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Breaking the Metadata Bottleneck: the Exascale Filesystem DeltaFS as a LANL and Carnegie Mellon Collaboration

Qing Zheng
Carnegie Mellon University

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Chuck Cranor, Greg Ganger, Garth Gibson, George Amvrosiadis
Bradley Settlemyer[†], Gary Grider[†]
Carnegie Mellon University
[†]Los Alamos National Laboratory

Everyone Loves Fast Storage

DeltaFS: **20,000**x faster than FS today

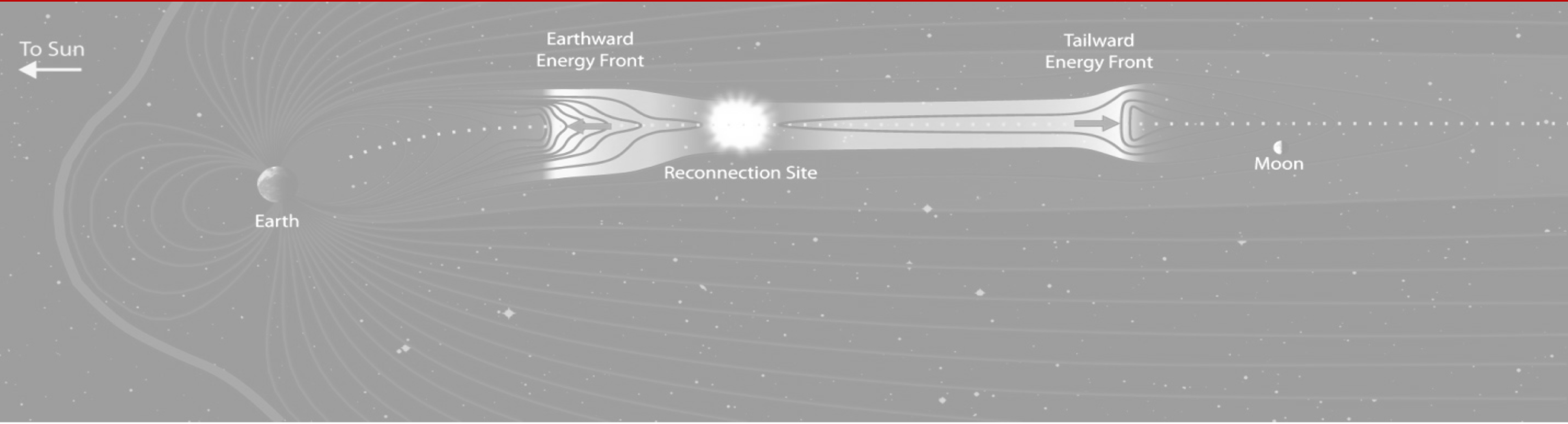

Image from http://esp.igpp.ucla.edu illustrating earth’s magnetic field under the influence of the solar wind.

Everyone Loves Fast Storage

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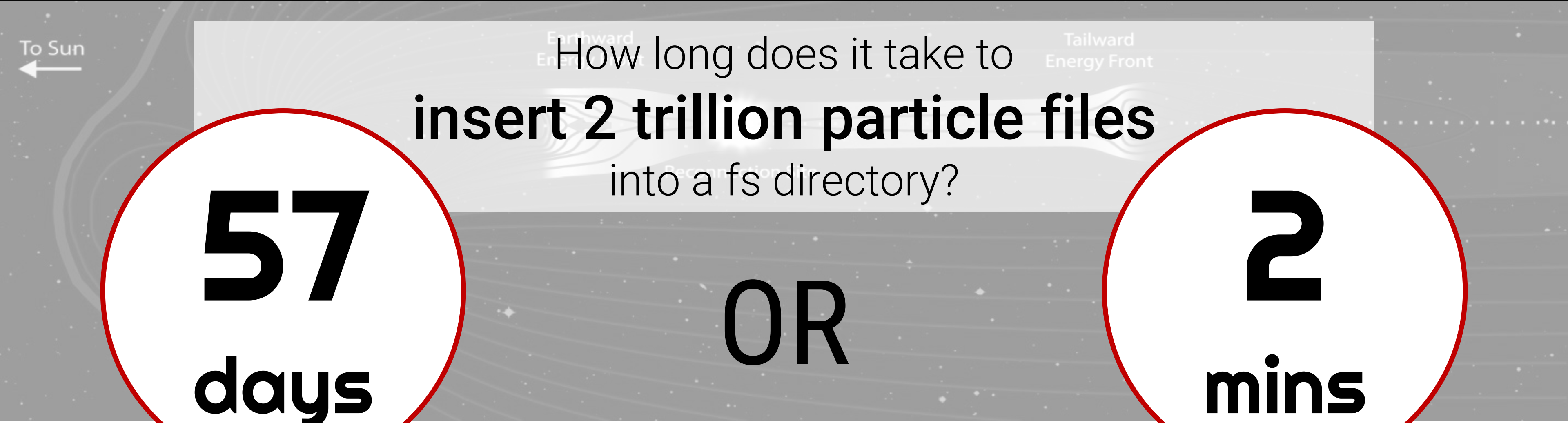


How long does it take to

insert 2 trillion particle files

into a fs directory?

57 days

OR

2 mins

Existing FS uses Dedicated Resources

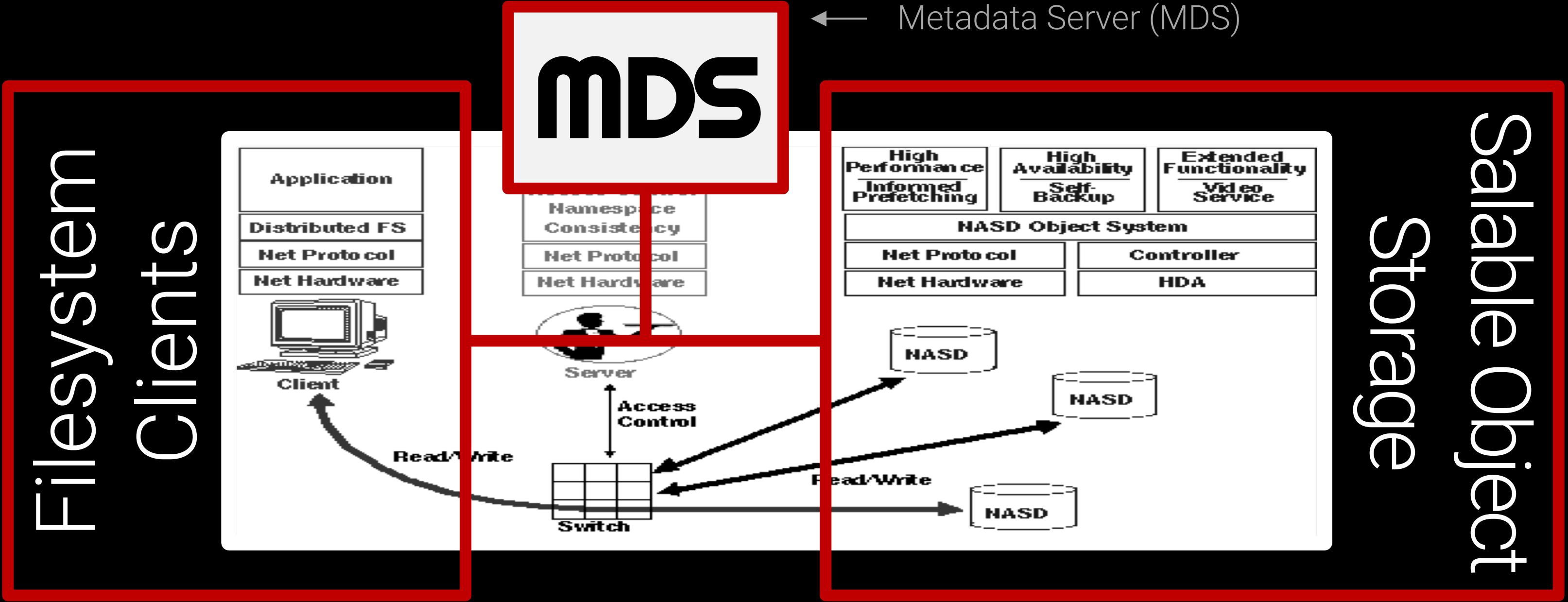
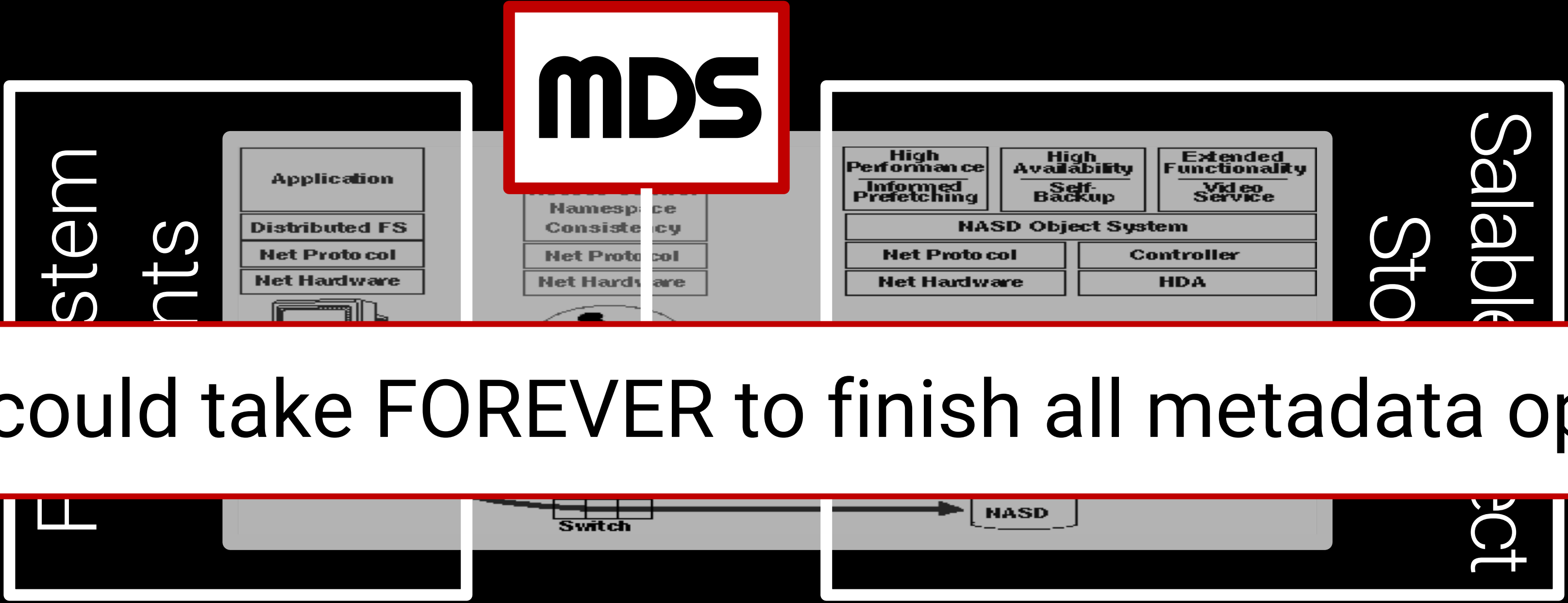


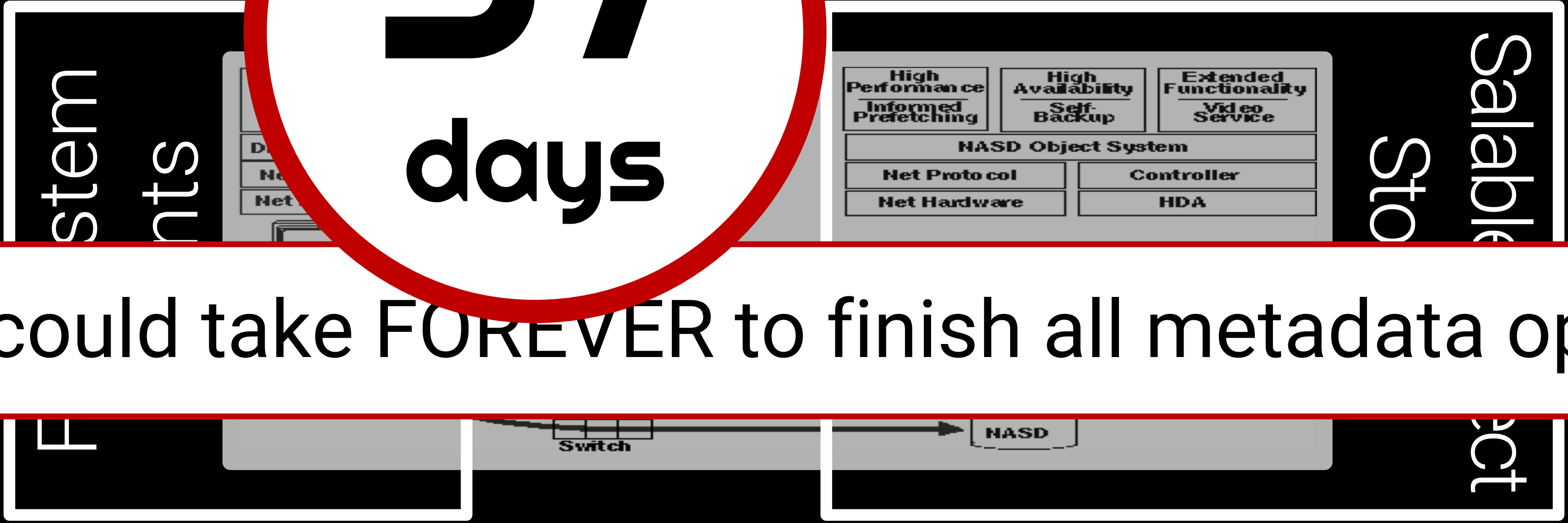
Figure shows CMU's NASD (OSD) design (now ANSI T10), root of many today's distributed filesystem designs.

MDS often a Bottleneck



It could take FOREVER to finish all metadata ops

n a Bottleneck



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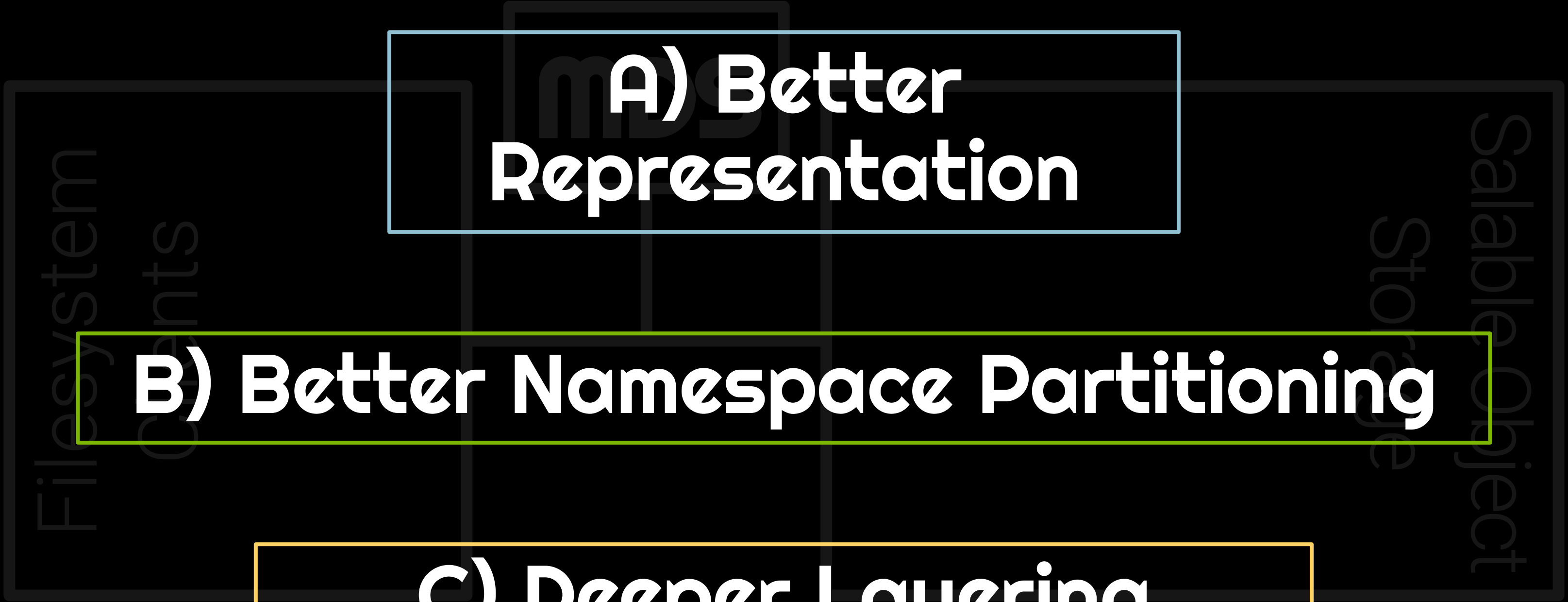
Common Ways for Stronger MDS

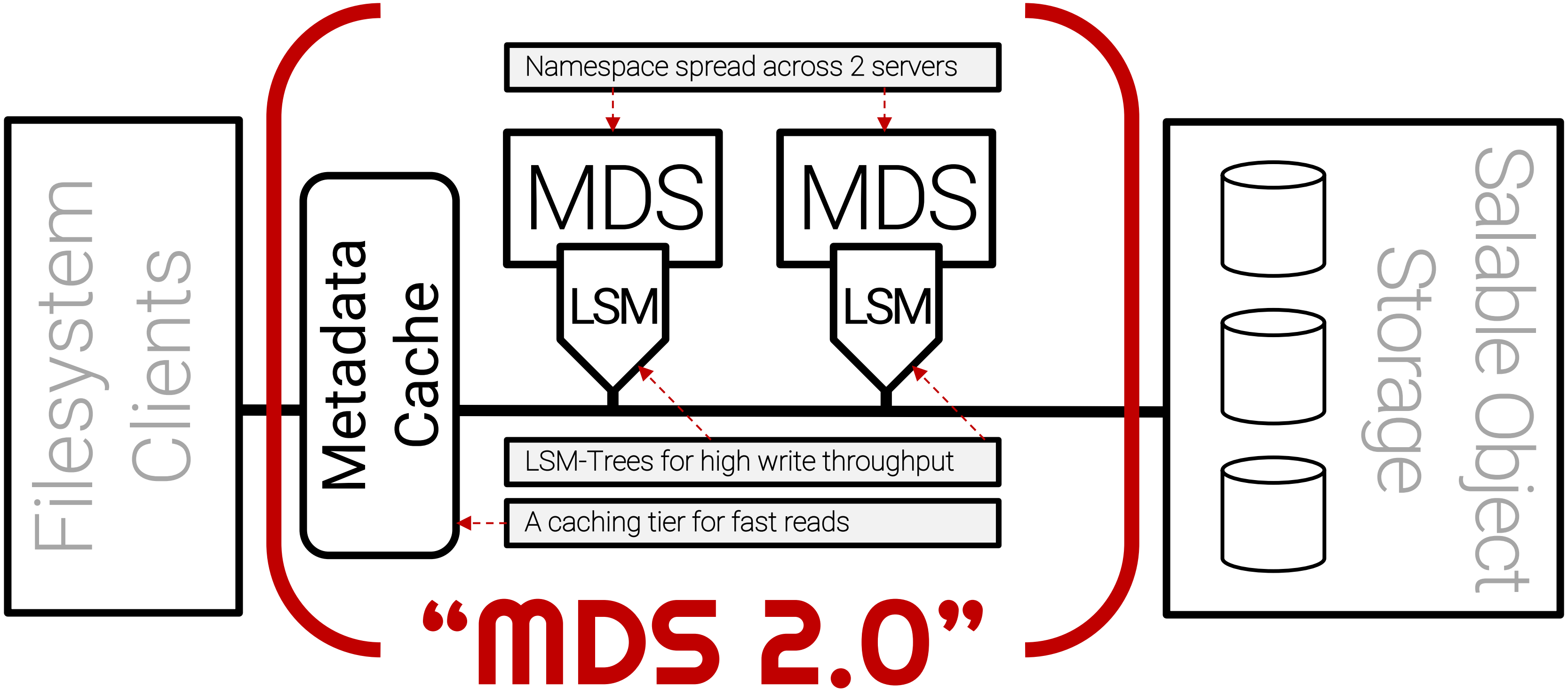


A) Better Representation

B) Better Namespace Partitioning

C) Deeper Layering

We Could Build Something Like This



Namespace spread across 2 servers

LSM-Trees for high write throughput

A caching tier for fast reads

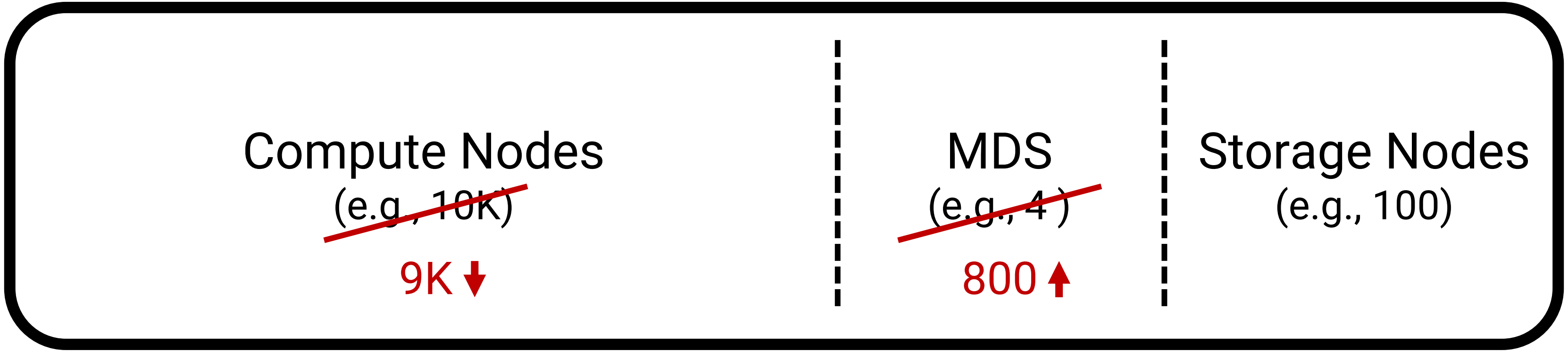
Might work but would be

EXTREMELY INEFFICIENT

in delivering 1 trillion file creates in 2 mins

Need 800 servers if each can do 10 million file creates/s.

Budget is Fixed for Each Machine



Compute Nodes
~~(e.g., 10K)~~
9K ↓

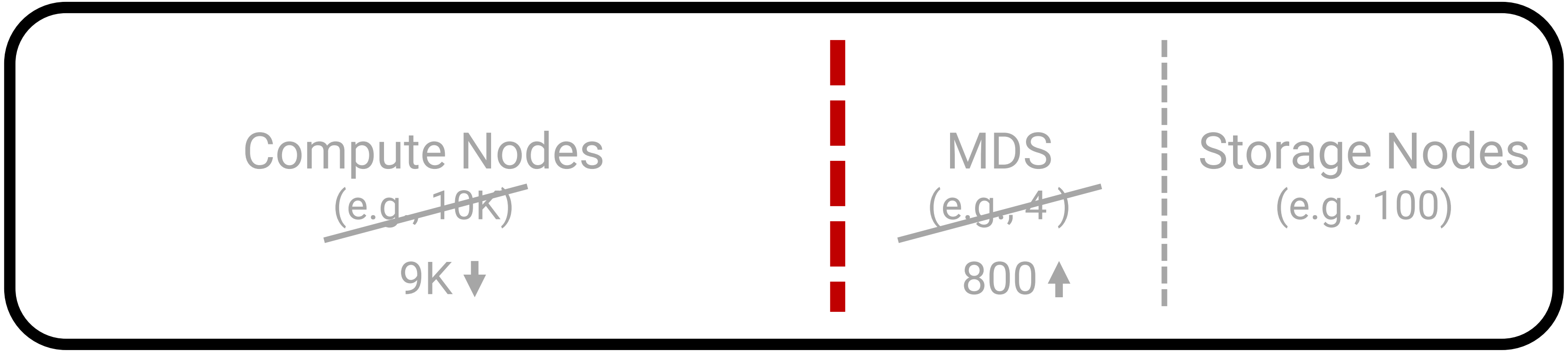
MDS
~~(e.g., 4)~~
800 ↑

Storage Nodes
(e.g., 100)

More MDS nodes means less compute nodes

MDS not busy all the time

Budget is Fixed for Each Machine



Compute Nodes
~~(e.g., 10K)~~
9K ↓

MDS
~~(e.g., 4)~~
800 ↑

Storage Nodes
(e.g., 100)

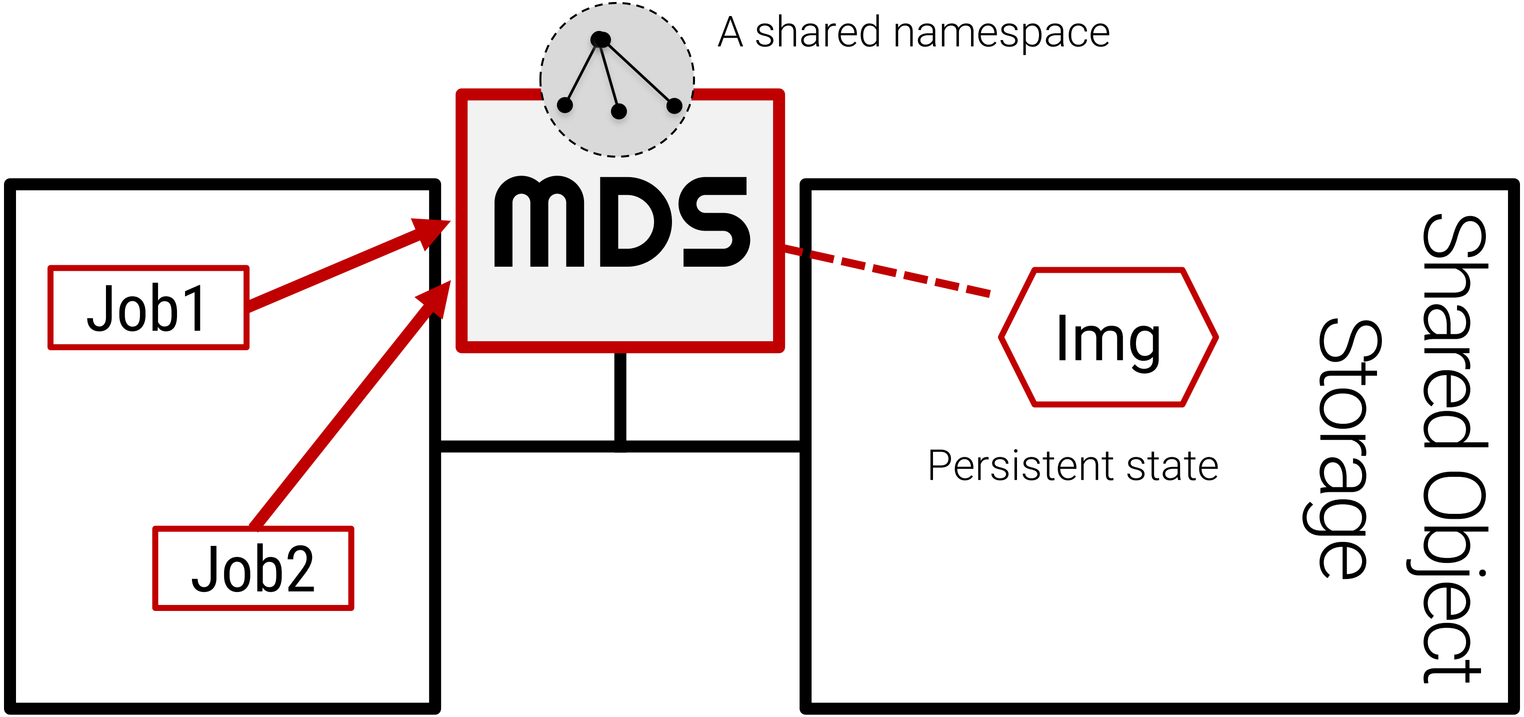
We blame the bar that separates the nodes

A waste: unable to use MDS nodes to run jobs

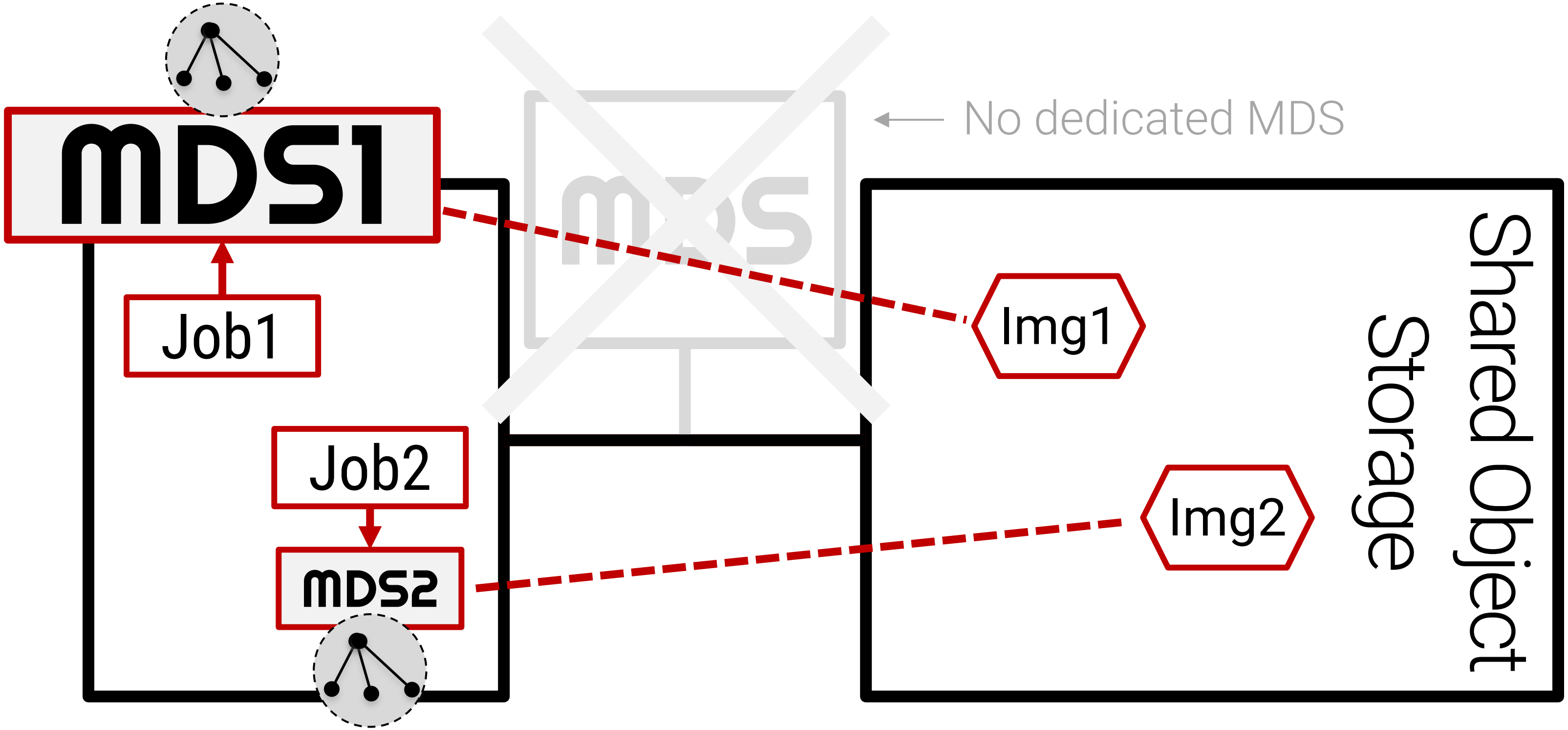
A much bigger waste: unable to utilize compute nodes to process metadata

A BOLD idea: having filesystems run directly on job nodes (DeltaFS)

Today: A Dedicated MDS Per Machine



Better: Dynamically Instantiating MDS for Jobs



Immediate Benefits from No Dedicated MDS

Simplified cluster design

No need to pool resources for MDS during cluster planning

No false sharing

My cache entries do not get invalidated by someone else’s activities

Highly agile scalability

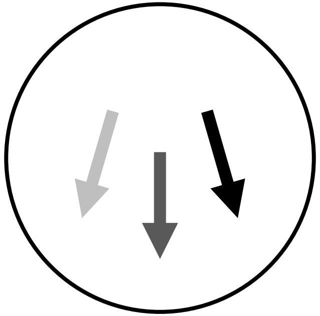
Larger jobs can devote more resources to MDS

Better resource utilization

Would-be idle CPU cycles can be utilized to process metadata

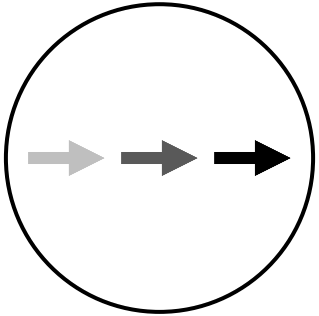
Does this really work for my applications?

Three Types of Interaction



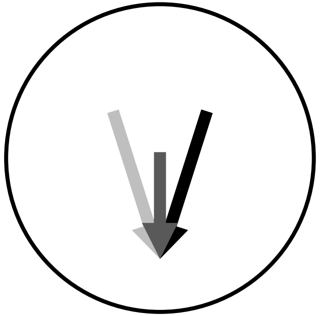
No sharing

Different jobs access different sets of files



Sequential sharing

One job's output is another job's input



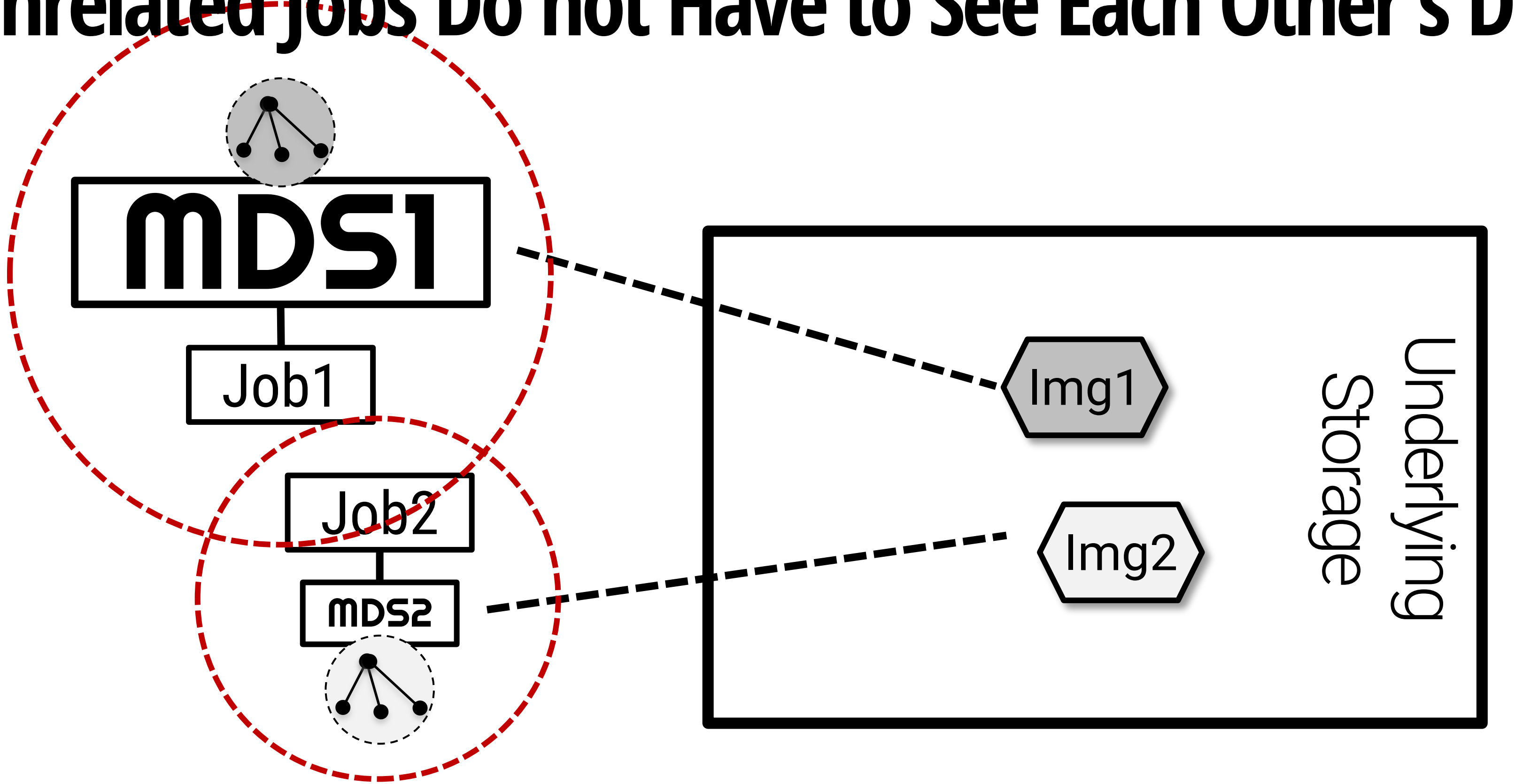
Concurrent sharing

Multiple jobs read & write a same set of files

Works trivially today: **1** dedicated MDS, **1** global namespace

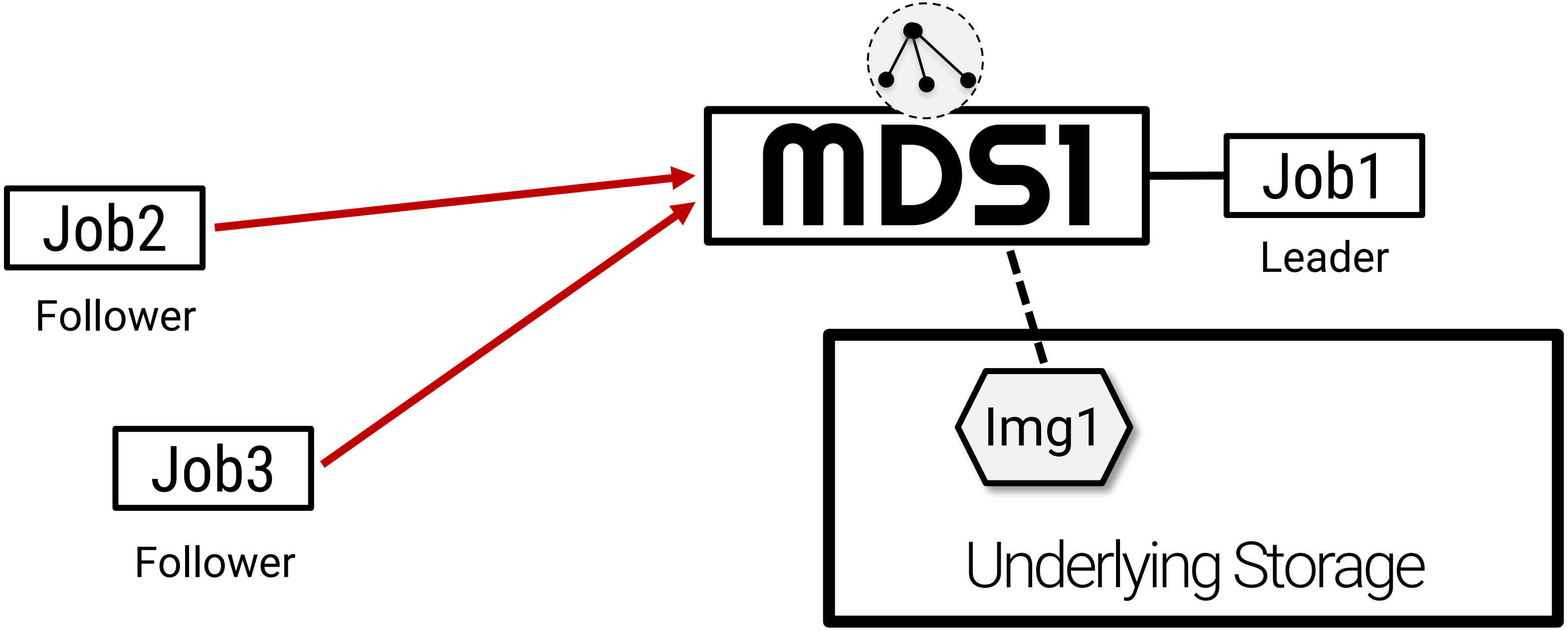
But a global namespace is not always required for existing jobs to work

Unrelated Jobs Do not Have to See Each Other's Data

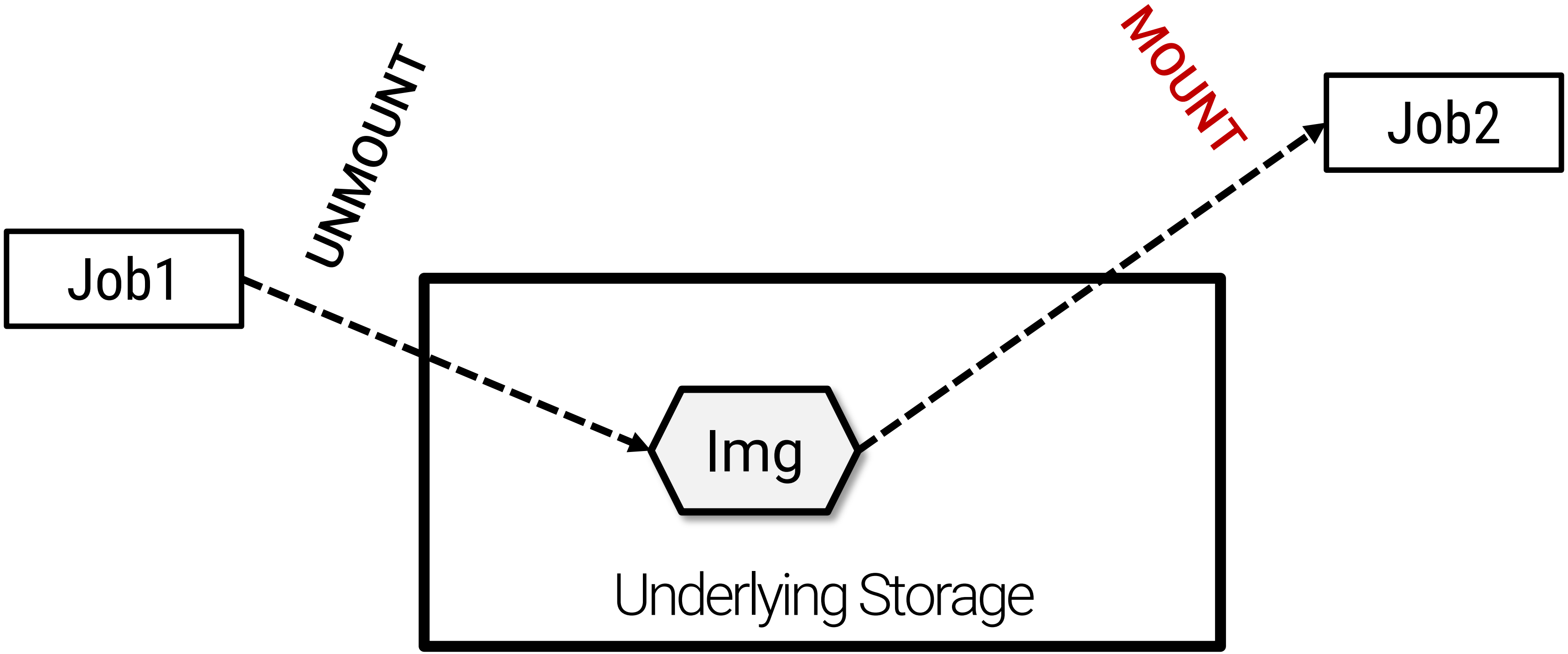


Concurrent Sharing? Connect to the Leader

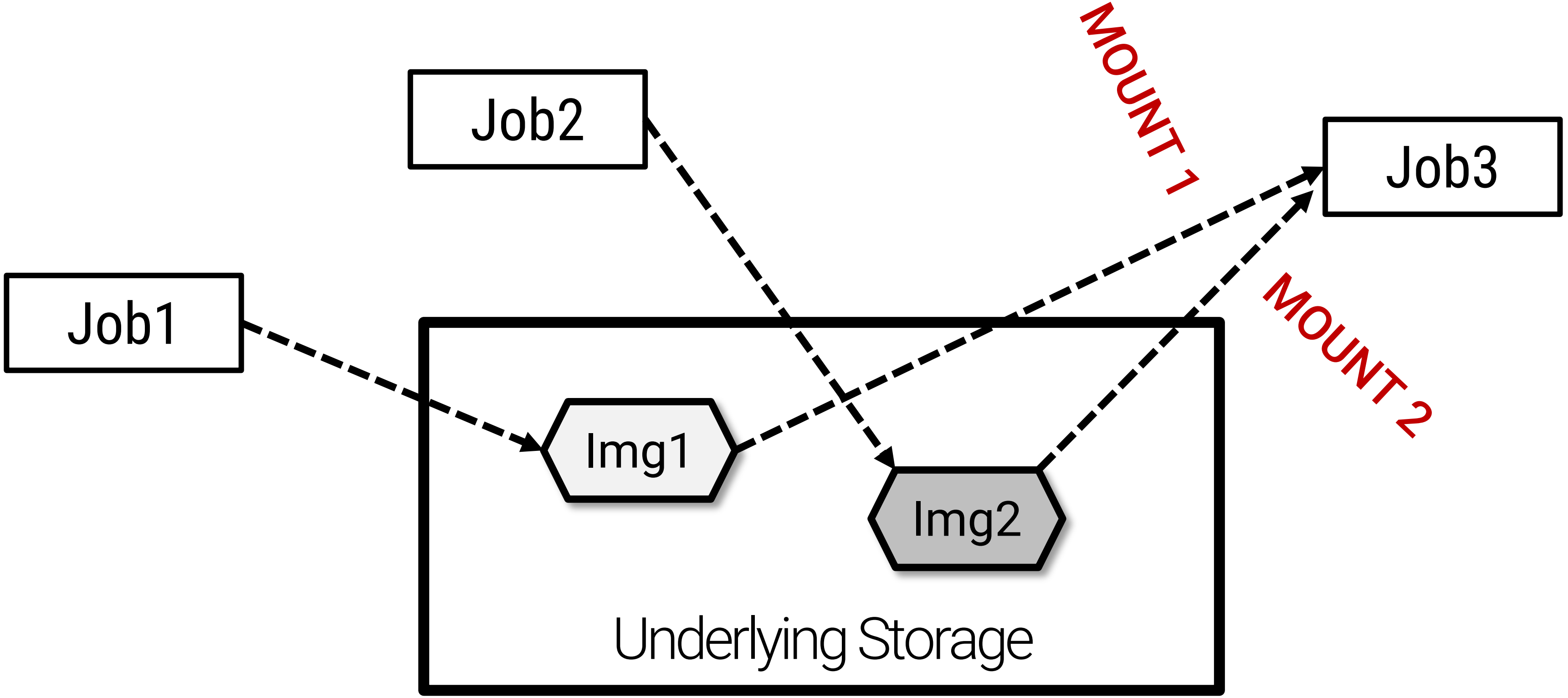
One use case: user monitoring such as "***ls -l***" & "***tail -F***"



Need Another Job's Data? Just Mount it & Carry on



Mount Many If Necessary



A namespace is as good as a global namespace if a job sees all related data

Re-imagining filesystems for future

Machine-Oriented v.s. Job-Oriented

A component of a machine	*A component of a running job*
Always ON, centralized	Dynamically instantiated by jobs
Uses a fixed set of dedicated nodes	**Highly agile**: scales with job allocations
Long-standing	**Transient**: lives within a job
Accessible from every node of a machine	**Private**: accessed only by a job
A shared FS image per machine	**No false sharing**: one per job
Runs background activities (e.g., reorganizing indexes for fast reads)	**No jitters**: all background FS work is scheduled by jobs
One piece of code	**Software-defined**: code optimized for the work at hand

Machine-Oriented v.s. Job-Oriented

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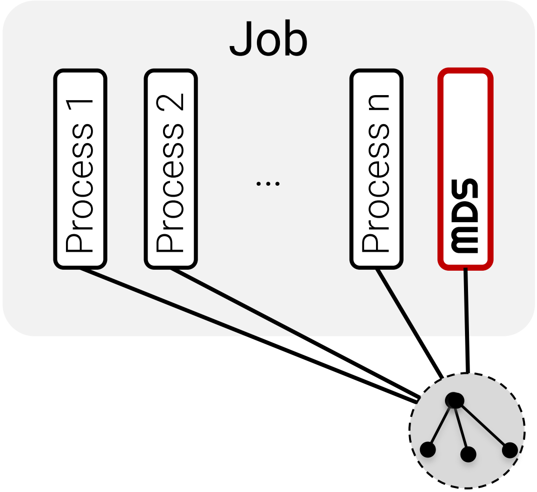
Private: accessed only by a job
No false sharing: one per job

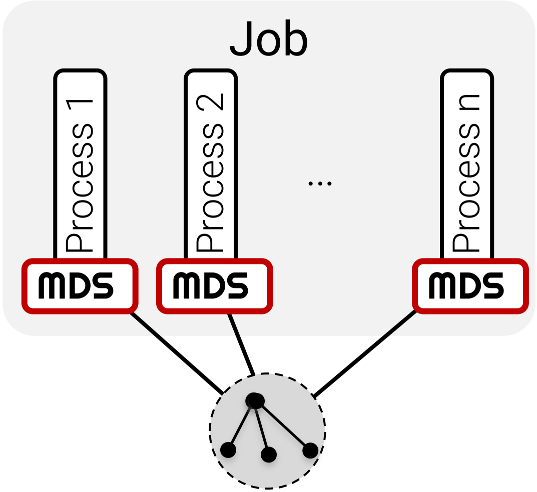
No jitters: all background FS work is scheduled by jobs
Software-defined: code optimized for the work at hand

Decoupling MDS from the Machine

Each ***job*** can be viewed as a ***process group***

A group of processes self-found their MDS service





One option: MDS runs as a separate job process

Decoupled from the machine

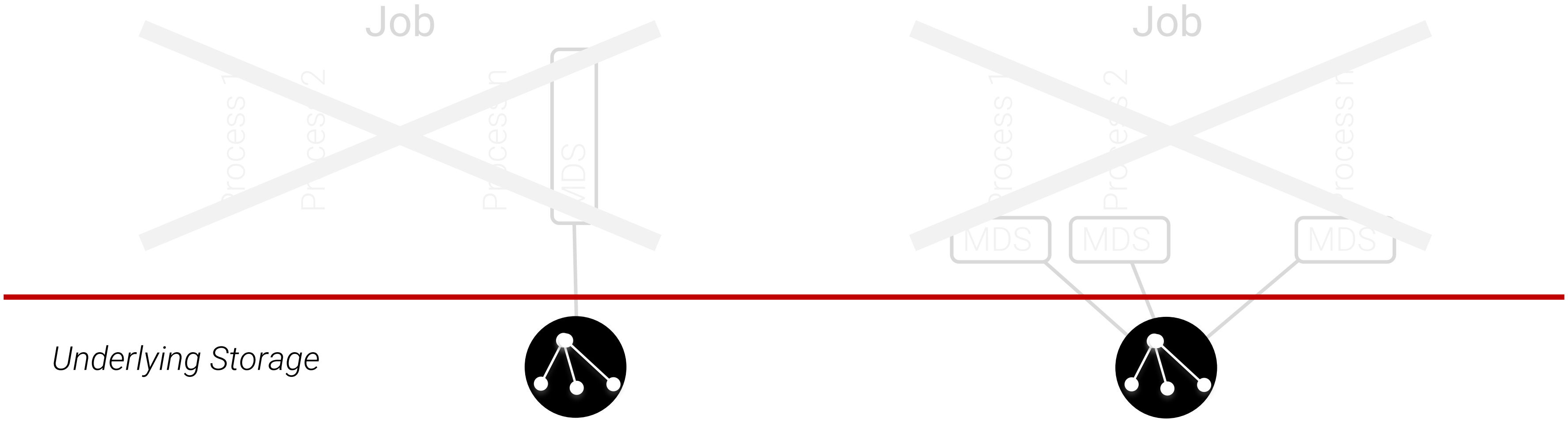
Another option: MDS runs as library within processes

Again, decoupled from the machine

Transient Service, Persistent Data

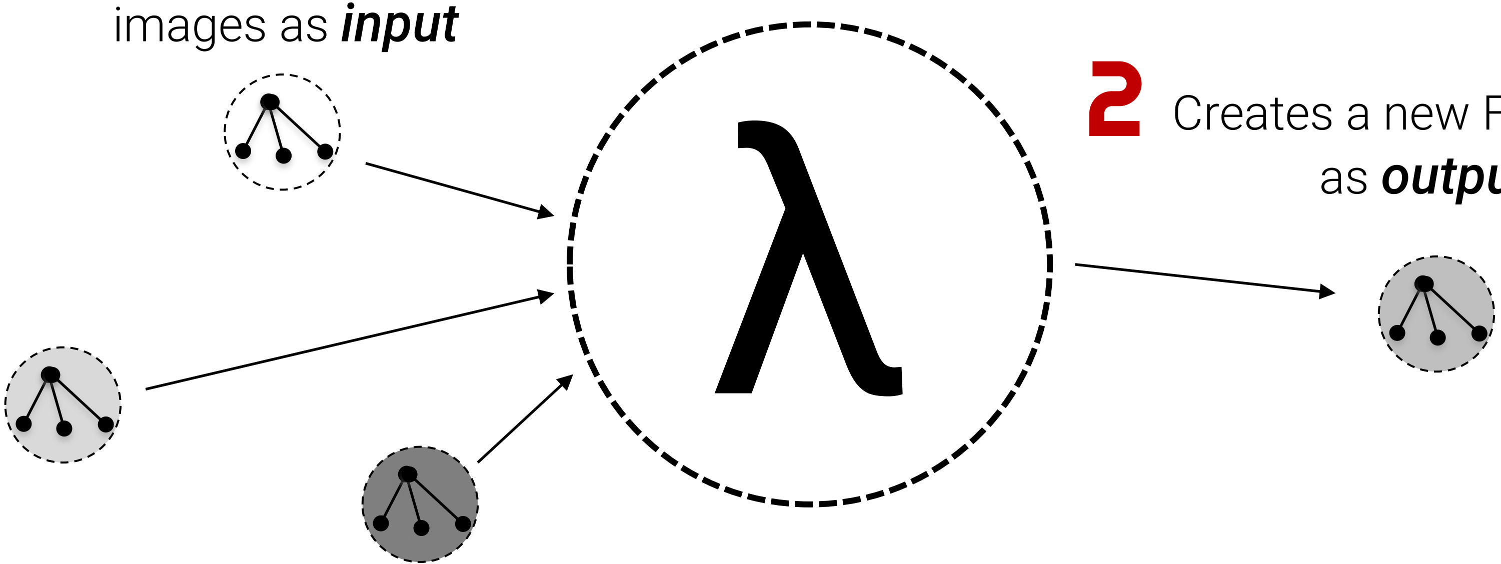
When a job ends, its FS “service” goes with it

Data stays in the underlying storage



Each Job Acts as a Function

1 Takes one or more FS images as ***input***

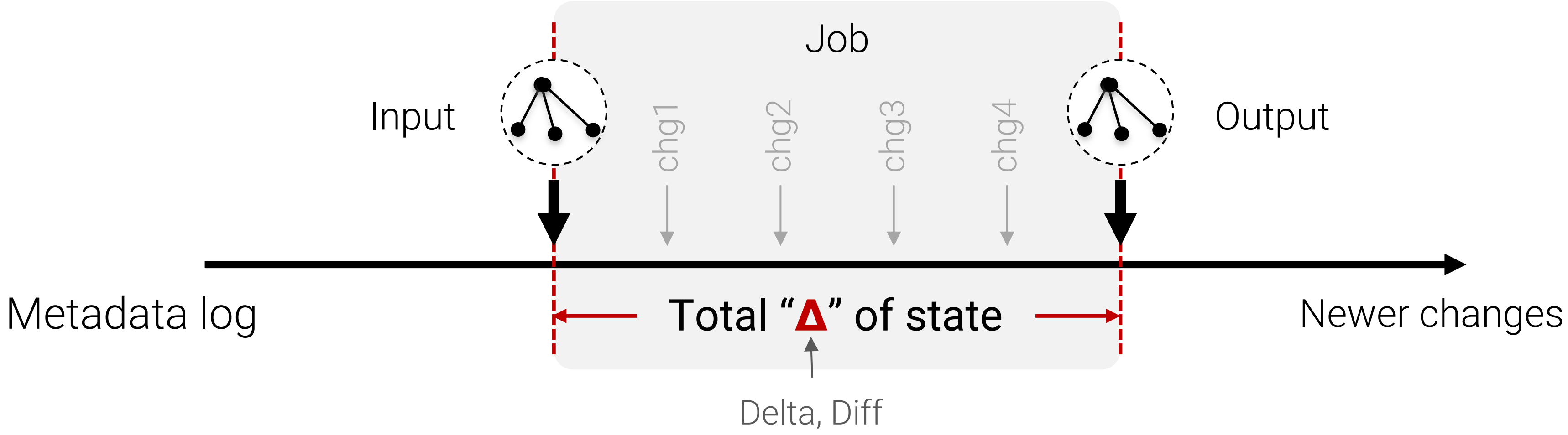


2 Creates a new FS image as ***output***

3 ***No side effect***

Log-Structured: Each Job Appends Changes to a Log

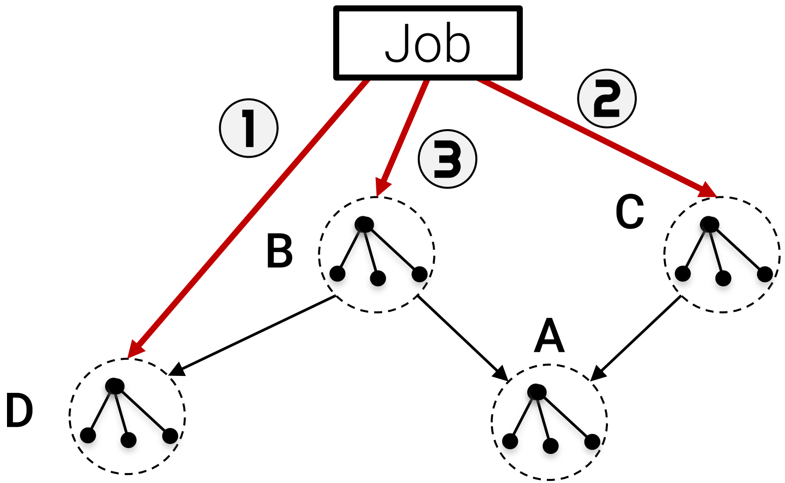
Keeping input ***immutable*** so that they can be shared in a scalable way

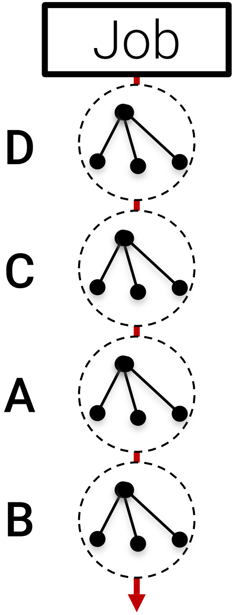


Each FS image essentially a ***pointer*** to a logical log

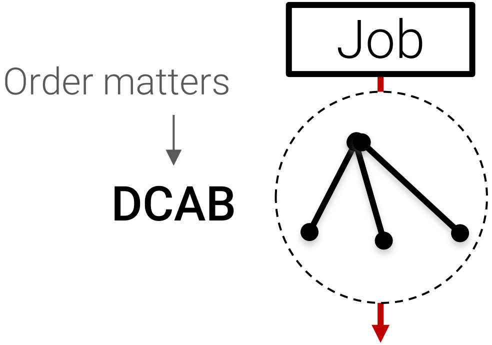
Turtles All the Way Down

Reading from an FS image is searching through a DAG of “Δ”s





Resolve conflicts using a ***job-specified ordering***

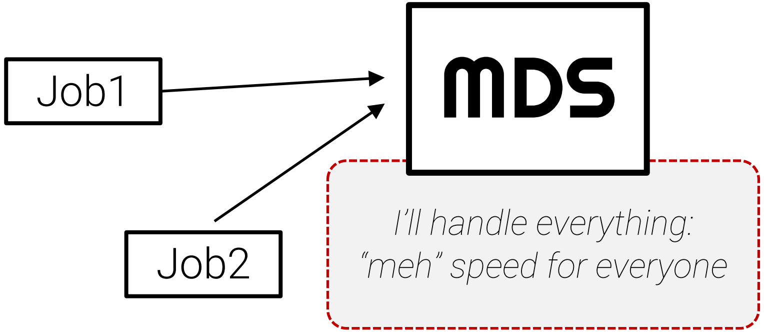


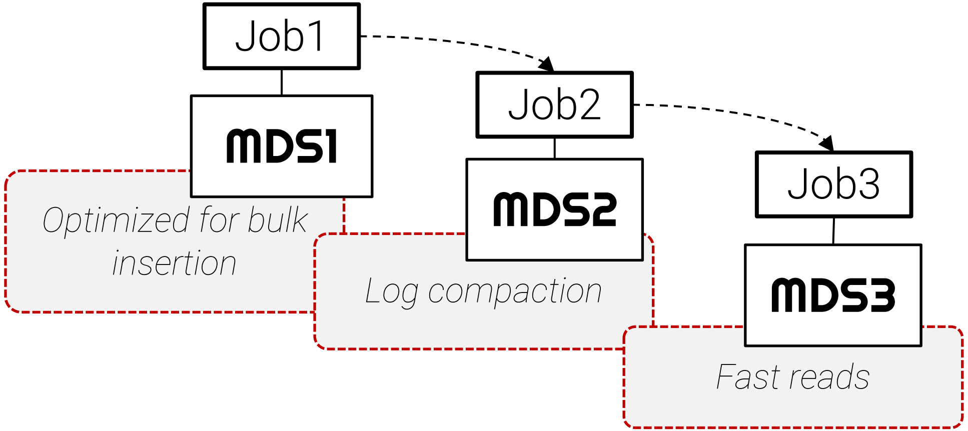
Merging & flattening for fast reads via ***log compaction***

User Pays for Speed *(by Scheduling Log Compactions)*

Log compaction reduces search depth & reclaims space

Often time-consuming





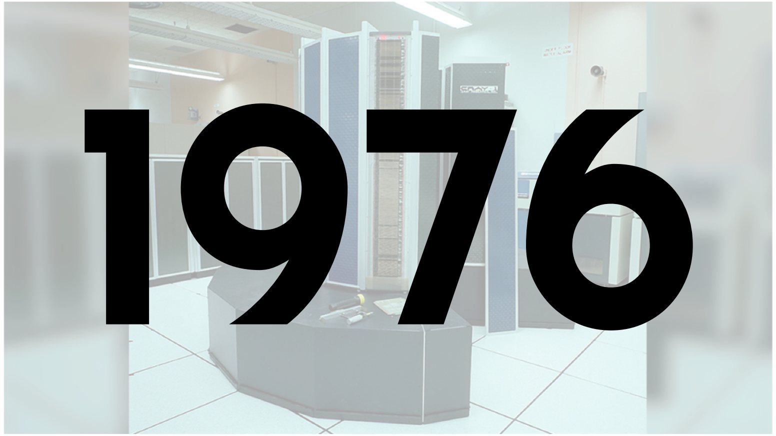
Traditional: done by a dedicated MDS
Jitters or ***wasted work***

Better: explicitly scheduled by apps
Predictable high performance

How does my job find its input data?

It’s All about Mapping Names to Data

User specifies names; a mechanism handles the mapping



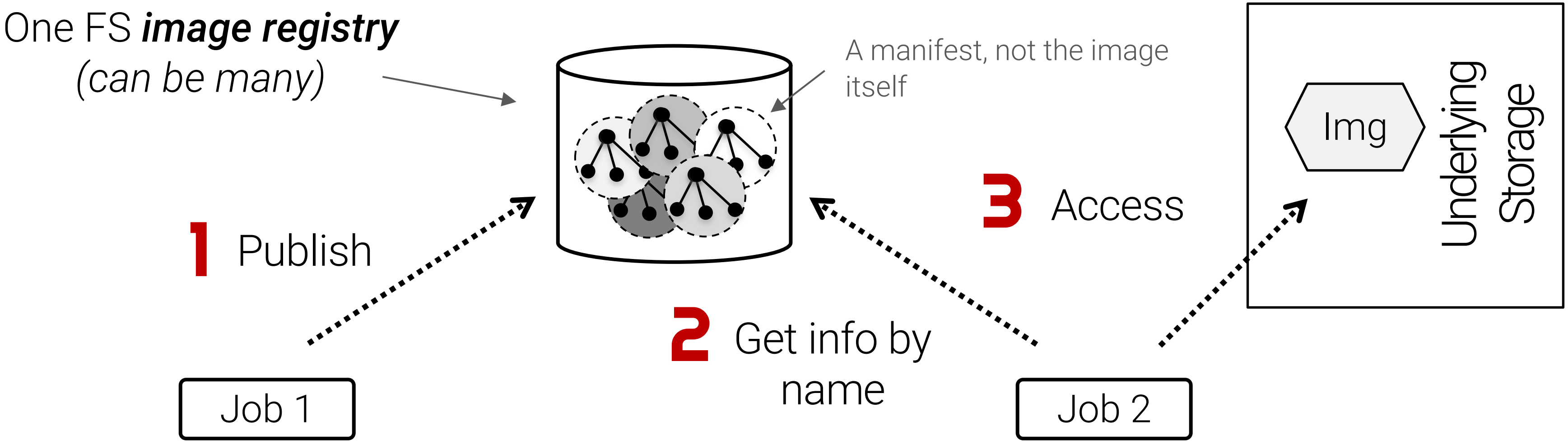
The good old days: a ***job control system*** does the mapping

Today: a ***global filesystem namespace*** does the mapping

LANL’s Cray-1 (left) and Trinity computer (right), https://www.lanl.gov/asci/platforms/index.php

A New Kind of Mapper: Filesystem Image Registry

Works like github.com, jobs "git-clone" their input datasets



One FS ***image registry***
(can be many)

A manifest, not the image itself

1 Publish

2 Get info by name

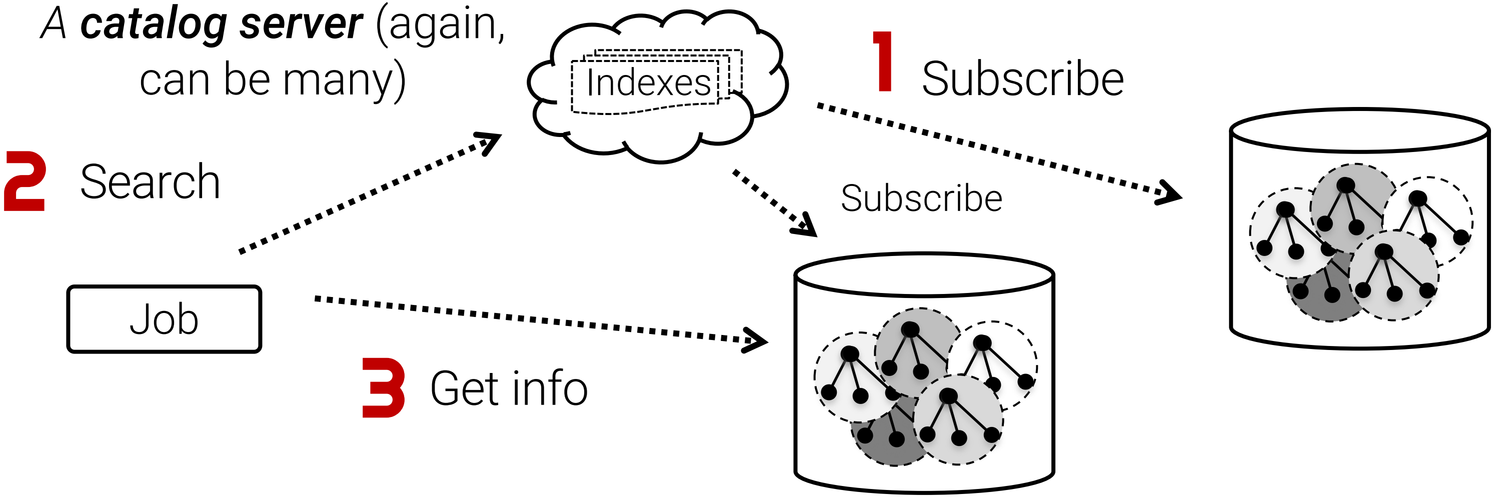
3 Access

*Publication & collection may be automated by **workflow engines***

Which Registry did I Use? Ask a Catalog Service

Is it github.com or bitbucket.org?

A ***catalog server*** (again, can be many)



Related talk: LANL's catalog service GUFI by Dominic Manno

Session 63, 2pm Wed, Lafayette room

Sounds Good. *Remind me Why Perf. is Better…*

1. More CPUs

Able to use more resources to do FS work

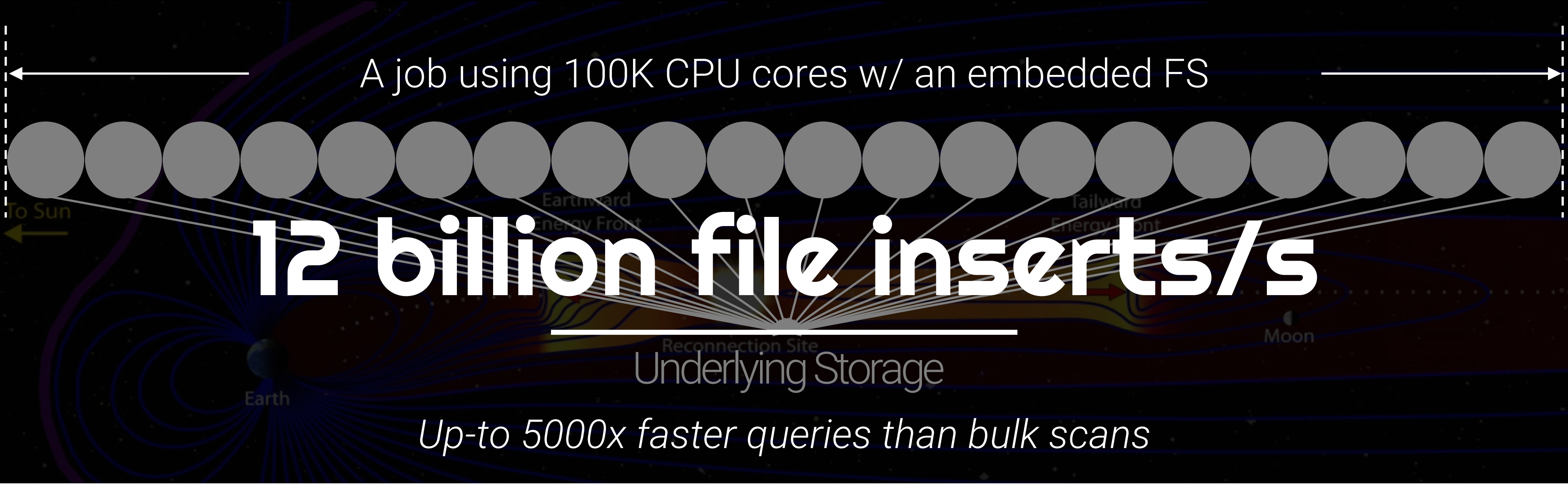
2. More Efficient

No false sharing, less synchronization, better caching

3. Software-Defined

Smart clients, simple storage

Example: Making a Needle-in-a-Haystack Hero



A job using 100K CPU cores w/ an embedded FS

12 billion file inserts/s

Underlying Storage

Up-to 5000x faster queries than bulk scans

Under the hood: a) leveraged idle CPU cycles, b) deep writeback buffering, c) optimized storage layout

Conclusion

Existing FS clients sync too often with servers

Synchronization of anything global should be avoided at extreme scales

Removing servers forces us to review what’s necessary

Enabling sequential sharing is where filesystems shrine

Need radically different models for shared storage

A job-oriented filesystem scales better in many computing scenarios

Thank you.