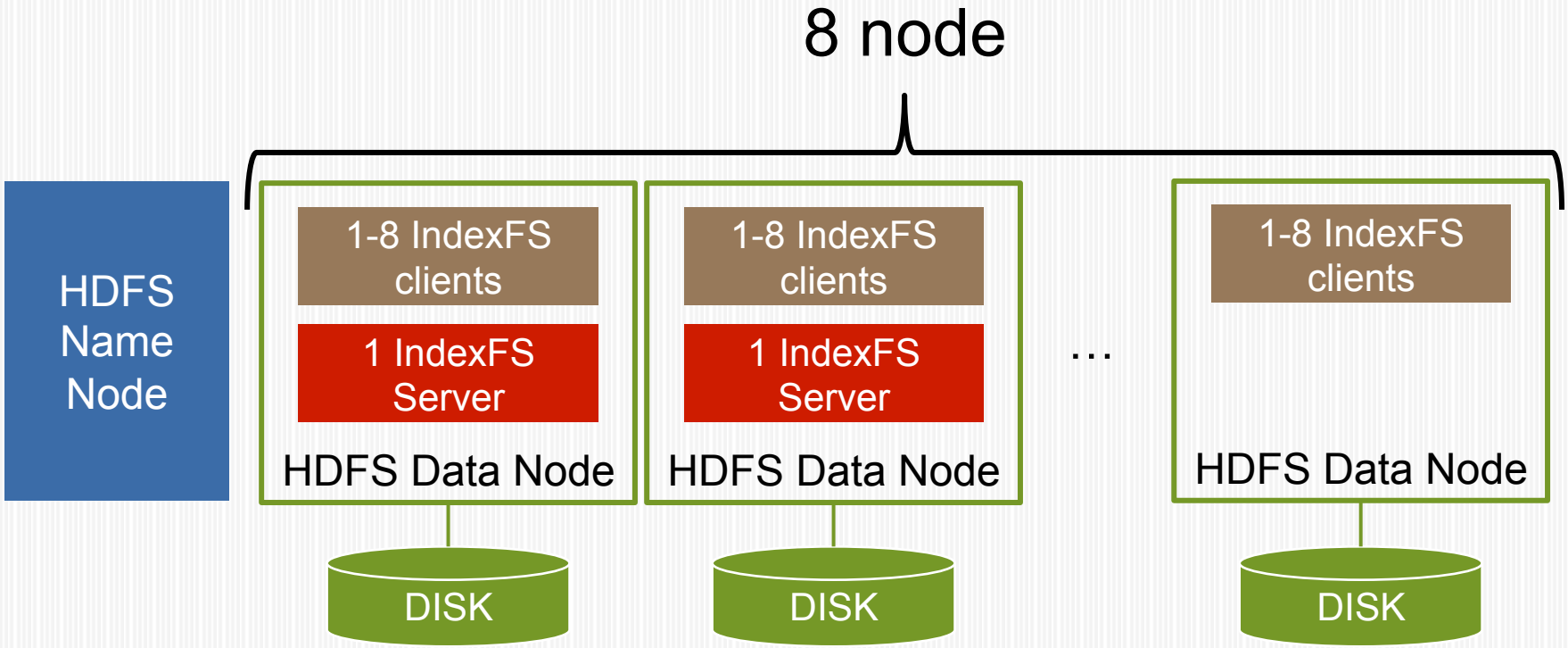
Clients create private directories & insert empty files



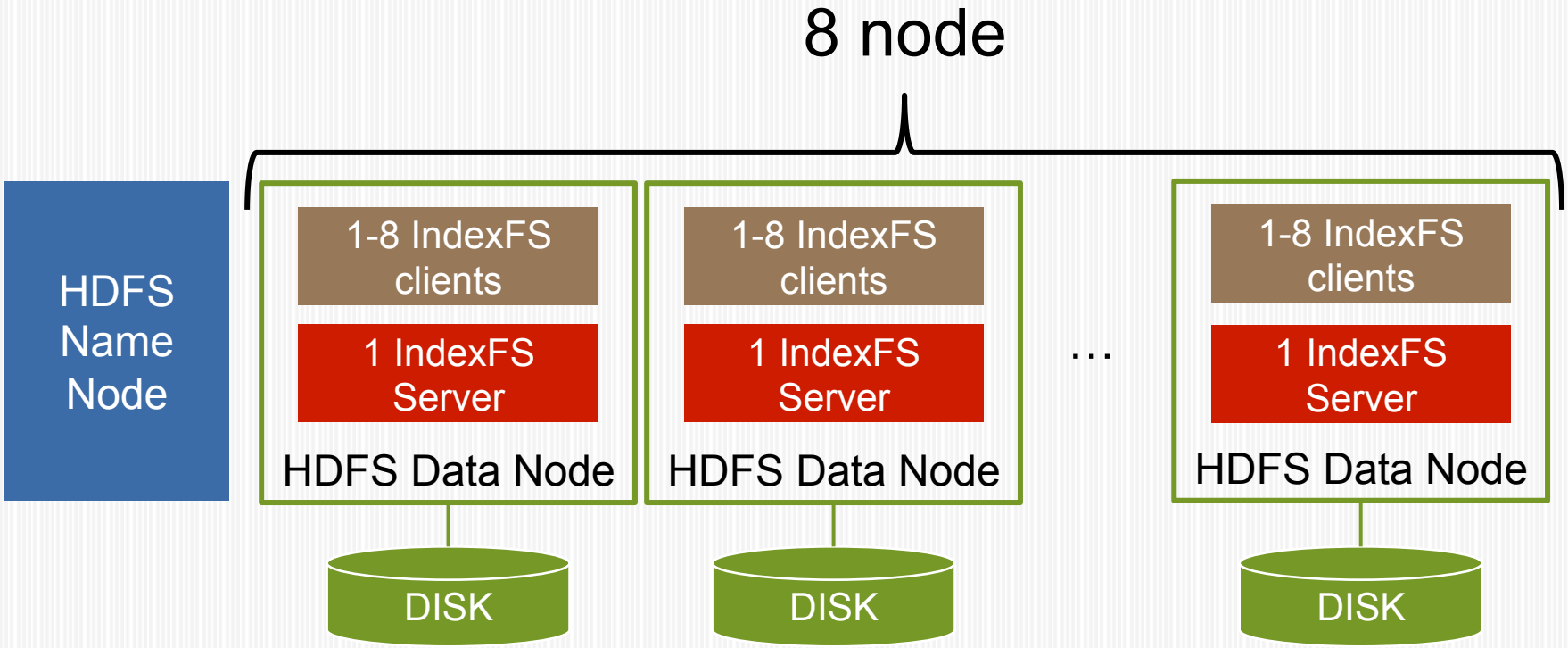
Experiment Setup #1



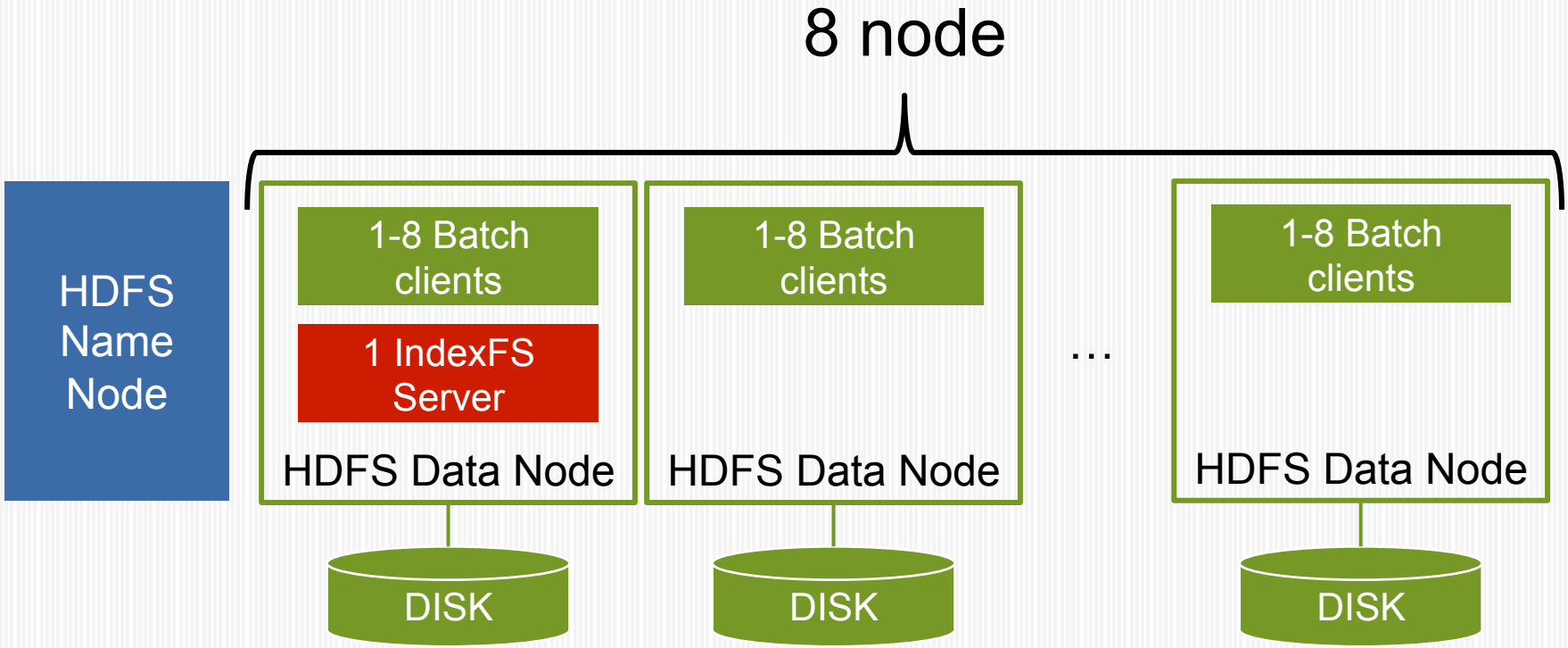
Experiment Setup #2



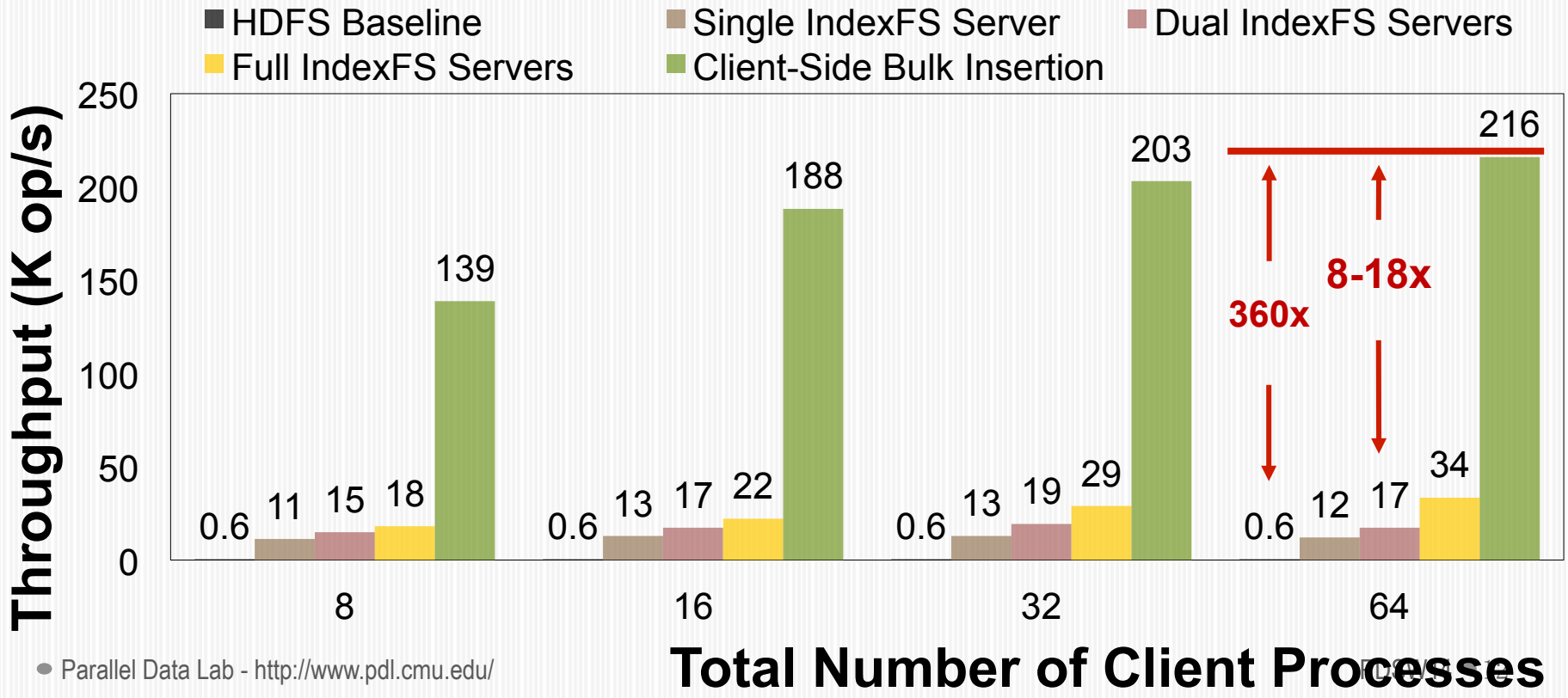
Experiment Setup #3



Experiment Setup #4



8x-360x Perf. Improvements

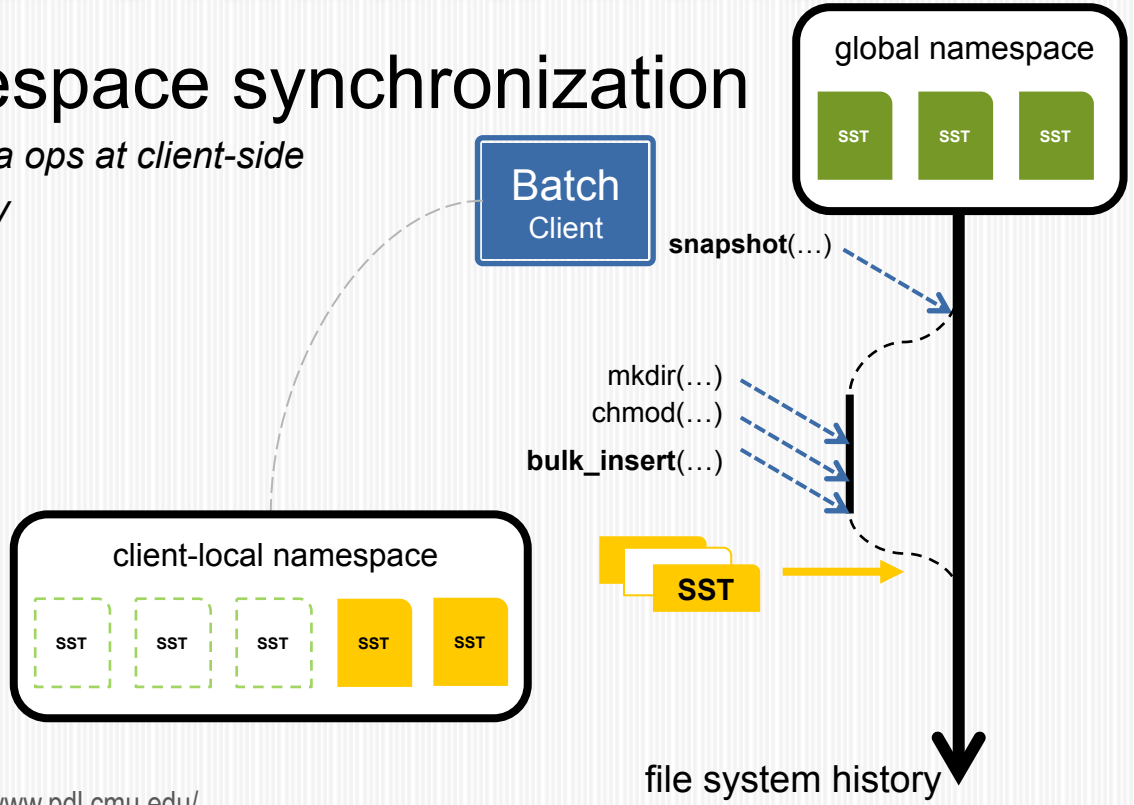


Deep Metadata Batch

Lazy namespace synchronization

Pre-execute metadata ops at client-side

Snapshot consistency



Deep Metadata Batch

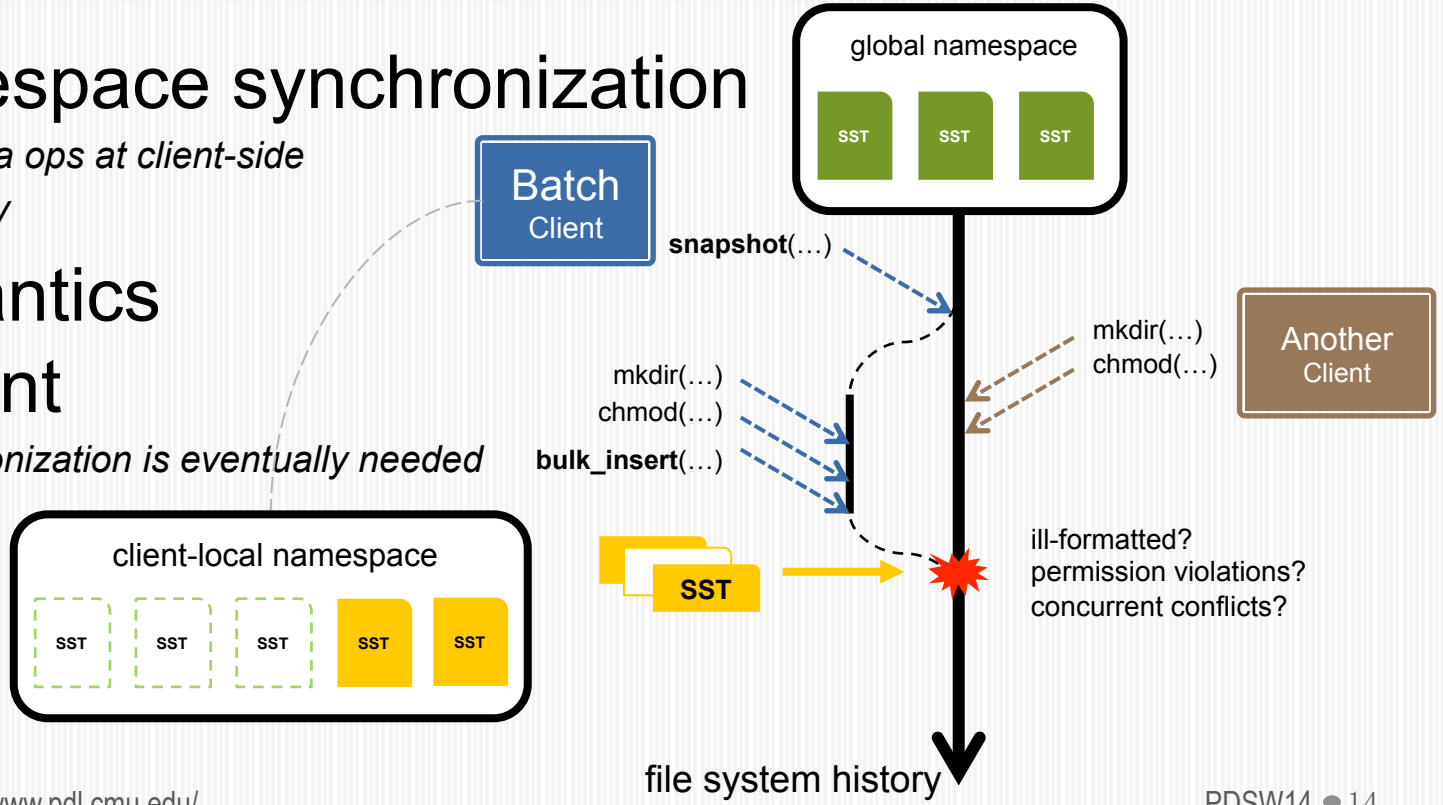
Lazy namespace synchronization

Pre-execute metadata ops at client-side

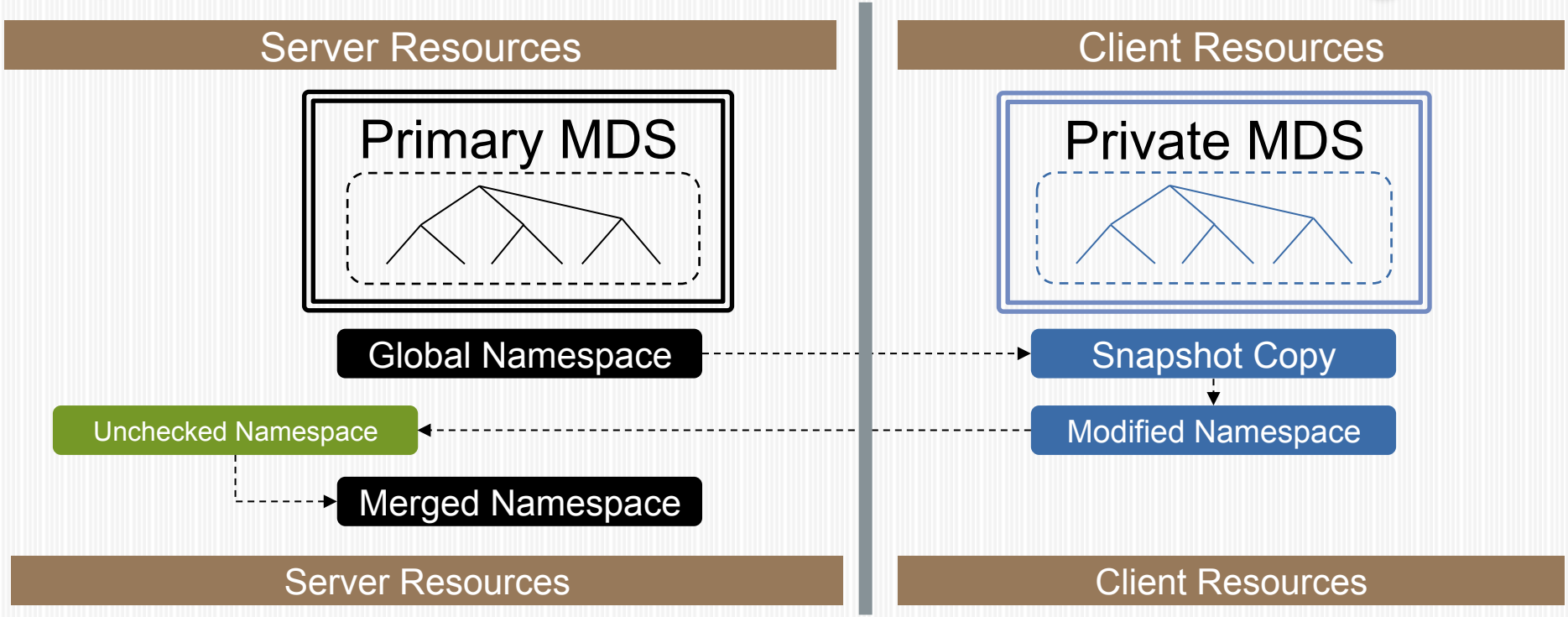
Snapshot consistency

Lazy semantics enforcement

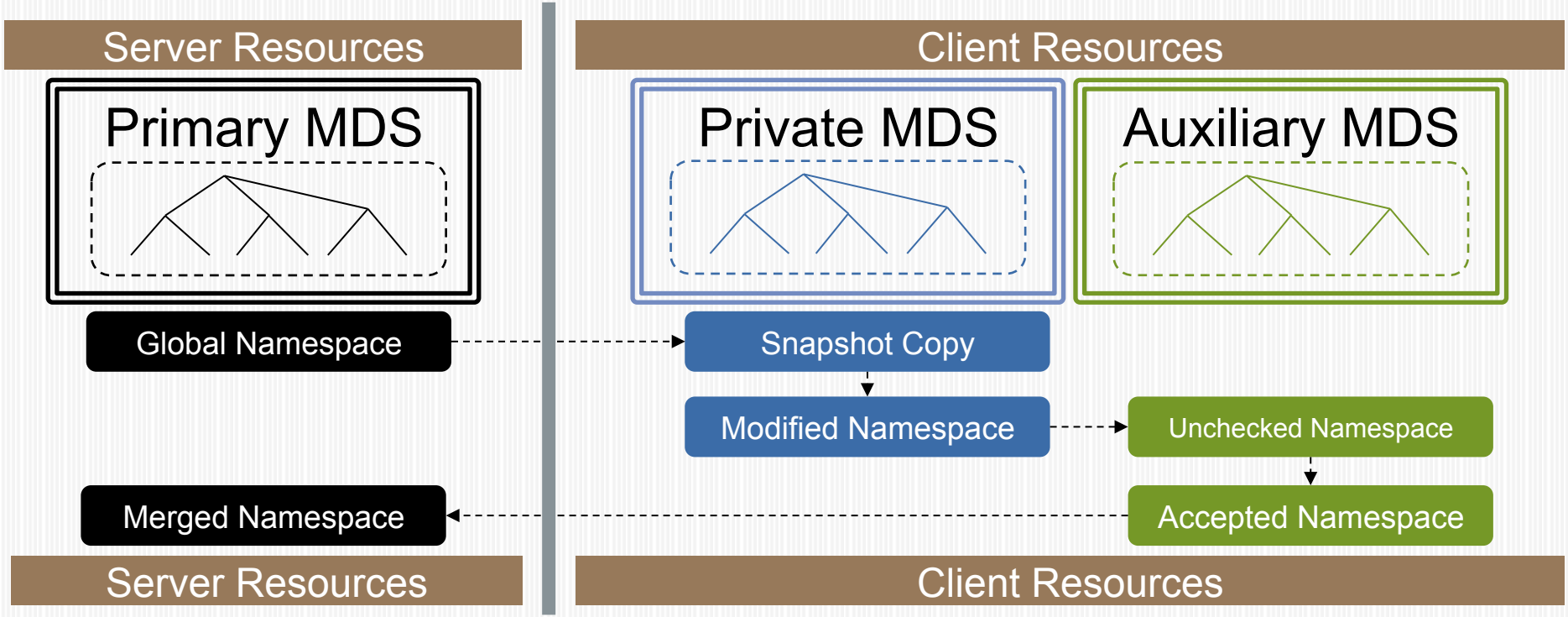
Delayed until synchronization is eventually needed



Client-Funded Metadata Processing



Client-Funded Metadata Verification

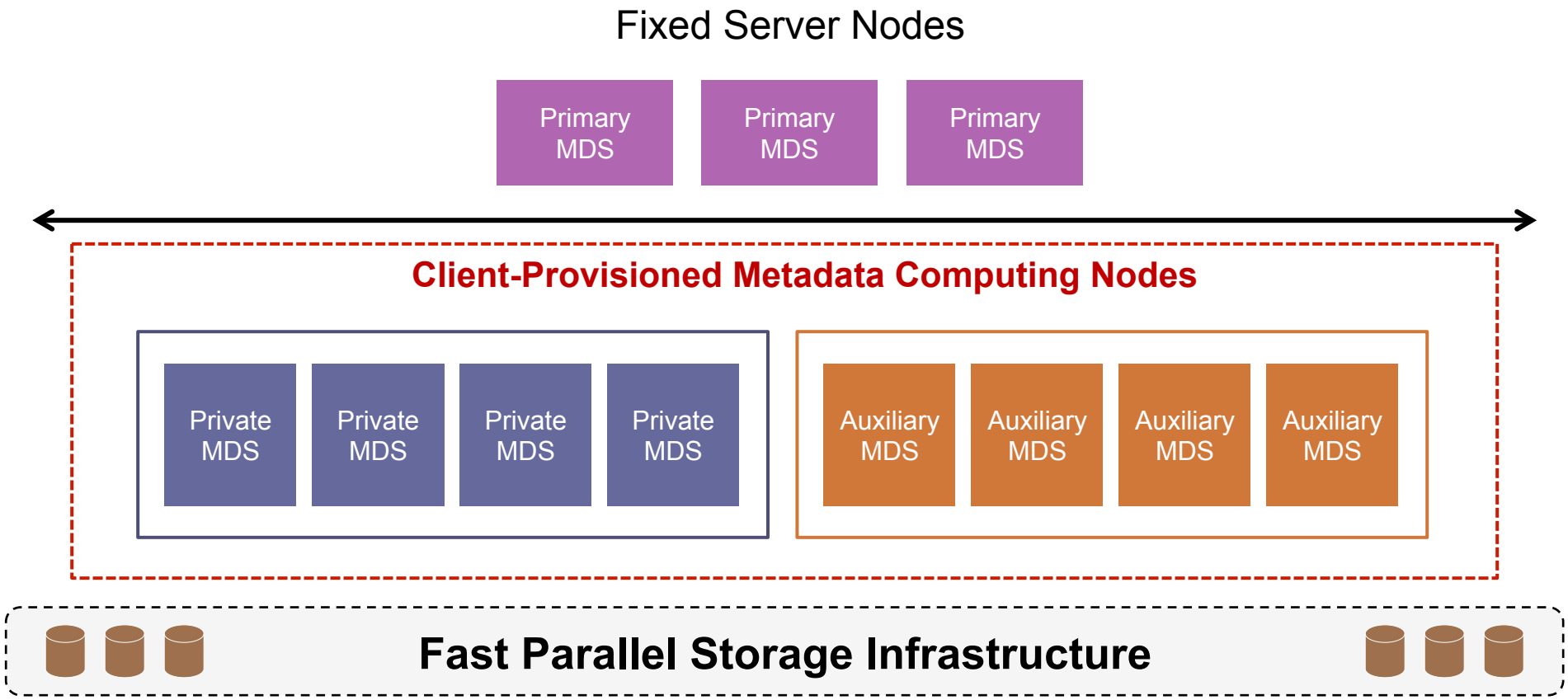


SUMMARY

BATCHFS

At least one RPC per operation	✖
Inefficient metadata representation	✖
Pessimistic concurrency control	✖
Synchronous metadata interface	✖
Dedicated authorization service	✖

BatchFS Architecture Revisited



BatchFS scales with the number of client nodes

Next Challenge: Get rid of Primary MDS servers

Ephemeral File Systems

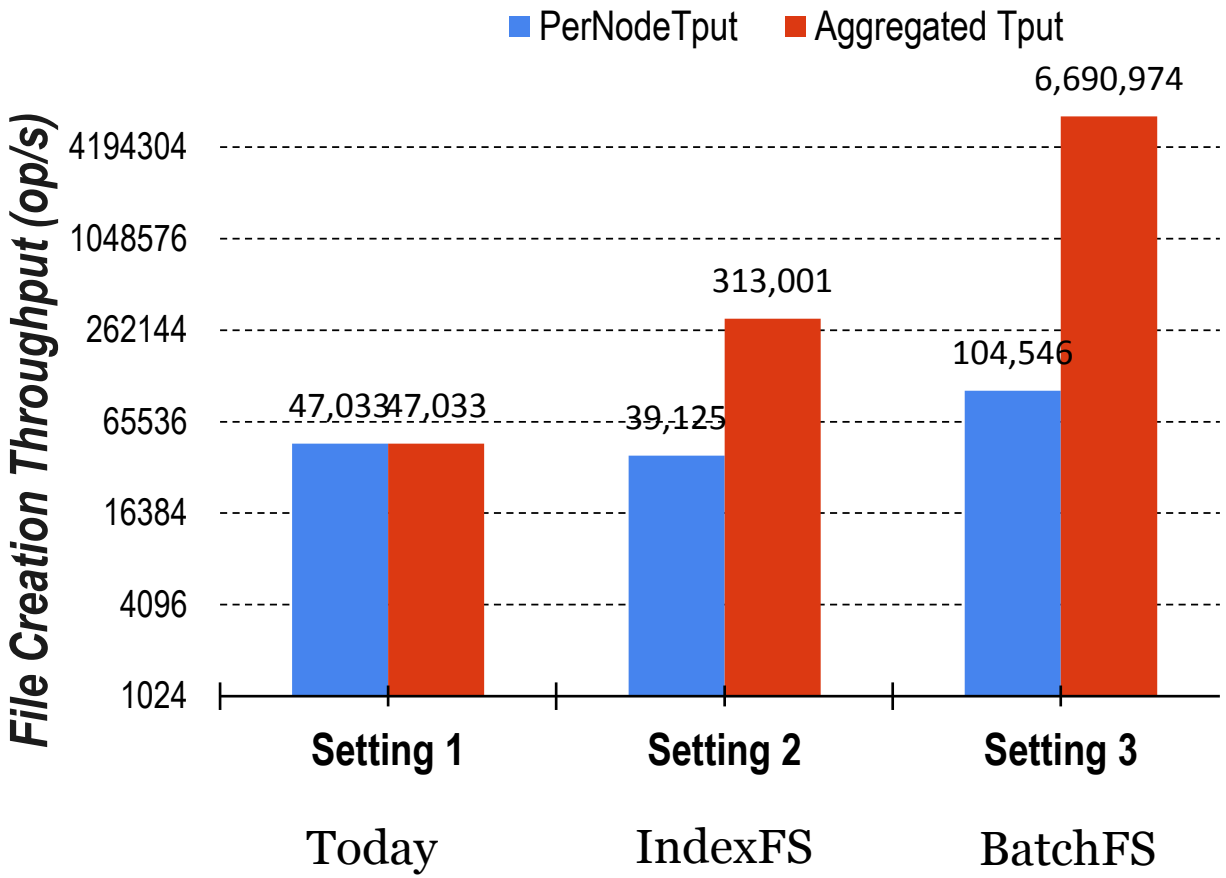
- We can scale object storage
  - Partition into pools tied to storage
- IndexFS/BatchFS built on non-scalable PFS
  - Escape dependence on presence of a PFS
  - Port IndexFS/BatchFS to raw object storage
    - Ceph's RADOS today
    - Replace FS directory with list-of-objects object
- Branching namespace consistency model
  - Parallel job starts with snapshot, builds a branch
  - Workflow/job scheduler passes branch directly
  - Completed workflow publishes branch
  - Curated trunk periodically merges branches

Preliminary RADOS-on-Flash Experiments

	Setting 1	Setting 2	Setting 3
Total Files Created	8,000,000	64,000,000	512,000,000
RADOS: 2-way replicated, built on top of 8x 16GB tmpfs (in total 128GB sto			
1x Head Node	1x ceph-mon 8x indexfs-mds	1x ceph-mon	1x ceph-mon 8x indexfs-mds (primary mds)
8x Data Nodes	32x ceph-osd	32x ceph-osd 64x indexfs-mds	32x ceph-osd
64x Compute Nodes	256x indexfs-clients	1024x indexfs-clients	512x indexfs-bulk-clients (private mds)

Two Orders of Magnitude FASTER

Parallel Metadata-Intensive Job Generating a Namespace Branch



Conclusions and Directions

- Object storage scales data throughput
- Metadata service partitioned over many servers
- Batches/logs/LSM objects encapsulate metadata
- Namespaces as collections of metadata objects
- Decreased frequency of namespace synch
- Middleware execution of namespace mgmt
- Fund scalable metadata from client resources

- Exascale parallel filesystem
  without parallel file systems servers!
- Collaborating with ANL, LANL for Exascale HPC