Ceph: A Scalable, High-Performance Distributed File System

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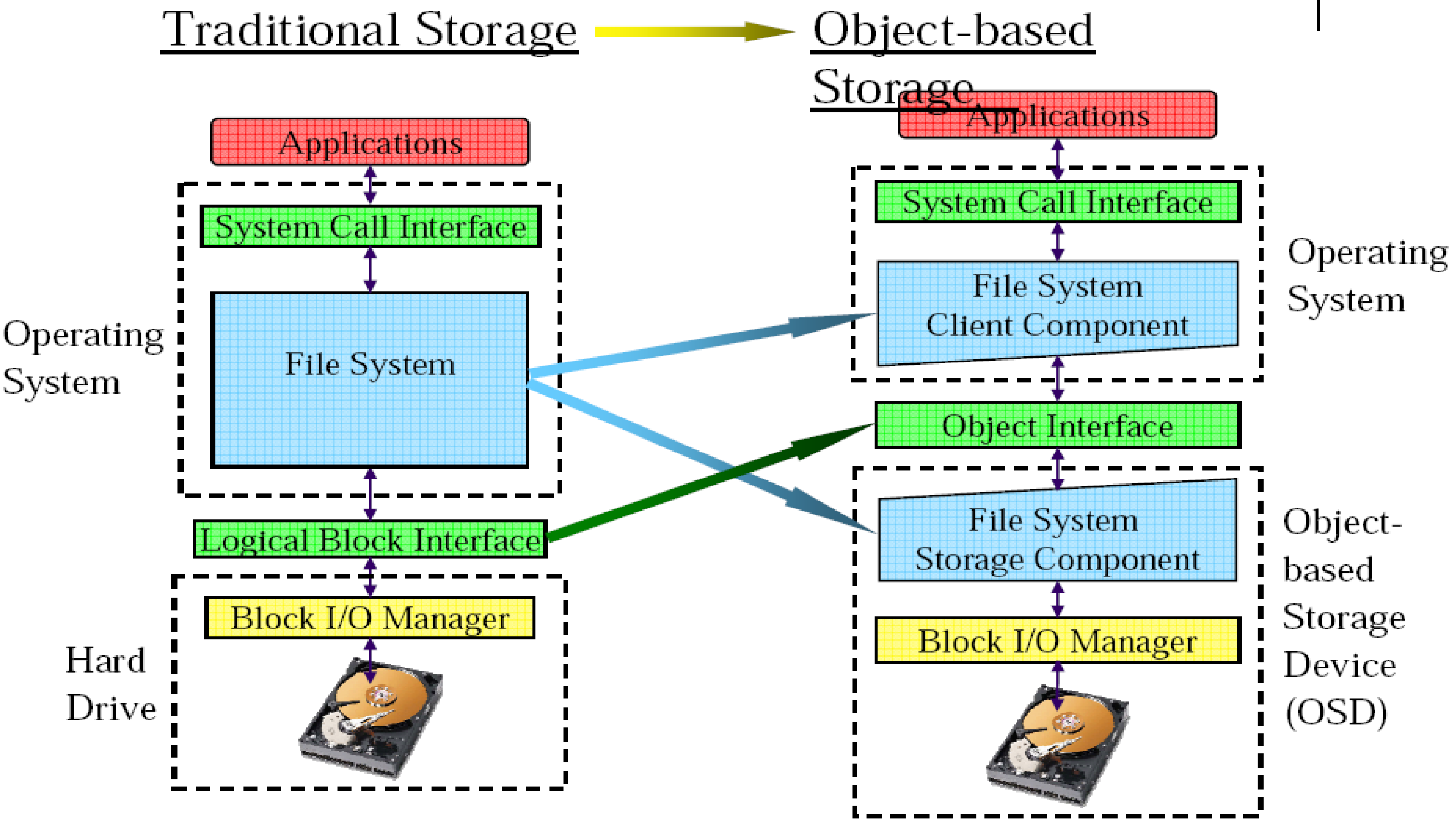
Contents

- Goals
- System Overview
- Client Operation
- Dynamically Distributed Metadata
- Distributed Object Storage
- Performance

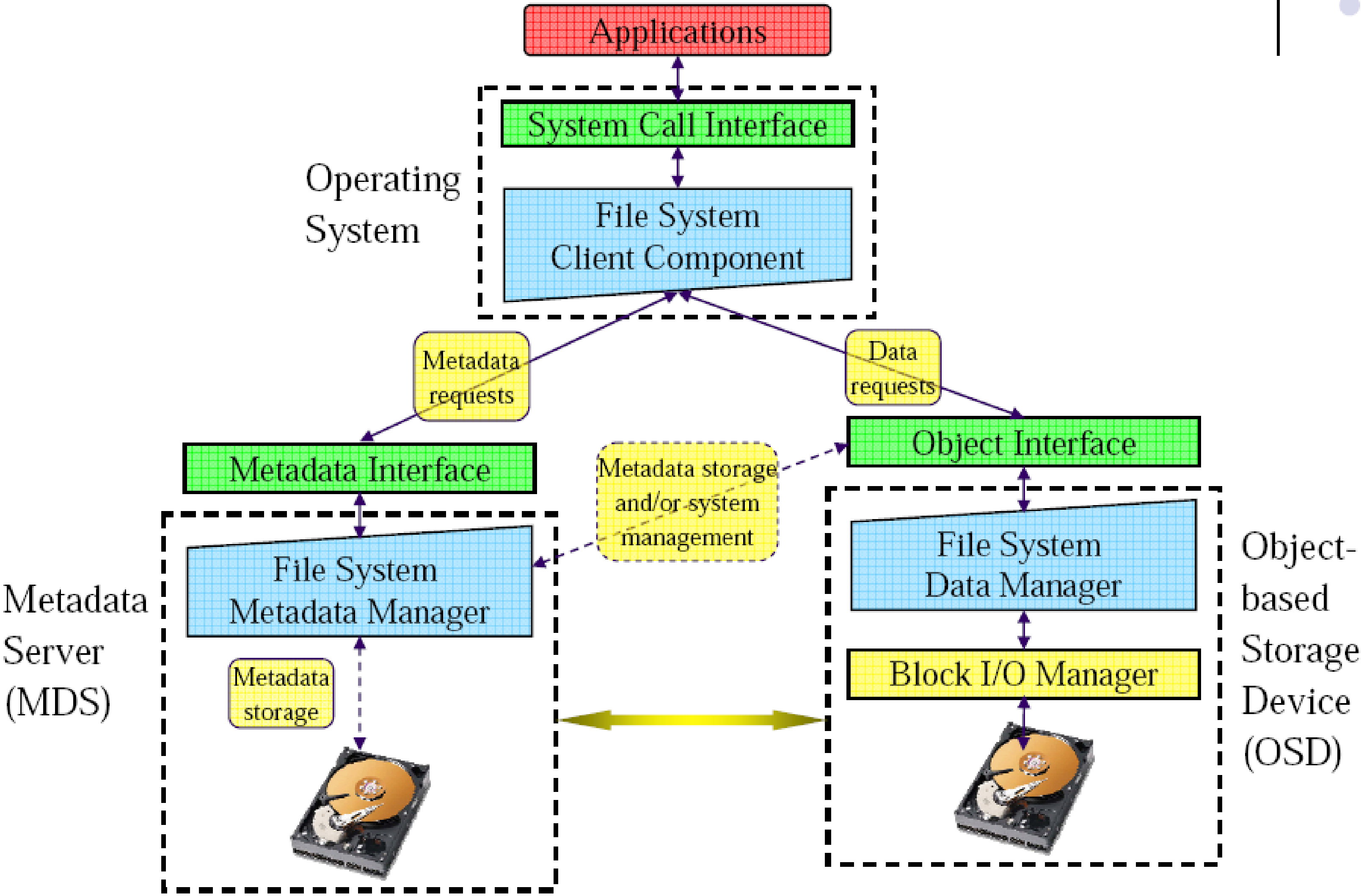
Goals

- Scalability
  - Storage capacity, throughput, client performance. Emphasis on HPC.
- Reliability
  - "…failures are the norm rather than the exception…"
- Performance
  - Dynamic workloads

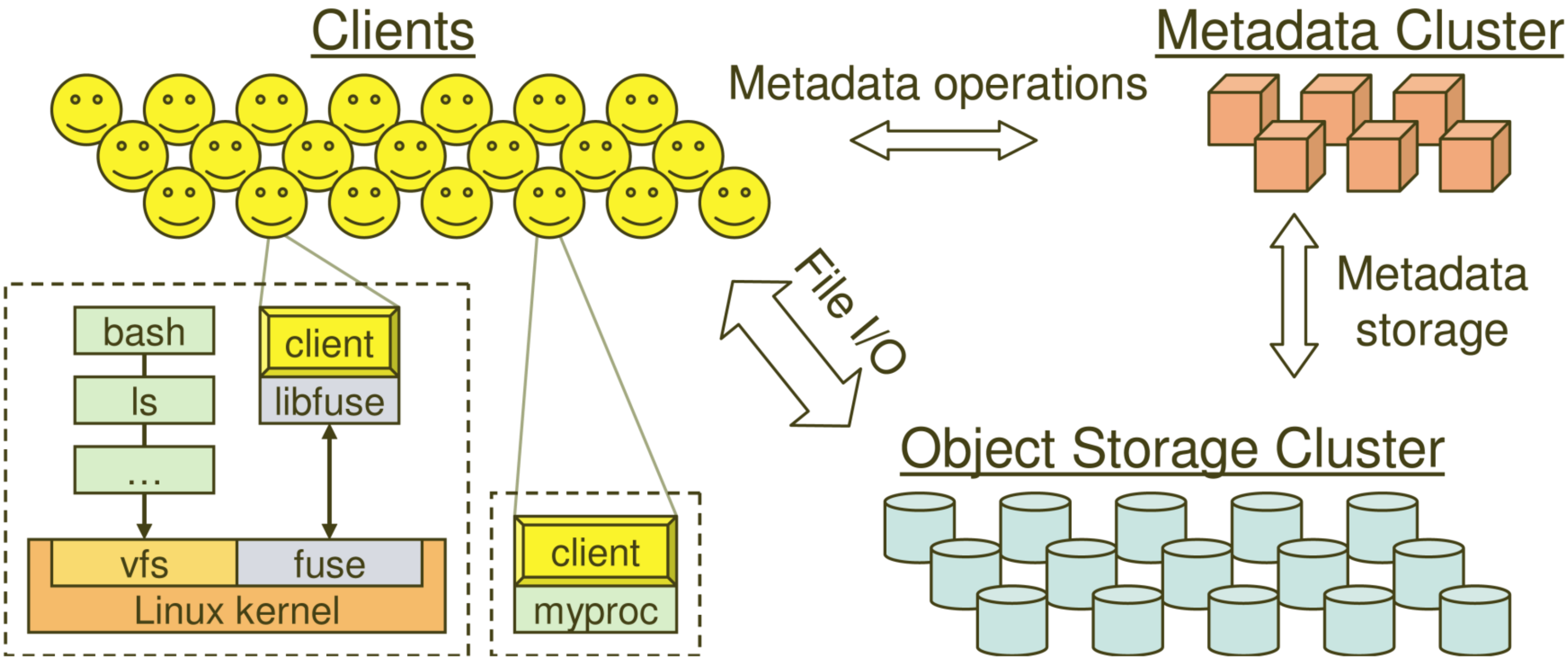
First Key Idea: Object-based Storage



Second Key Idea: Decoupled Data and Metadata



System Overview



Key Features

- Decoupled data and metadata
  - CRUSH
    - Files striped onto predictably named objects
    - CRUSH maps objects to storage devices
- Dynamic Distributed Metadata Management
  - Dynamic subtree partitioning
    - Distributes metadata amongst MDSs
- Object-based storage
  - OSDs handle migration, replication, failure detection and recovery

Client Operation

- Ceph interface
  - Nearly POSIX
  - Decoupled data and metadata operation
- User space implementation
  - FUSE or directly linked

FUSE is a software allowing to implement a file system in a user space

Client Access Example

1. Client sends *open* request to MDS
2. MDS returns capability, file inode, file size and stripe information
3. Client read/write directly from/to OSDs
4. MDS manages the capability
5. Client sends *close* request, relinquishes capability, provides details to MDS

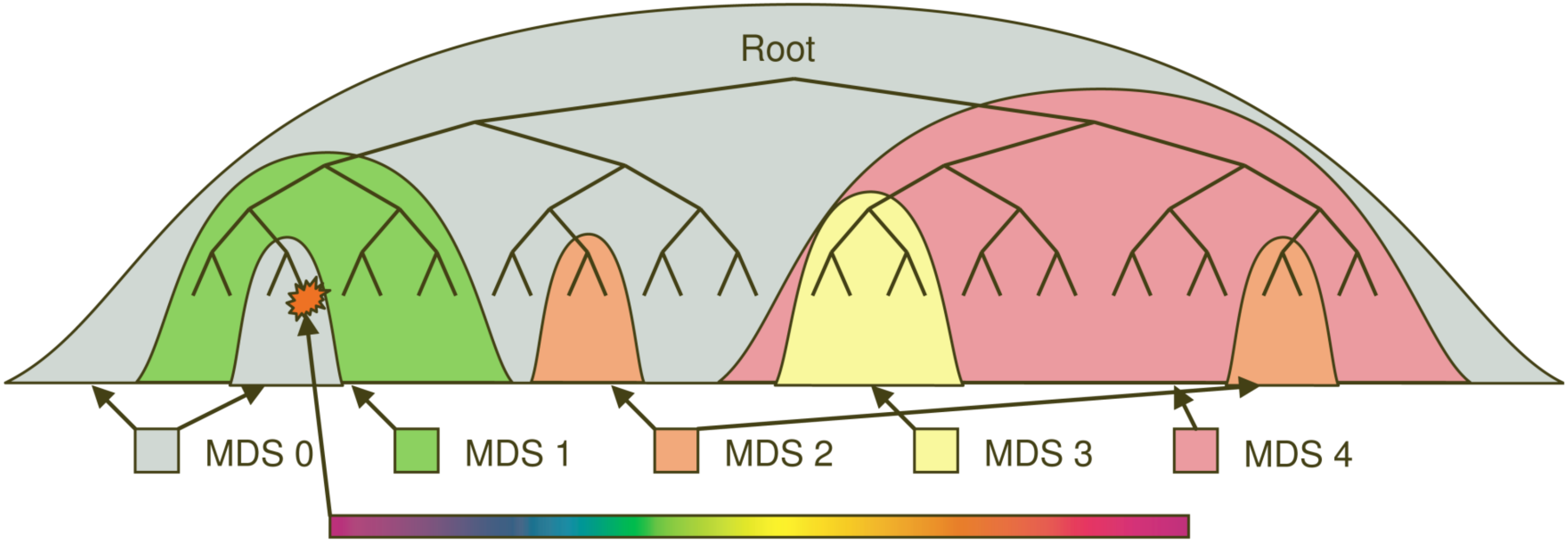
Synchronization

- Adheres to POSIX
- Includes HPC oriented extensions
  - Consistency / correctness by default
  - Optionally relax constraints via extensions
  - Extensions for both data and metadata
- Synchronous I/O used with multiple writers or mix of readers and writers

Distributed Metadata

- “Metadata operations often make up as much as half of file system workloads…”
- MDSs use journaling
  - Repetitive metadata updates handled in memory
  - Optimizes on-disk layout for read access
- Adaptively distributes cached metadata across a set of nodes

Dynamic Subtree Partitioning

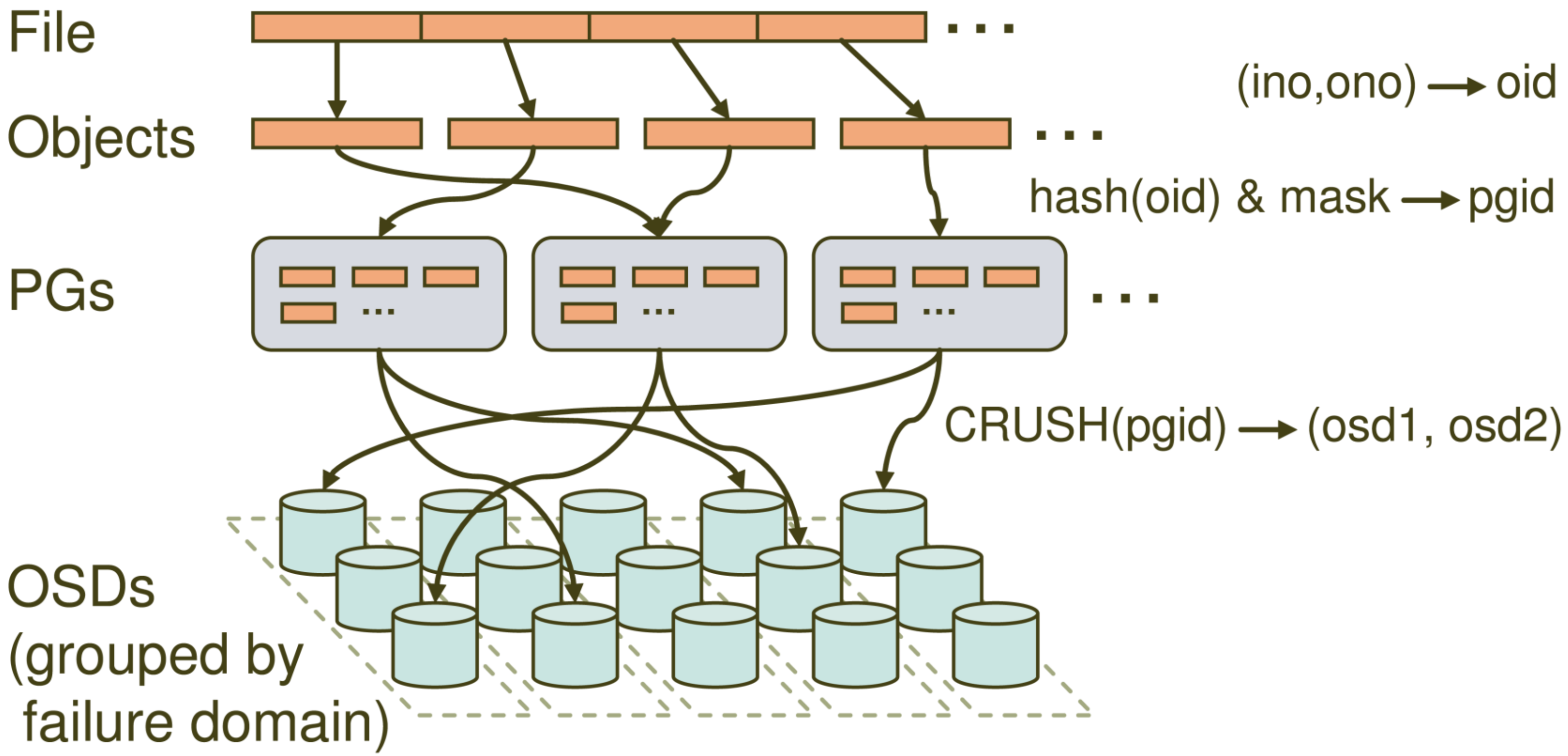


Busy directory hashed across many MDS's

Distributed Object Storage

- Files are split across objects
- Objects are members of placement groups
- Placement groups are distributed across OSDs.

Distributed Object Storage



CRUSH

- CRUSH(x) → (osd_{n1}, osd_{n2}, osd_{n3})
  - – Inputs
    - x is the placement group
    - Hierarchical cluster map
    - Placement rules
  - – Outputs a list of OSDs
- Advantages
  - – Anyone can calculate object location
  - – Cluster map infrequently updated

Data distribution

(not a part of the original PowerPoint presentation)

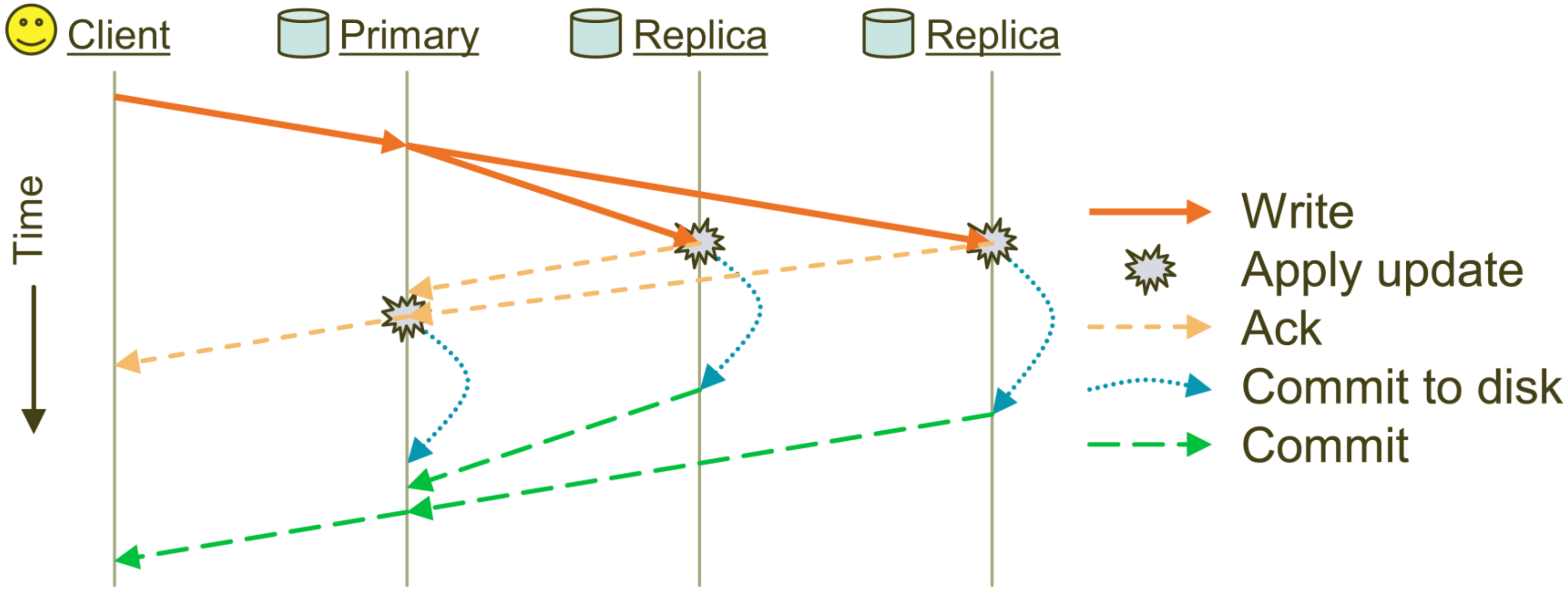
1. Files are striped into many objects
   (ino, ono) □oid

2. Ceph maps objects into placement groups (PGs)
   hash(oid) & mask_□pgid

3. CRUSH assigns placement groups to OSDs
   CRUSH(pgid) □ (osd1, osd2)

Replication

- Objects are replicated on OSDs within same PG
  - – Client is oblivious to replication



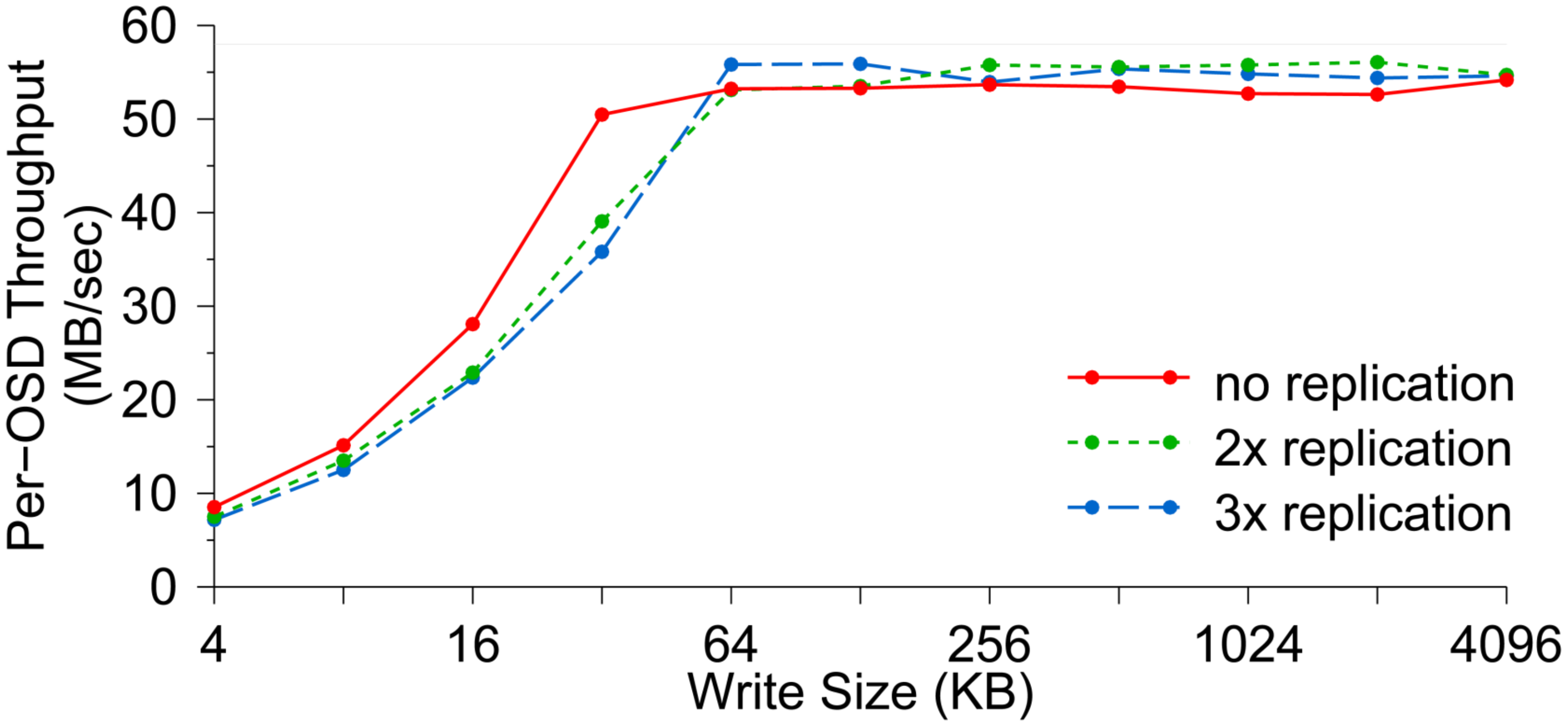
Failure Detection and Recovery

- *Down* and *Out*
- Monitors check for intermittent problems
- New or recovered OSDs peer with other OSDs within PG

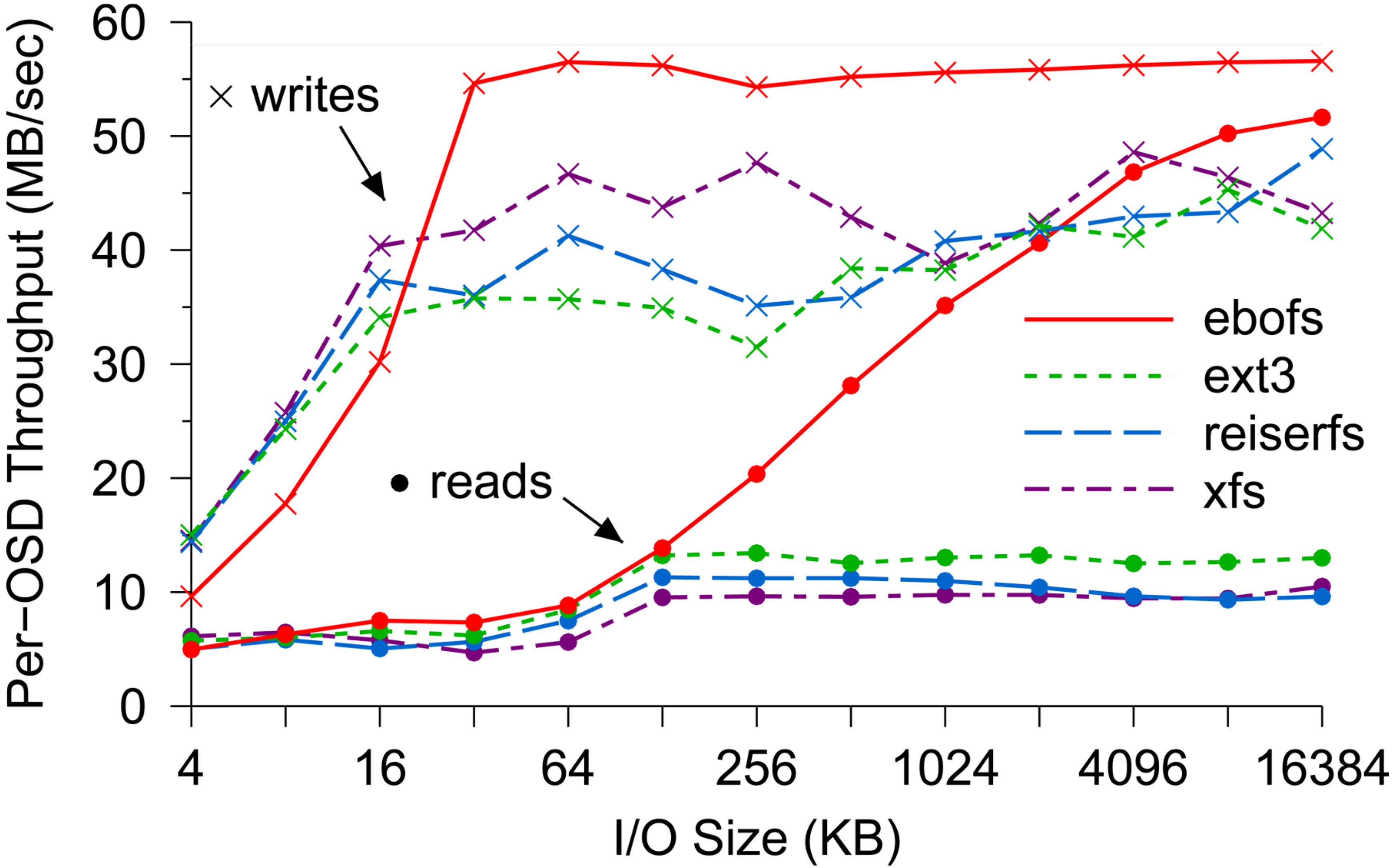
Conclusion

- Scalability, Reliability, Performance
- Separation of data and metadata
  - CRUSH data distribution function
- Object based storage

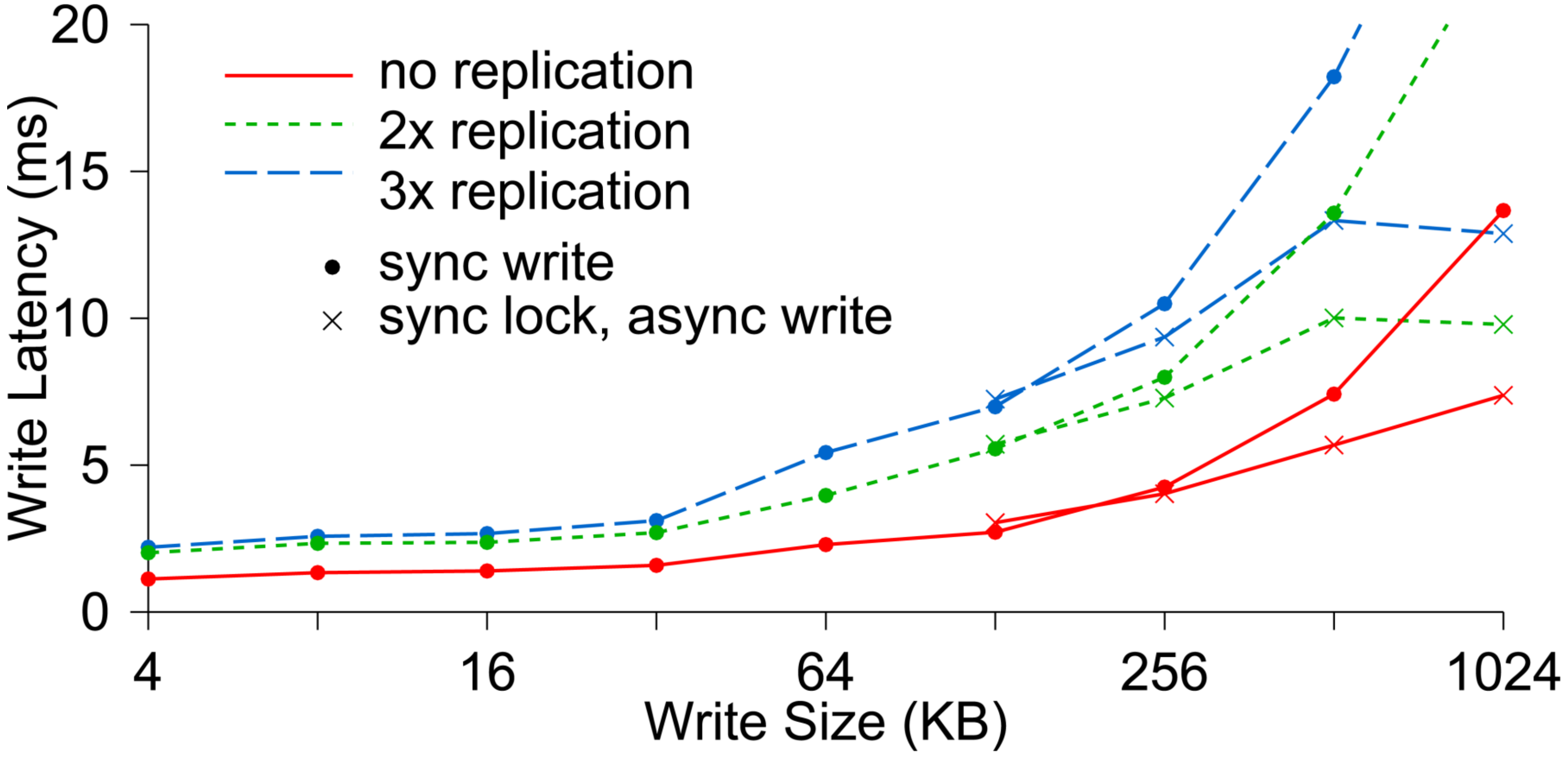
Per-OSD Write Performance



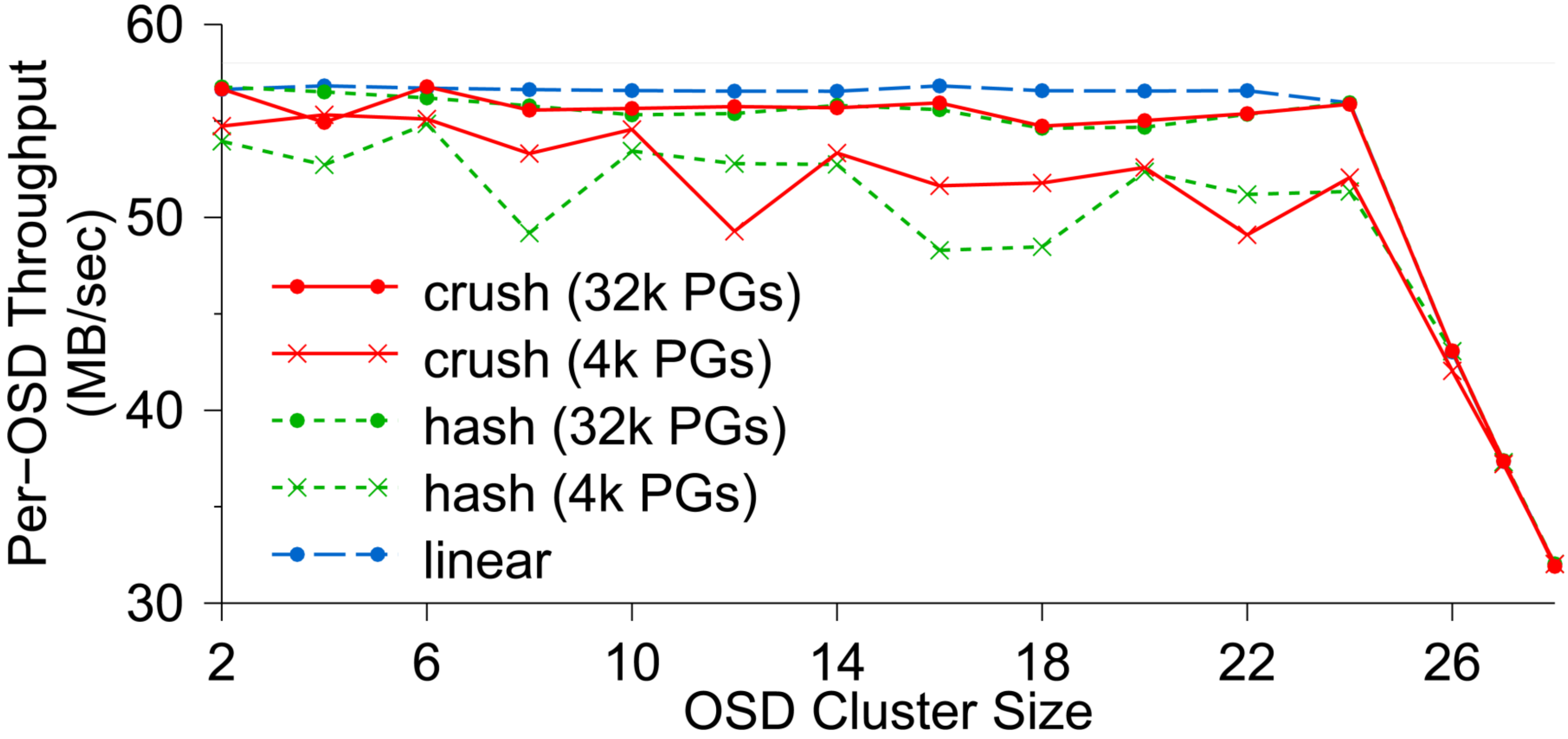
EBOFS Performance



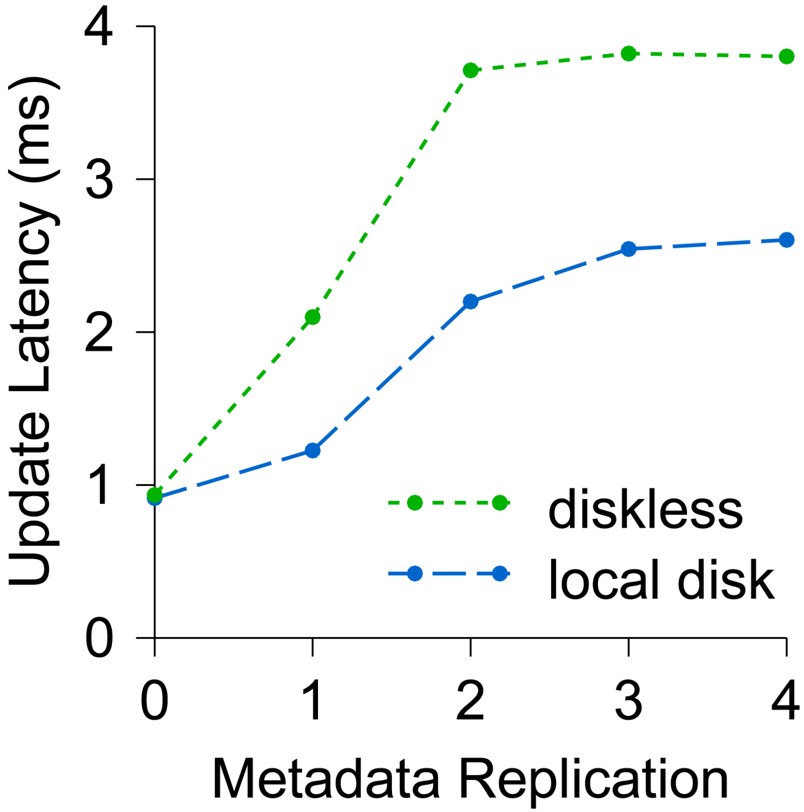
Write Latency

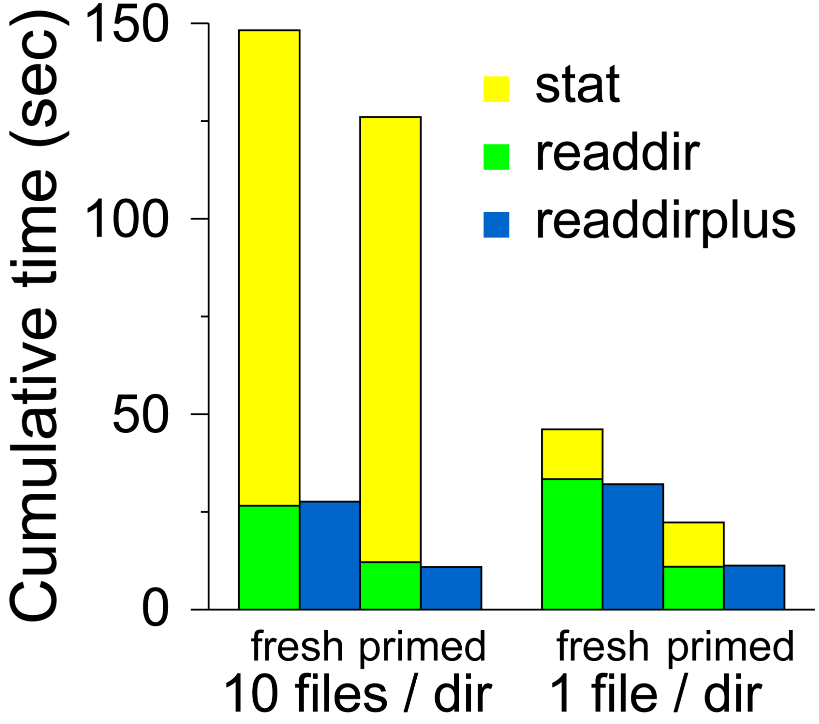


OSD Write Performance



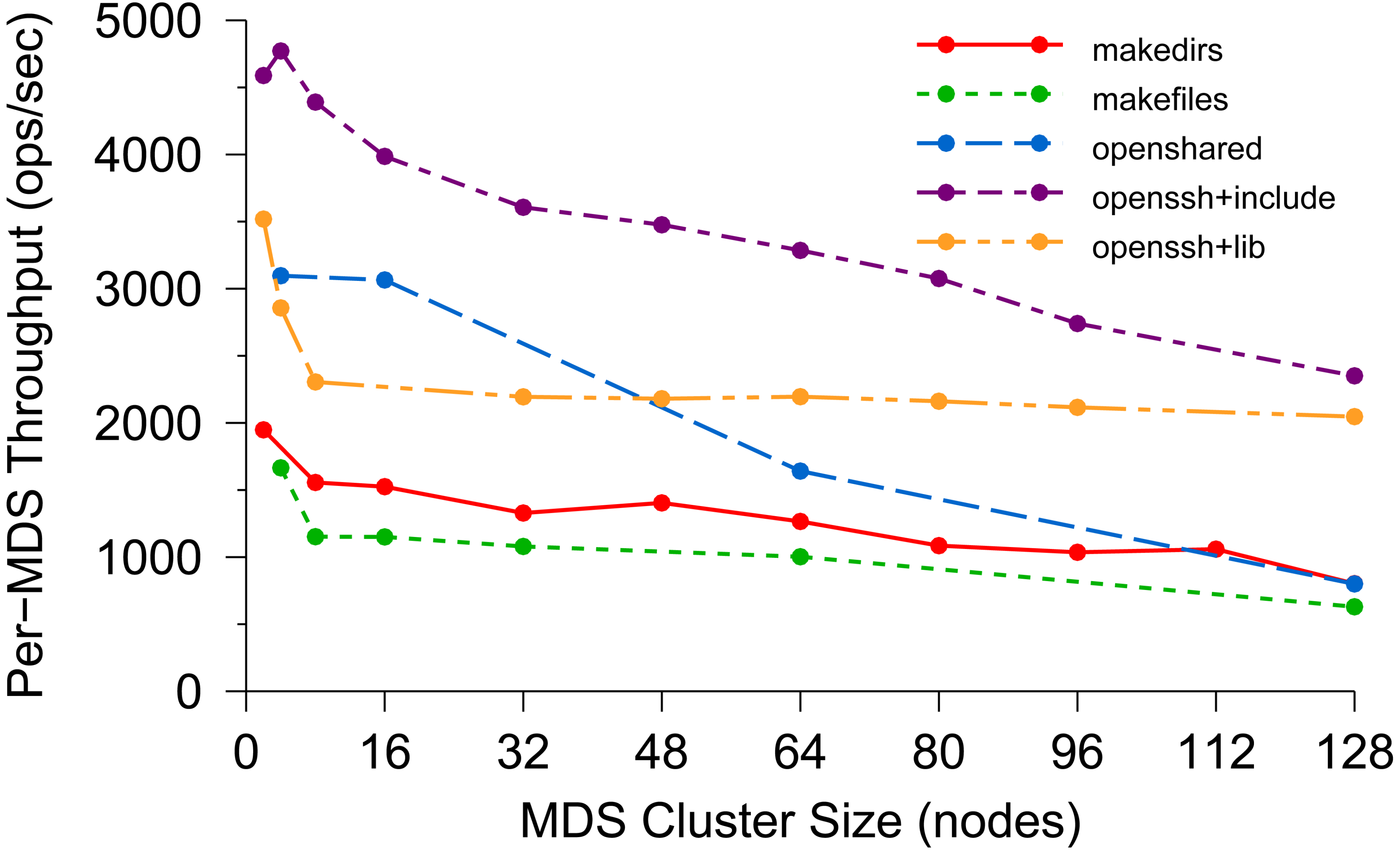
Diskless vs. Local Disk



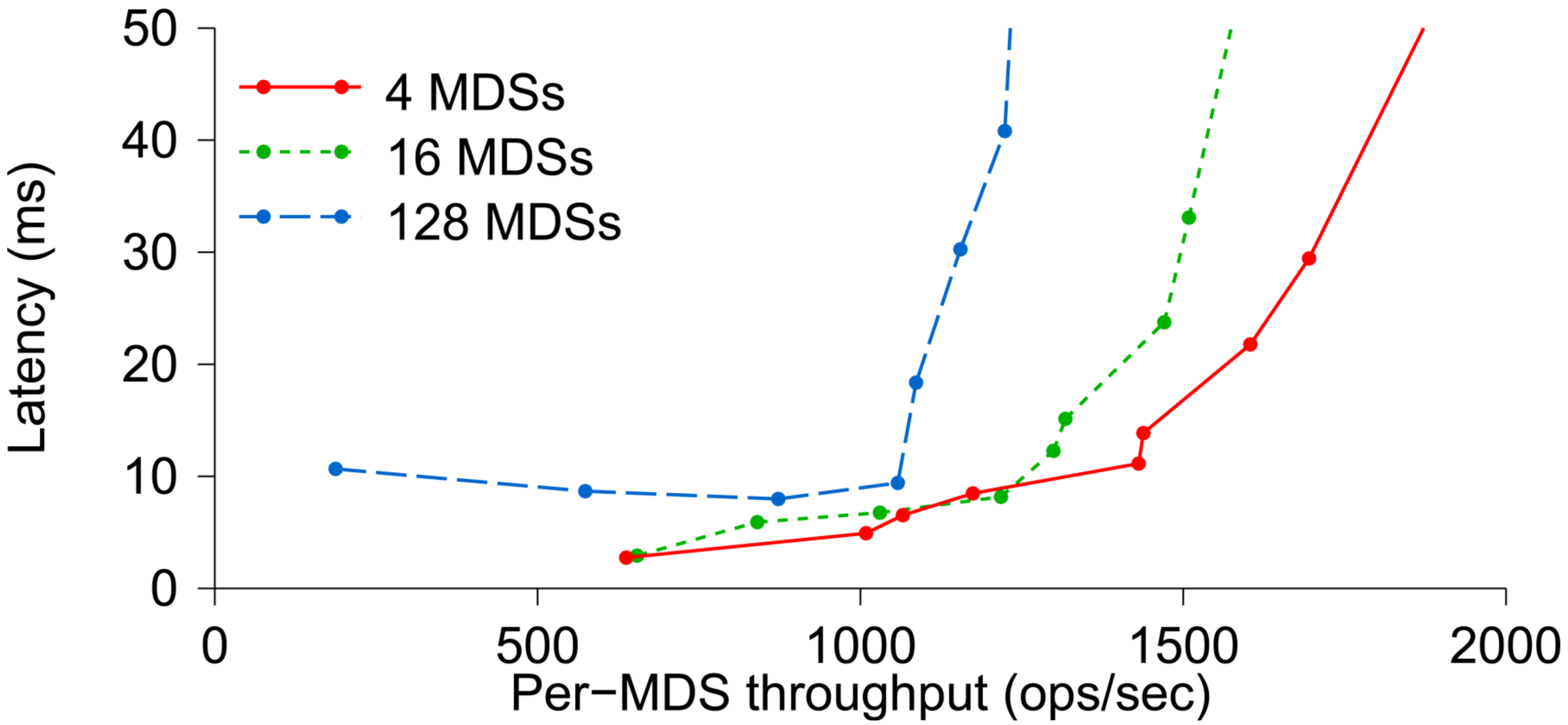


Compare latencies of (a) a MDS where all metadata are stored in a shared OSD cluster and (b) a MDS which has a local disk containing its journaling

Per-MDS Throughput



Average Latency



Lessons learned

(not a part of the original PowerPoint presentation)

1. Replacing file allocation metadata with a globally known distribution function was a good idea
   - Simplified our design
2. We were right not to use an existing kernel file system for local object storage
3. The MDS load balancer has an important impact on overall system scalability but deciding which mtadata to migrate where is a difficult task
4. Implementing the client interface was more difficult than expected
   - Idiosyncrasies of FUSE

Related Links

- OBFS: A File System for Object-based Storage Devices
  - ssrc.cse.ucsc.edu/Papers/wang-mss04b.pdf
- OSD
  - www.snia.org/tech_activities/workgroups/osd/
- Ceph Presentation
  - http://institutes.lanl.gov/science/institutes/current/ComputerScience/ISSDM-07-26-2006-Brandt-Talk.pdf
  - Slides 4 and 5 from Brandt’s presentation

Acronyms

- **CRUSH**: Controlled Replication Under Scalable Hashing
- **EBOFS**: Extent and B-tree based Object File System
- **HPC**: High Performance Computing
- **MDS**: MetaData server
- **OSD**: Object Storage Device
- **PG**: Placement Group
- **POSIX**: Portable Operating System Interface for uniX
- **RADOS**: Reliable Autonomic Distributed Object Store