Fast Forward I/O & Storage

Eric Barton

Lead Architect
High Performance Data Division

Department of Energy - Fast Forward Challenge

FastForward RFP provided US Government funding for exascale research and development

Sponsored by 7 leading US national labs

Aims to solve the currently intractable problems of Exascale to meet the 2020 goal of an exascale machine

RFP elements were CPU, Memory and Filesystem

Whamcloud won the Filesystem component

- HDF Group – HDF5 modifications and extensions
- EMC – Burst Buffer manager and I/O Dispatcher
- Cray - Test

Contract renegotiated on Intel acquisition of Whamcloud

- Intel - Arbitrary Connected Graph Computation
- DDN - Versioning OSD

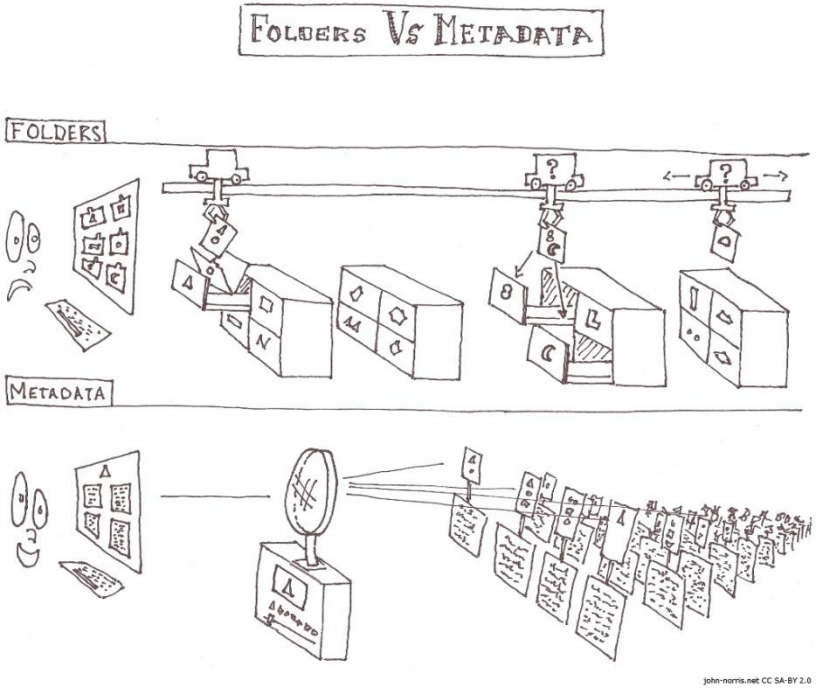
Exascale I/O technology drivers

	2012	2020
Nodes	10-100K	100K-1M
Threads/node	~10	~1000
Total concurrency	100K-1M	100M-1B
Object create	**100K/s**	**100M/s**
Memory	1-4PB	30-60PB
FS Size	10-100PB	600-3000PB
MTTI	1-5 Days	6 Hours
Memory Dump	< 2000s	< 300s
Peak I/O BW	**1-2TB/s**	**100-200TB/s**
Sustained I/O BW	**10-200GB/s**	**20TB/s**

Exascale I/O technology drivers

(Meta)data explosion

- Many billions of entities
  - Mesh elements / graph nodes
- Complex relationships
- UQ ensemble runs
  - Data provenance + quality



OODB

- Read/Write -> Instantiate/Persist
- Fast / ad-hoc search: “Where’s the 100 year wave?”
  - Multiple indexes
  - Analysis shipping

Exascale I/O requirements

Constant failures expected at exascale

Filesystem must guarantee data **and** metadata consistency

- Metadata at one level of abstraction is data to the level below

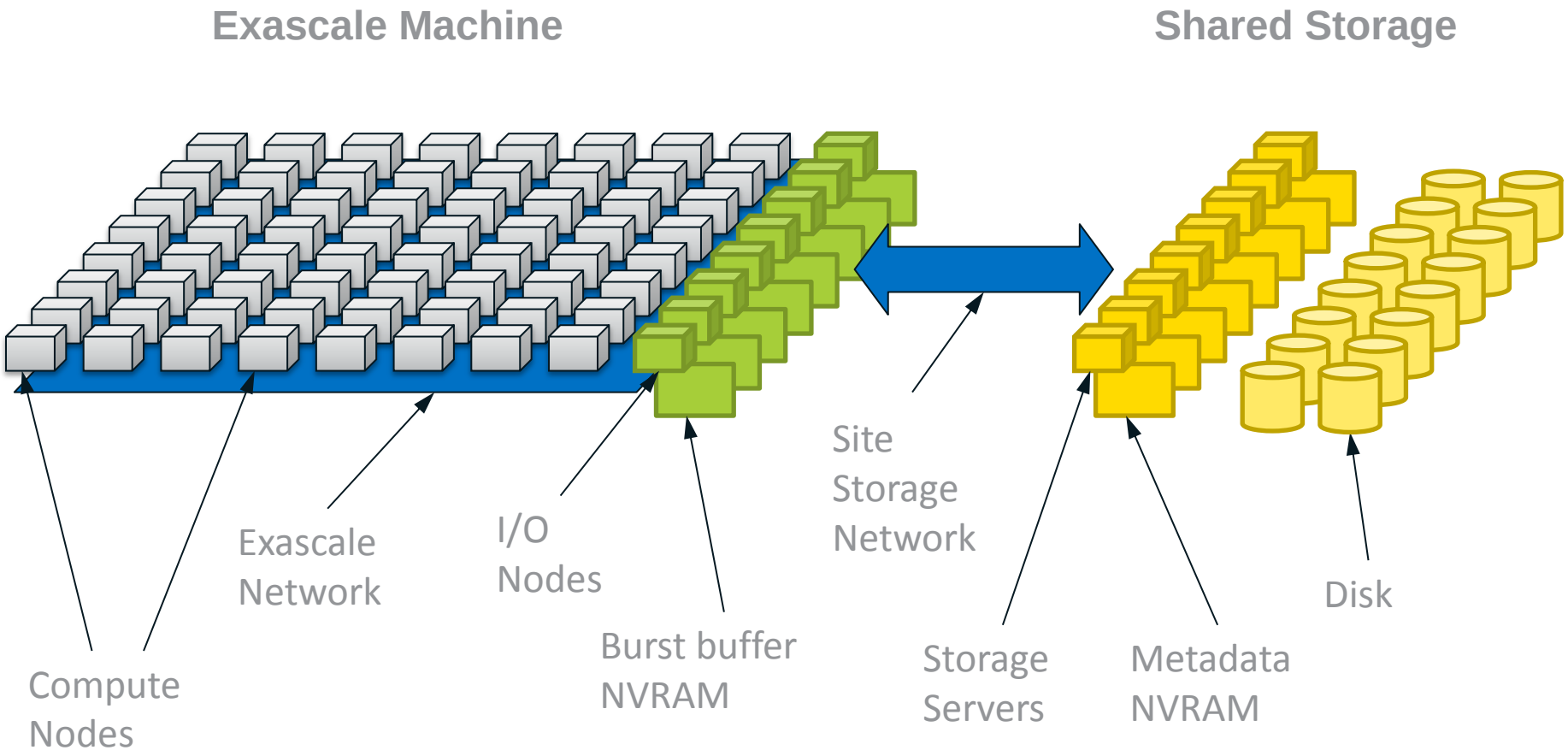
Filesystem must guarantee data integrity

- Required end-to-end

Filesystem must always be available

- Balanced recovery strategies
  - Transactional models
    - Fast cleanup up failure
  - Scrubbing
    - Repair / resource recovery that may take days-weeks

Exascale I/O Architecture

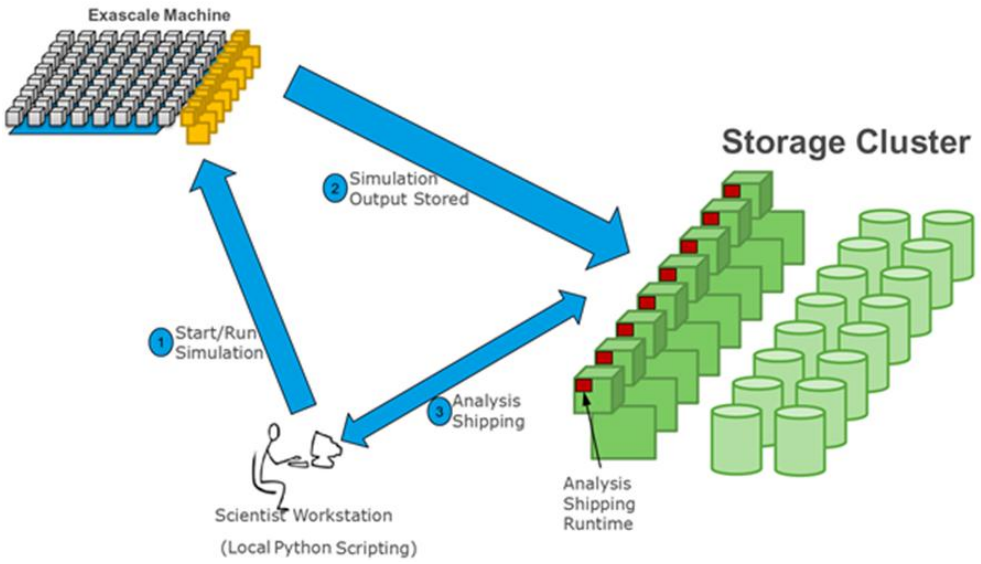


Project Goals

Storage as a tool of the Scientist

Manage the explosive growth and complexity of application data and metadata at Exascale

- Support complex / flexible analysis to enable scientists to engage with their datasets



Overcome today's filesystem scaling limits

- Provide the storage performance and capacity Exascale science will require

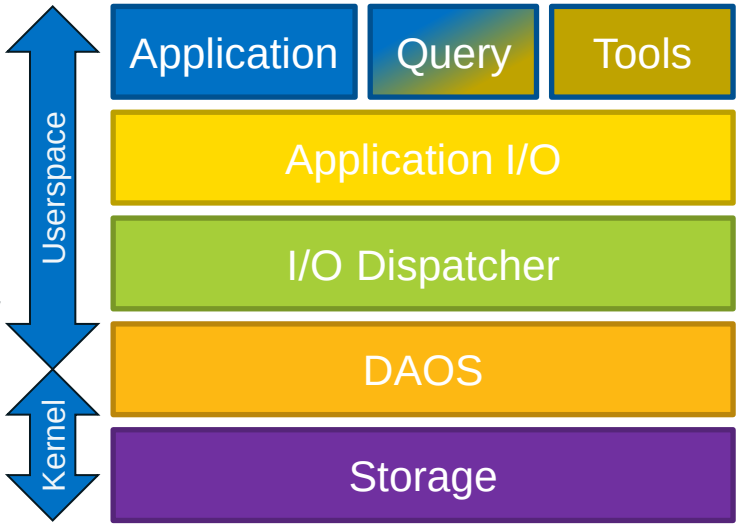
Provide unprecedented fault tolerance

- Design ground-up to handle failure as the norm rather than the exception
- Guarantee data and application metadata consistency
- Guarantee data and application metadata integrity

I/O stack

Features & requirements

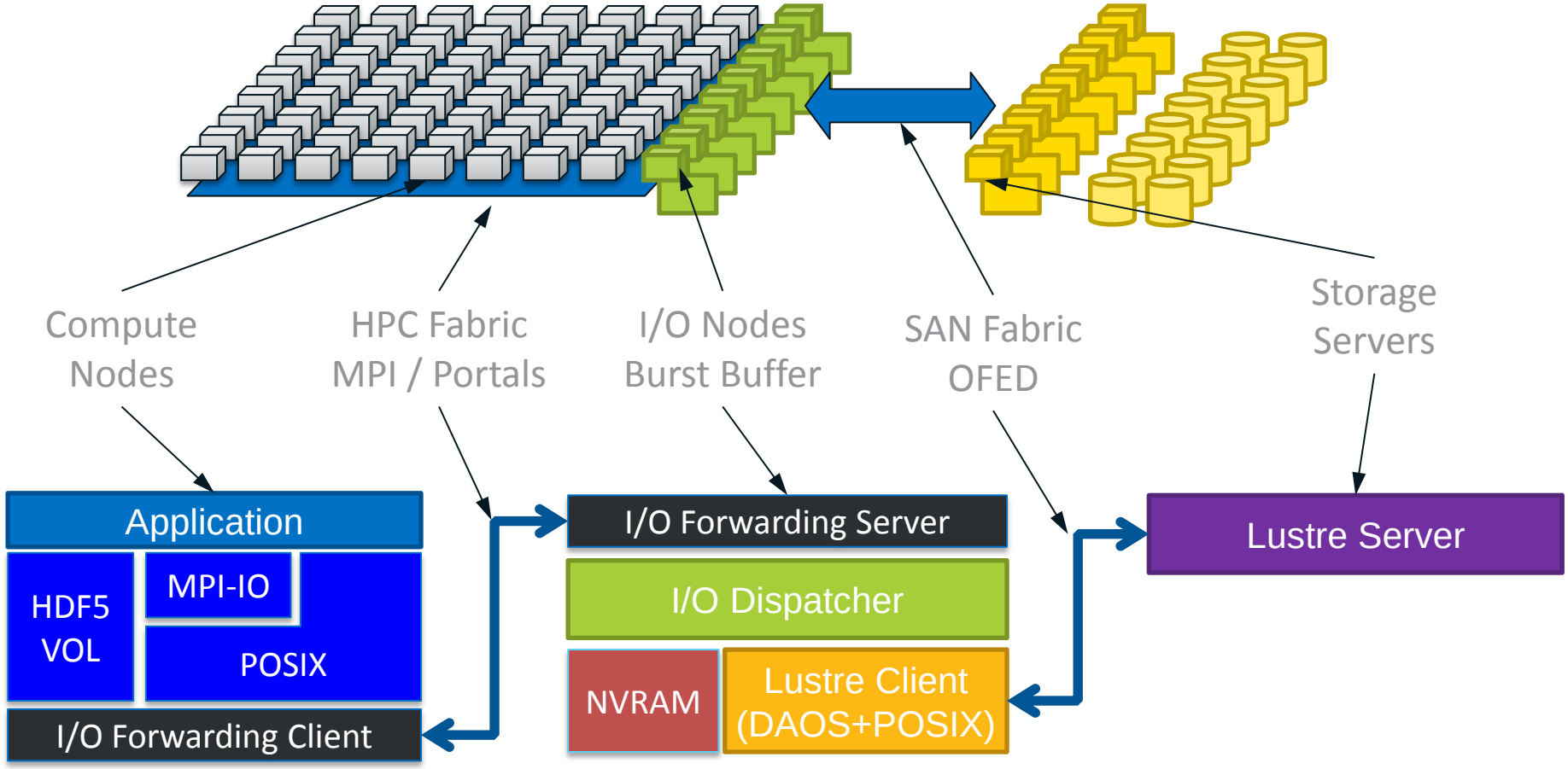
- Non-blocking APIs
  - Asynchronous programming models
- Transactional == consistent thru failure
  - End-to-end application data & metadata integrity
- Low latency / OS bypass
  - Fragmented / Irregular data



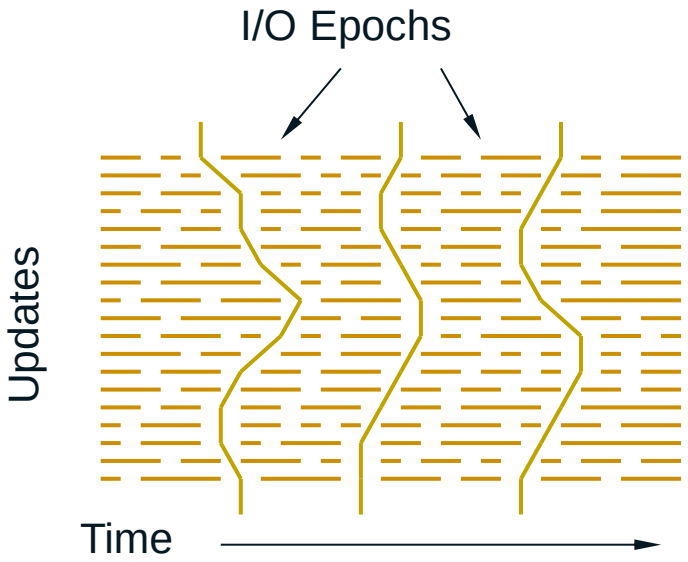
Layered Stack

- Application I/O
  - Multiple top-level APIs to support general purpose or application-specific I/O models
- I/O Dispatcher
  - Match conflicting application and storage object models
  - Manage NVRAM burst buffer / cache
- DAOS
  - Scalable, transactional global shared object storage

Fast Forward I/O Architecture



Transactions



Consistency and Integrity

- Guarantee required on any and all failures
  - Foundational component of system resilience
- Required at all levels of the I/O stack
  - Metadata at one level is data to the level below

No blocking protocols

- Non-blocking on each OSD
- Non-blocking across OSDs

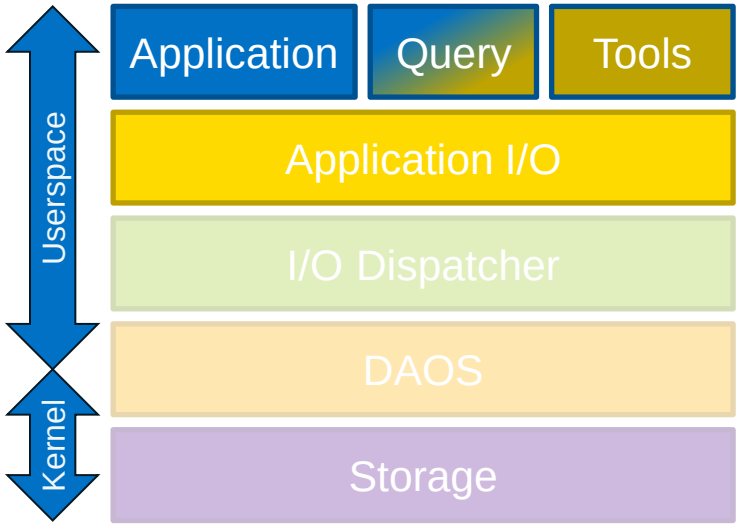
I/O Epochs demark globally consistent snapshots

- Guarantee all updates in one epoch are atomic
- Recovery == roll back to last globally persistent epoch
  - Roll forward using client replay logs for transparent fault handling
- Cull old epochs when next epoch persistent on all OSDs

I/O stack

Applications and tools

- Query, search and analysis
  - Index maintenance
- Data browsers, visualizers, editors
- Analysis shipping
  - Move I/O intensive operations to data



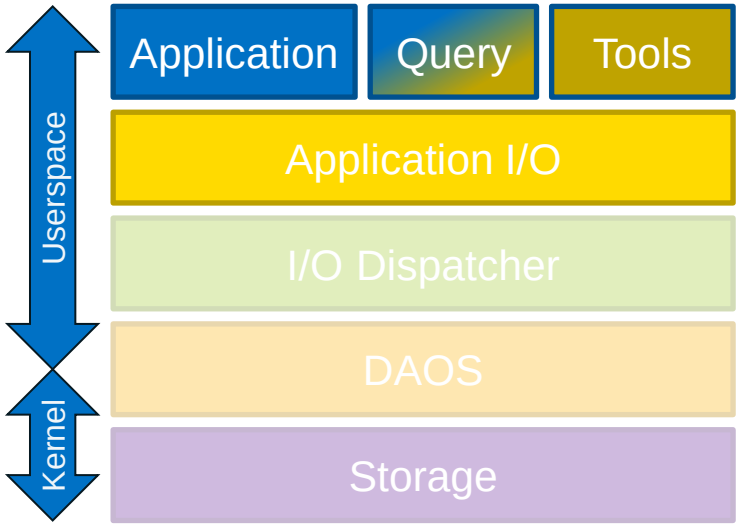
Application I/O

- Non-blocking APIs
- Function shipping CN/ION
- End-to-end application data/metadata integrity
- Domain-specific API styles
  - HDFS, Posix, …
  - OODB, HDF5, …
    - Complex data models

HDF5 Application I/O

DAOS-native Storage Format

- Built-for-HPC storage containers
- Leverage I/O Dispatcher/DAOS capabilities
- End-to-end metadata+data integrity



New Application Capabilities

- Asynchronous I/O
  - Create/modify/delete objects
  - Read/write dataset elements
- Transactions
  - Group many API operations into single transaction

Data Model Extensions

- Pluggable Indexing + Query Language
- Pointer datatypes

I/O Dispatcher

I/O rate/latency/bandwidth matching

- Burst buffer / prefetch cache
- Absorb peak application load
- Sustain global storage performance

Layout optimization

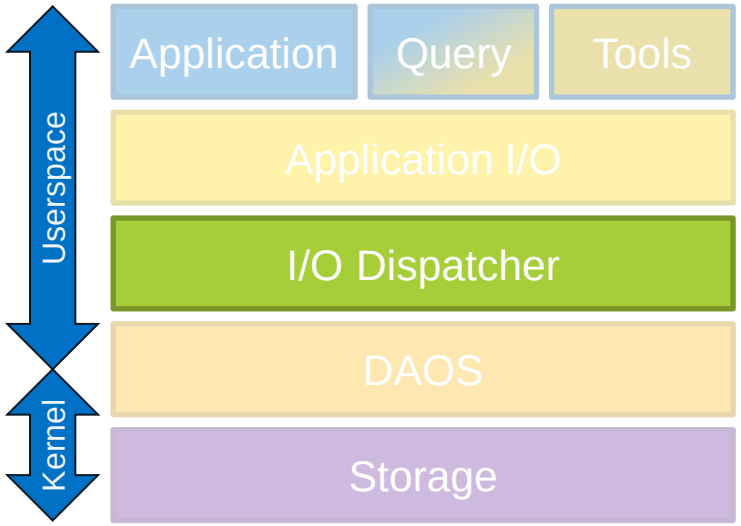
- Application object aggregation / sharding
- Upper layers provide expected usage

Higher-level resilience models

- Exploit redundancy across storage objects

Scheduler integration

- Pre-staging / Post flushing



DAOS Containers

Distributed Application Object Storage

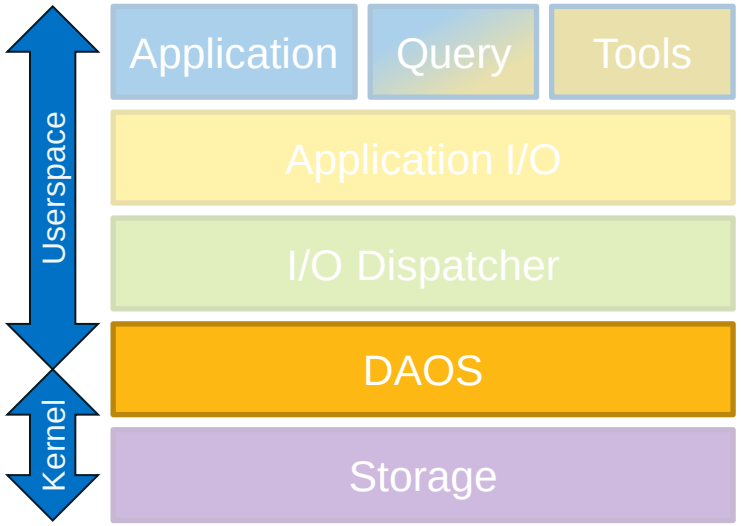
- Sharded transactional object storage
- Virtualizes underlying object storage
- Private object namespace / schema

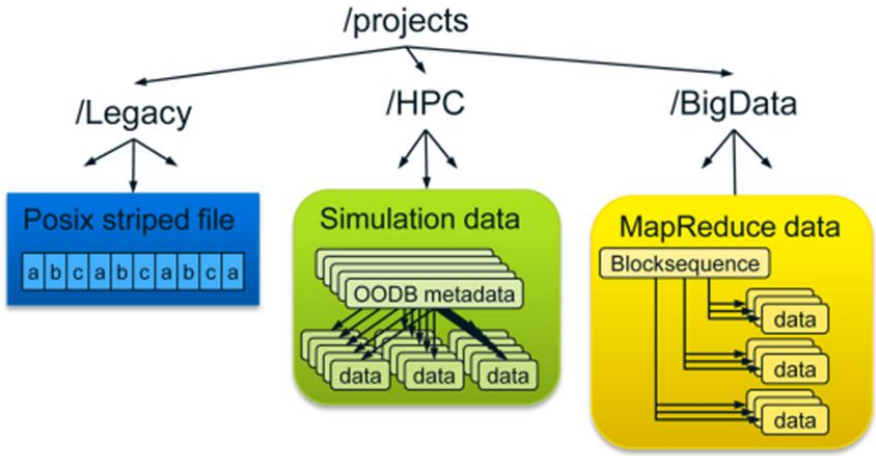
Share-nothing create/destroy, read/write

- 10s of billions of objects
- Distributed over thousands of servers
- Accessed by millions of application threads

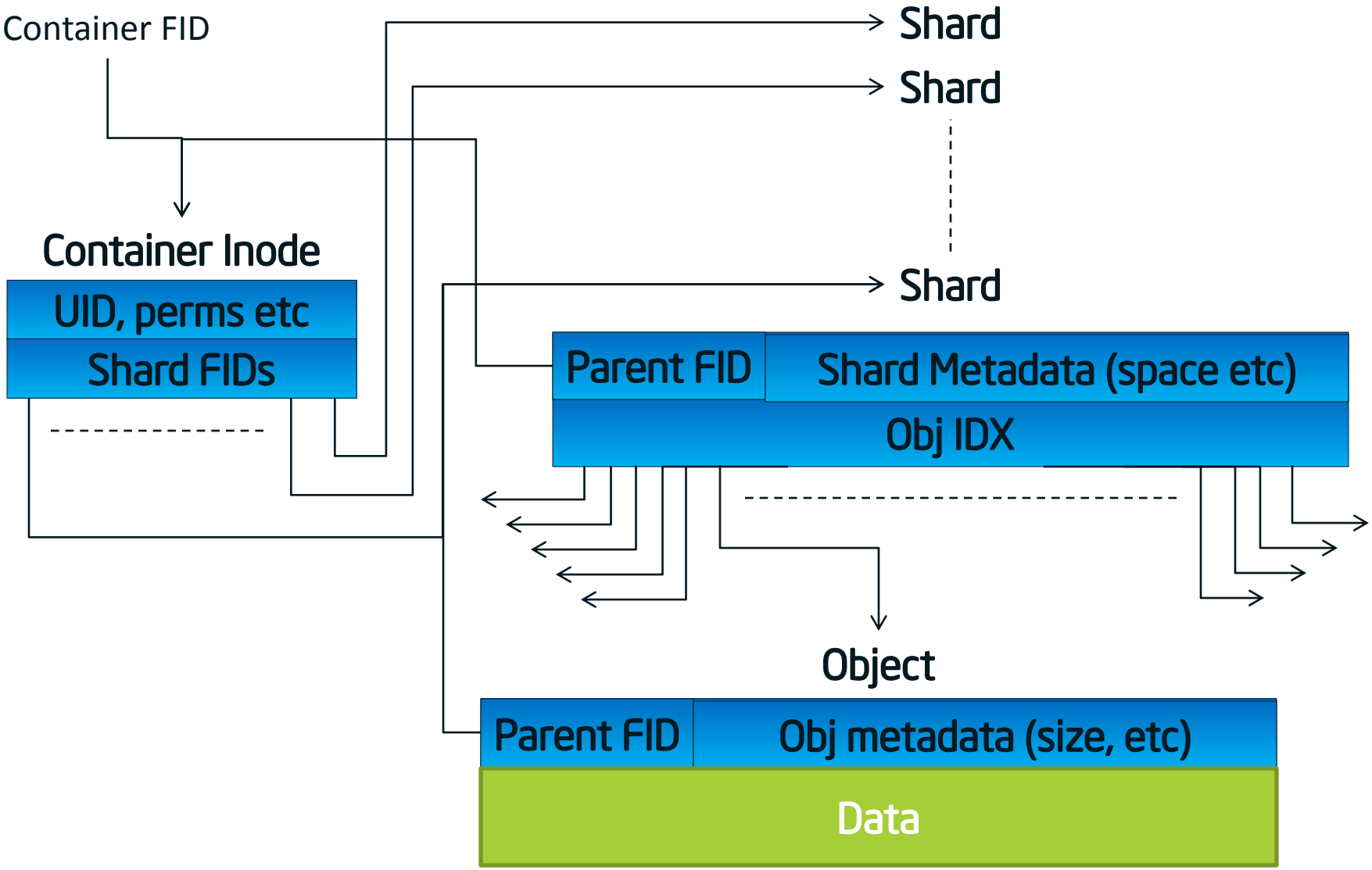
ACID transactions

- Defined state on any/all combinations of failures
- No scanning on recovery





DAOS Container



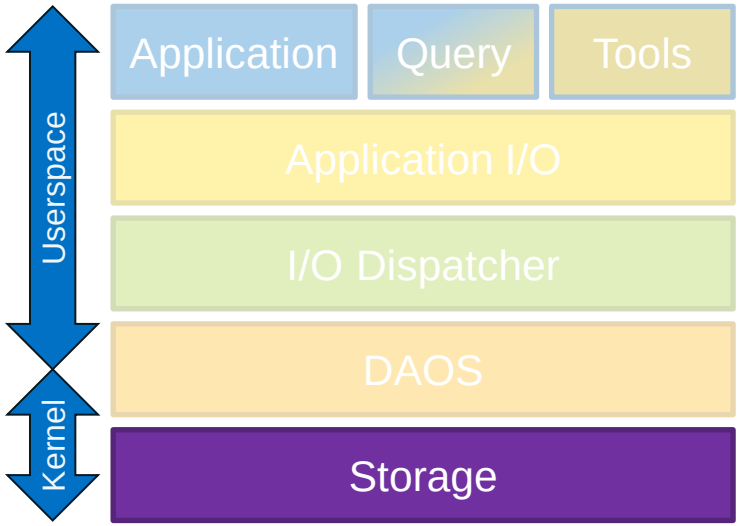
Versioning OSD

DAOS container shards

- Space accounting
- Quota
- Shard objects

Transactions

- Container shard versioned by epoch
  - Implicit commit
    - Epoch becomes durable when globally persistent
  - Explicit abort
    - Rollback to specific container version
- Out-of-epoch-order updates
- Version metadata aggregation

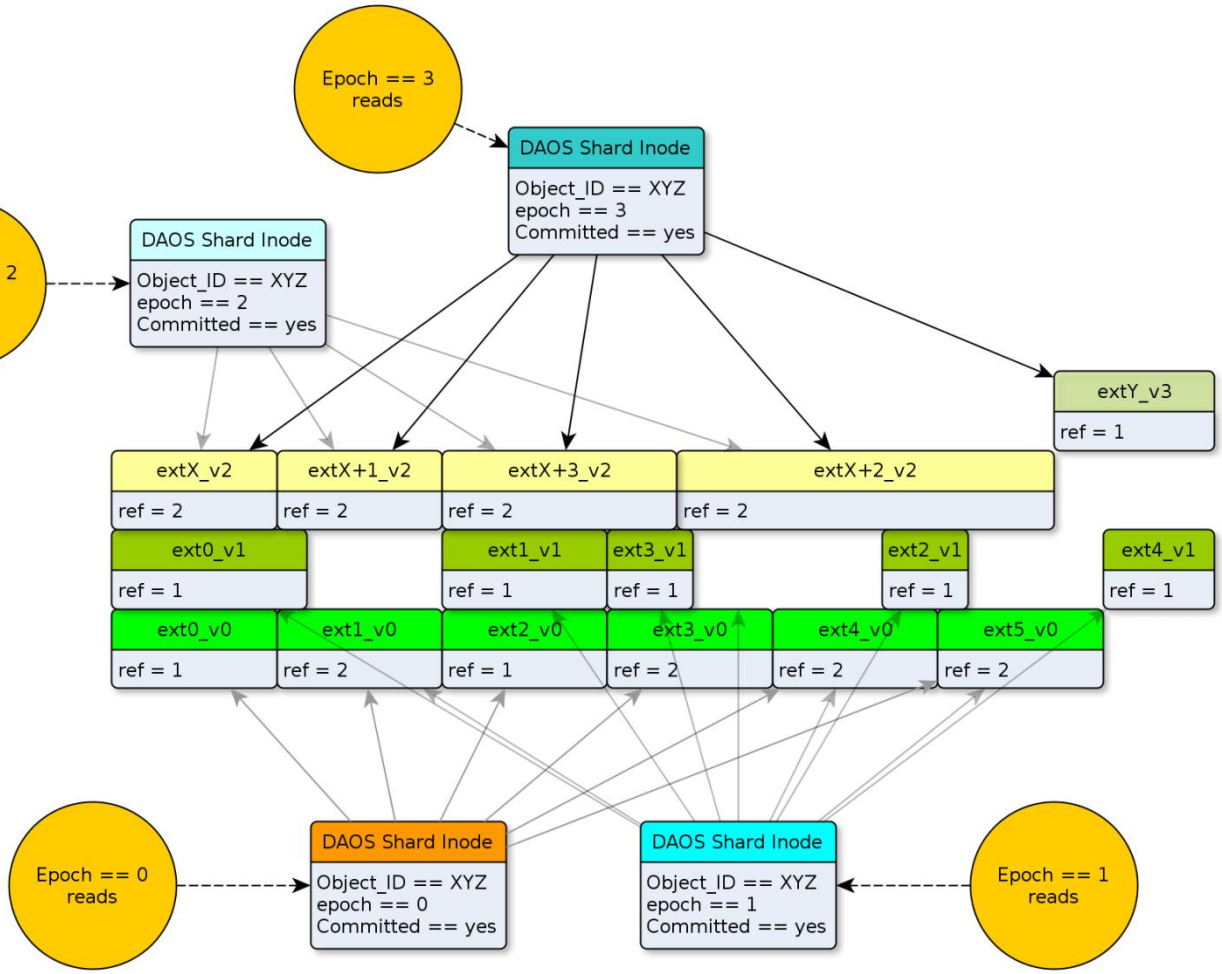


Versioning with CoW

New epoch directed to a clone

Cloned extents freed when no longer referenced

Requires epochs to be written in order

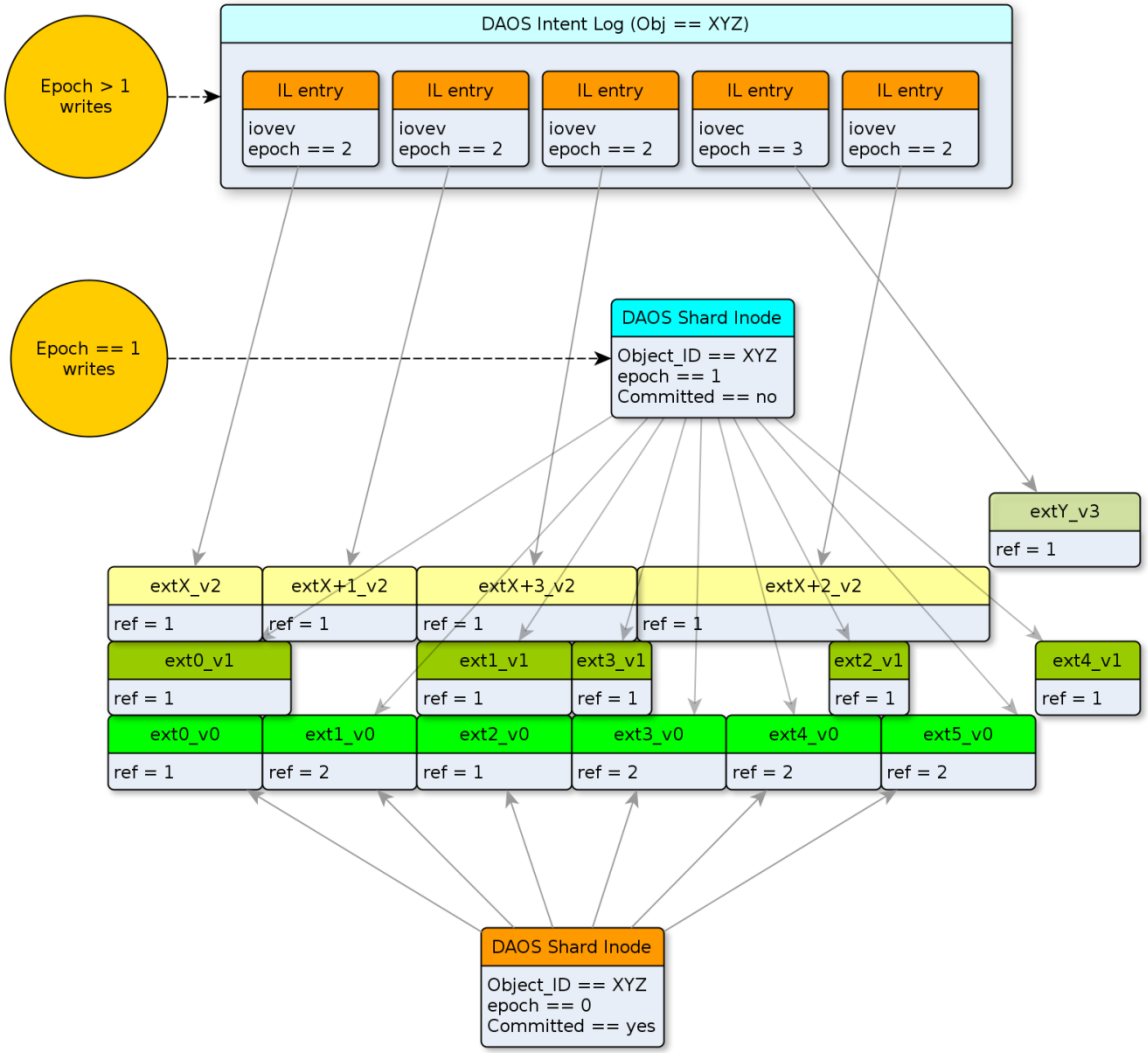


Versioning with an intent log

Out-of-order epoch writes logged

Log “flattened” into CoW clone on epoch close

Keeps storage system eager



Server Collectives

Collective client eviction

- Enables non-local/derived attribute caching (e.g. SOM)

Collective client health monitoring

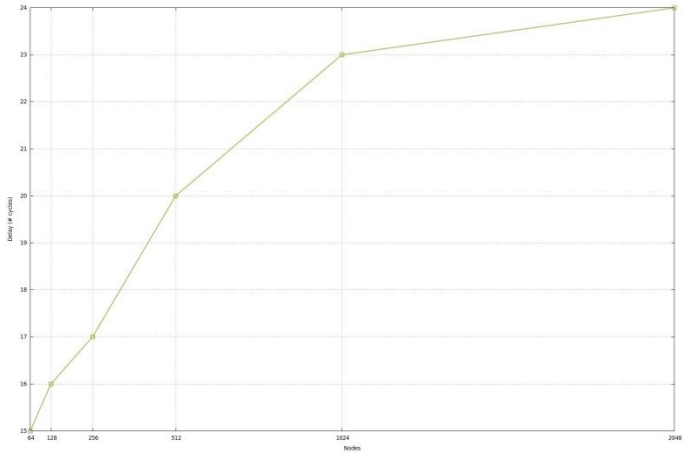
- Avoids “ping” storms

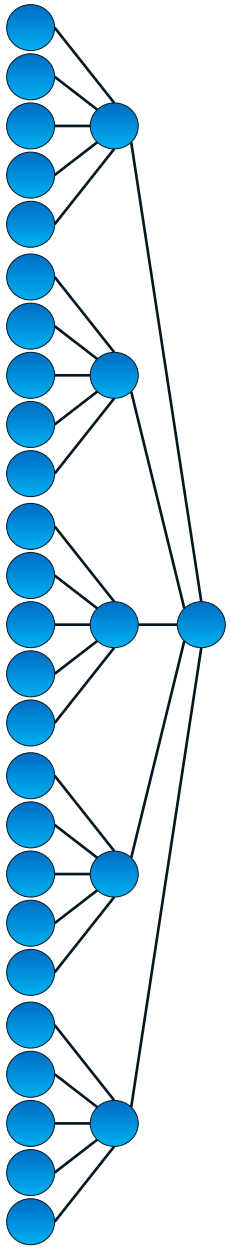
Global epoch persistence

- Enables distributed transactions (SNS)

Spanning Tree

- Scalable O(log n) latency
  - Collectives and notifications
- Discovery & Establishment
  - Gossip protocols
  - Accrual failure detection





Exascale filesystem

Integrated I/O Stack

- Epoch transaction model
- Non-blocking scalable object I/O

HDF5

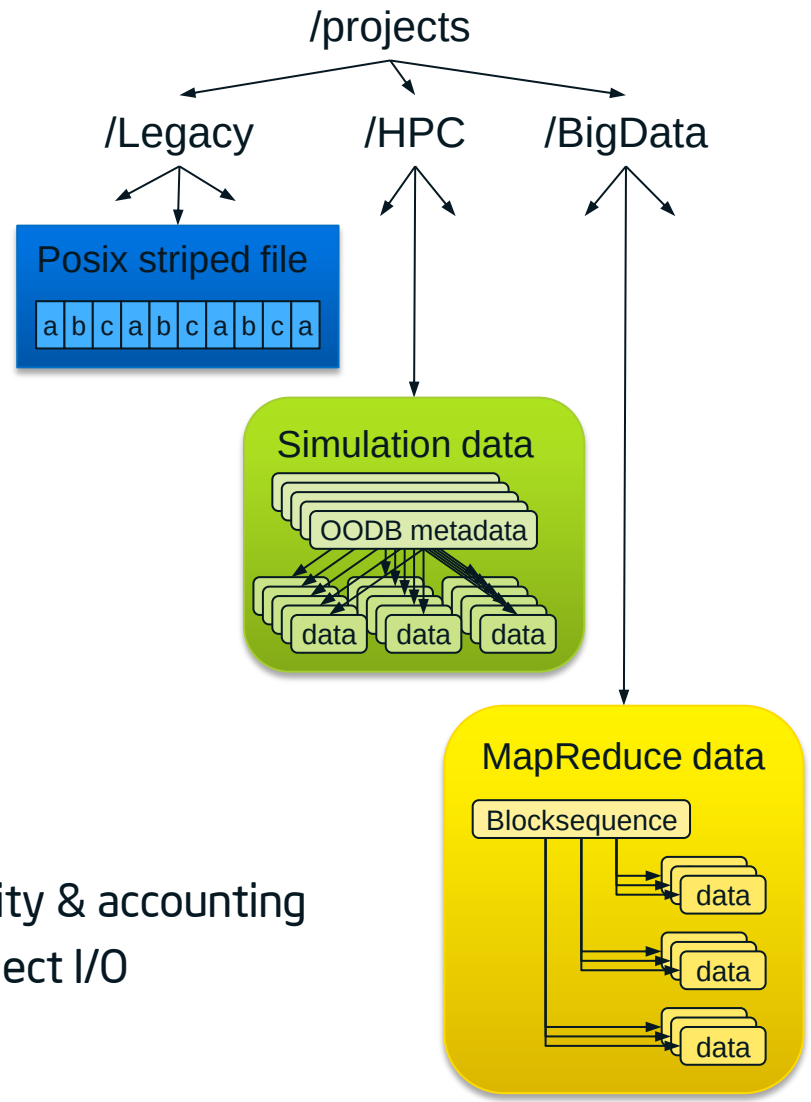
- High level application object I/O model
- I/O forwarding

I/O Dispatcher

- Burst Buffer management
- Impedance match application I/O performance to storage system capabilities

DAOS

- Conventional namespace for administration, security & accounting
- DAOS container files for transactional, scalable object I/O



Thank You