DAOS
An Architecture for Extreme Scale Storage

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Legal Information

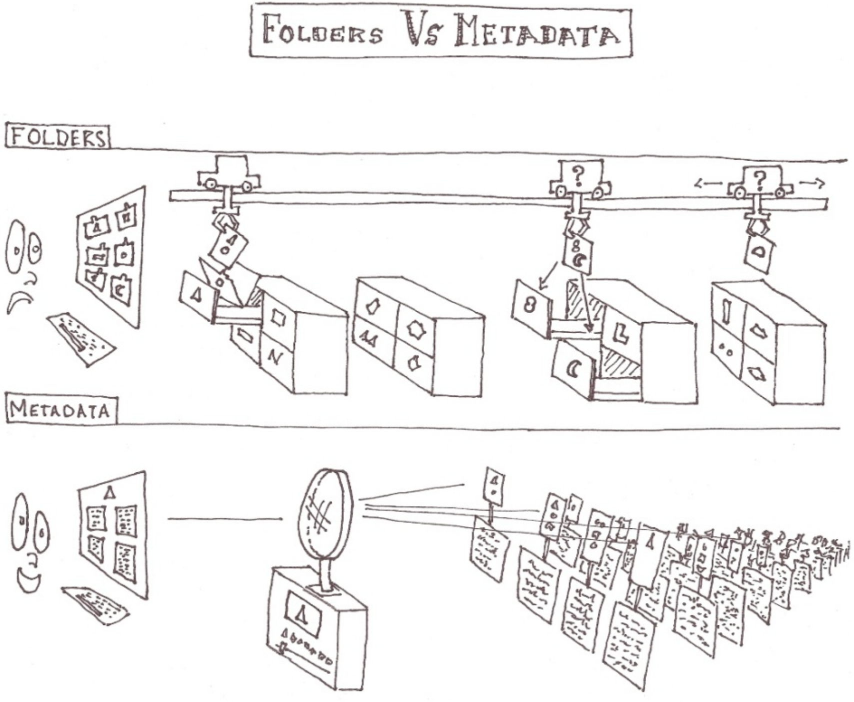
Emerging Trends

Increased computational power…

- Huge expansion of simulation data volume & metadata complexity
- Complex to manage and analyze

…achieved through parallelism

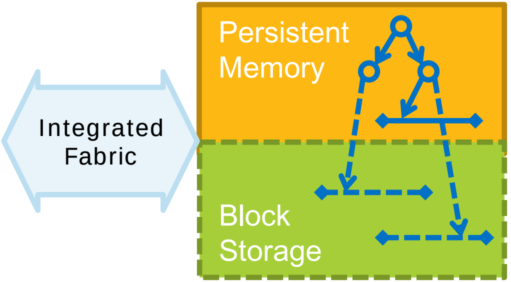
- 100,000s nodes with 10s millions cores
- More frequent hardware & software failures



Tiered storage architectures

- High performance fabric & solid state storage on-cluster
- Low performance, high capacity disk-based storage off-cluster

Disruptive Change



NVRAM + Integrated fabric

- Byte-granular storage access
- Sub-µS storage access latency
- µS network latency

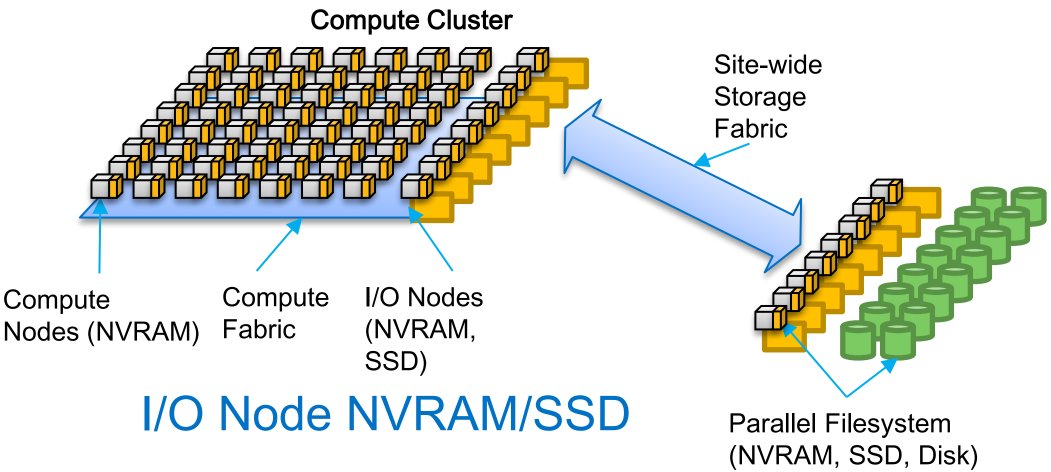
Conventional storage software

- Block granular access limits scaling
- High overhead
  - 10s µS lost to communications S/W
  - 100s µS lost to F/S & block I/O stack

I/O stack requirements

- Minimal software overhead
  - OS bypass
    - Communications
    - Latency sensitive I/O
- Fail-out resilience
- Persistent Memory storage
  - Filesystem & application metadata / hot data
- Block storage
  - SSD – warm data / Disk – lukewarm data

Storage Architecture



Compute Node NVRAM

- Hot data
  - High valence & velocity
  - Brute-force, ad-hoc analysis
  - Extreme scale-out
- Full fabric bandwidth
  - O(1PB/s)→O(10PB/s)
- Extremely low fabric & NVRAM latency
  - Extreme fine grain
  - New programming models

I/O Node NVRAM/SSD

- Semi-hot data / staging buffer
- Fractional fabric bandwidth
  - O(10TB/s)→O(100TB/s)

Parallel Filesystem NVRAM/SSD/Disk

- Site-wide shared warm storage
  - SAN limited – O(1TB/s)→O(10TB/s)
- Indexed data

On-cluster (hot) storage requirements

Scalable capacity

- O(10x) system DRAM

Scalable throughput

- Significant fraction of fabric bandwidth
- Significant fraction of fabric injection rate

Data integrity & consistency

- Tunable resilience/availability
- No silent failures
- Safe overwrite

Minimal usage constraints

- Global namespaces
  - System namespace shared across jobs
    - Connected workflows
  - Object namespaces shared across processes
    - Encapsulating entire simulation datasets
- Fine grained, random, massively concurrent

Minimal interference

- Data movement by unrelated workflows

Security

- Authorized/authenticated access

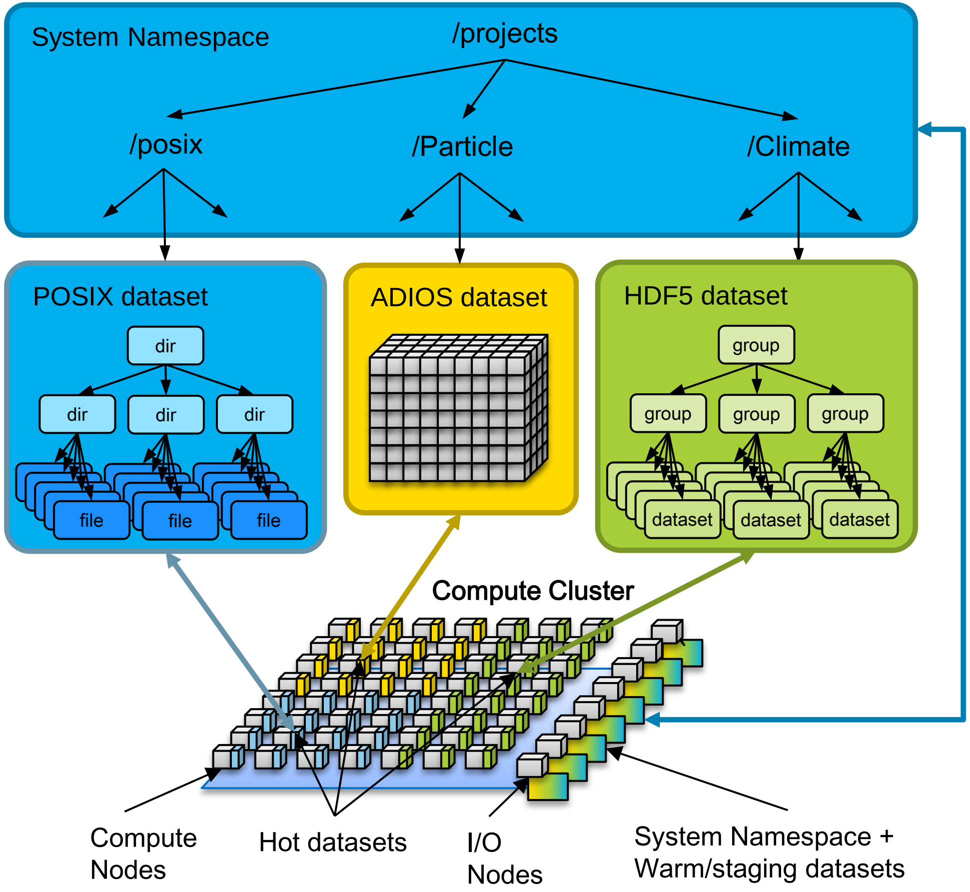
Global Namespaces

Containers

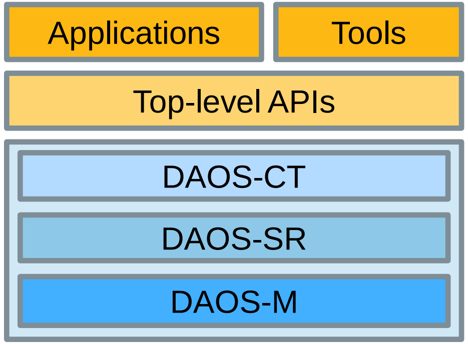
- Shared System Namespace
  - “Where’s my stuff”
- Private Namespaces
  - “My stuff”
  - Entire simulation datasets

Multiple Schemas

- POSIX*
  - Shared (system) & Private (legacy datasets)
  - No discontinuity for application developers
- Scientific: HDF5*, ADIOS*, SciDB*, …
- Big Data: HDFS*, Spark*, Graph Analytics, …



Distributed Application Object Storage



Exascale I/O stack

- Extreme scalability, ultra fine grain
- Integrity, availability, resilience
- Unified model over all storage tiers site-wide

Multiple Top Level APIs

- Domain-specific APIs
- High-level data models

DAOS-CT: Caching and Tiering

- Data migration over storage tiers
  - Guided by usage metadata
  - Driven by system resource manager

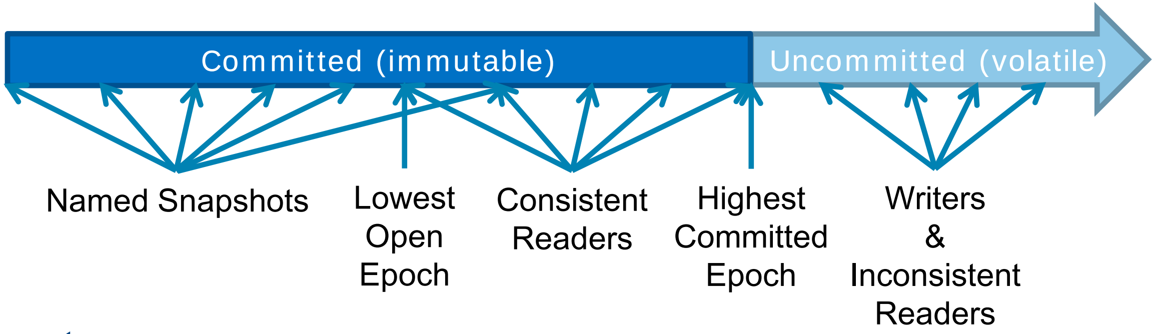
DAOS-SR: Sharding and Resilience

- Scaling throughput over storage nodes
- Fail-out resilience across storage nodes

DAOS-M: Persistent Memory Object Storage

- Ultra-low latency / fine grain I/O
- Fine-grain versioning & global consistency
- Location (latency & fault domain) aware

Transactions



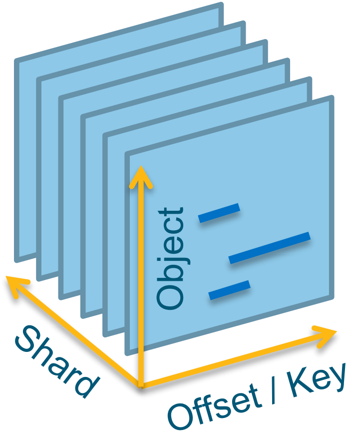
Why

- Simplify application development
  - Safe update in-place
  - Guaranteed data model consistency
  - Concurrent producer/consumer workflows
- Support resilience schemas
  - Guaranteed consistency for redundant distributed data
- Support tiered storage
  - Preserve integrity on data migration

How

- Multi-version concurrency control
  - Snapshot consistency on read
  - Maximize concurrency/asynchrony
- Process groups
  - Arbitrary numbers of collaborating processes
  - Arbitrary numbers of storage targets
  - Leader commit/snap/migrate

DAOS-M Object Storage



Multiple Independent Object Address Spaces

- Versioning Object PGAS
- Container = {container shards} + metadata
  - Container Shard = {objects}
    - Object = KV store or byte array
    - Sparsity exposed
  - Metadata = {shard list, commit state}
    - Minimal
    - Resilient (Replicated state machine)

Maximum concurrency

- Byte-granular MVCC
- Deferred integration of mutable data
- Writes eagerly accepted in arbitrary order
- Reads sample requested version snapshot

Distributed Transactions

- Prepare: Send updates tagged with version ‘t’
- Commit: Mark version ‘t’ committed in container MD
  - Version ‘t’ now immutable and globally consistent
- Abort: Discard version ‘t’ updates everywhere

Low latency

- End-to-end OS bypass
- Persistent Memory server
- Userspace fabric drivers

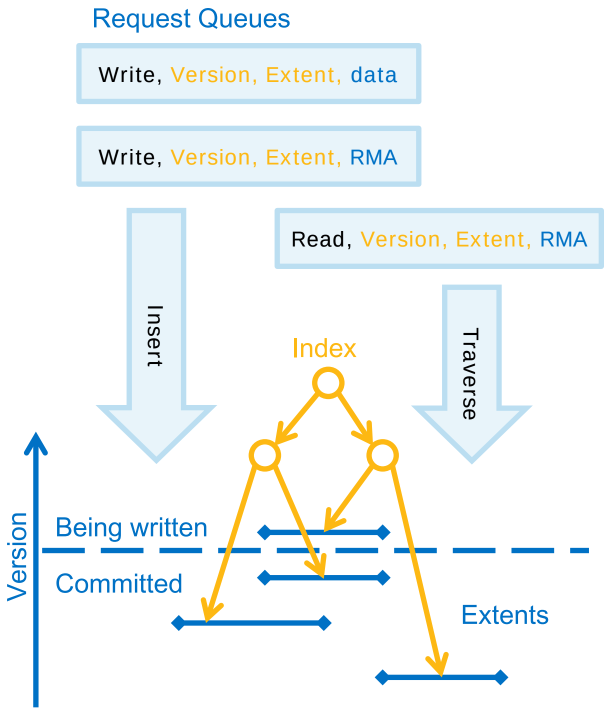
DAOS-M latency sensitive server operations

Byte array objects

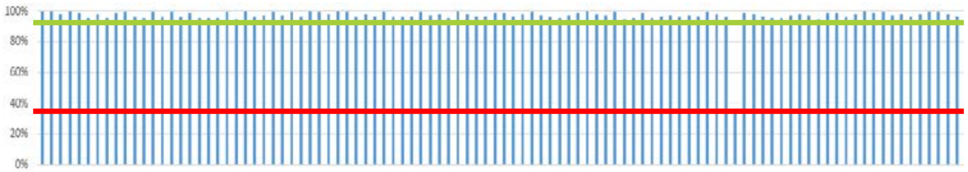
- Write (log data)
  - Allocate extent buffer in NVRAM
  - Copy immediate / RDMA READ remote
  - Insert into persistent extent.version index
- Read (data integration)
  - extent.version index traversal => gather descriptor
  - RDMA WRITE remote

Key-Value objects

- Insert/remove/retrieve value into key.version table



Sharding & Resilience



Multiple mixed schemas

Performance schemas

- Scale IOPs & bandwidth

Resilience schemas

- Data integrity
  - Checksums + data stored separately
- N-way replication
  - High performance for shared write objects
- Erasure codes
  - High efficiency for non-shared objects
- Asynchronous refactor, scrub & repair
  - Exploit immutability of committed data

Leverage DAOS-M

- Distributed consistency
- Sparsity

Scaling Requirements

- Onerous!
  - Aliasing of access & distribution patterns
  - Bulk synchronous workload == Amdahl's law vector
- Extreme object size dynamic range
  - “Megaliths” v. “grains of sand”
- Declustering
  - Rebalance on node addition
  - Distributed rebuild on node failure

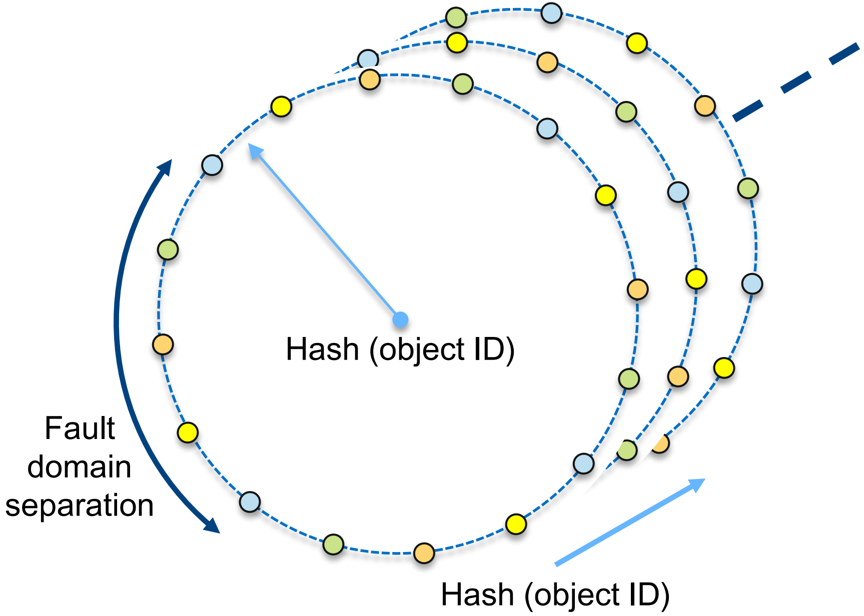
Sharding & Resilience

Algorithmic (O(0)) layout metadata

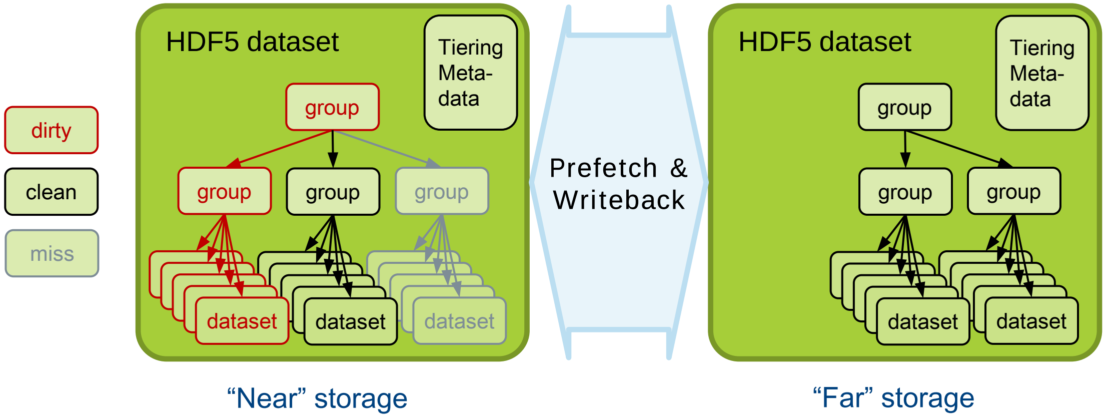
- Consistent hash randomizes placement
- Replicas placed adjacently
  - Hash must guarantee minimum separation of nodes in same fault domain
- Multiple hash rings for declustering

Explicit (O(n)) layout metadata

- Layout responsive to usage
  - Preserve locality / feed “hungriest mouth”
- O(0) structures used to store layout



Caching & Tiering



Metadata

- Residence maps
  - Whole object maintained directly
  - Sub-object leverages lower layers
- Access patterns
  - Historical
  - Explicit notification by upper levels
  - Data "colouring"

Data migration

- Resharding between tiers
  - Maintain distributed object semantics
  - Maximize performance on subsequent access
  - Select appropriate resiliency schemas

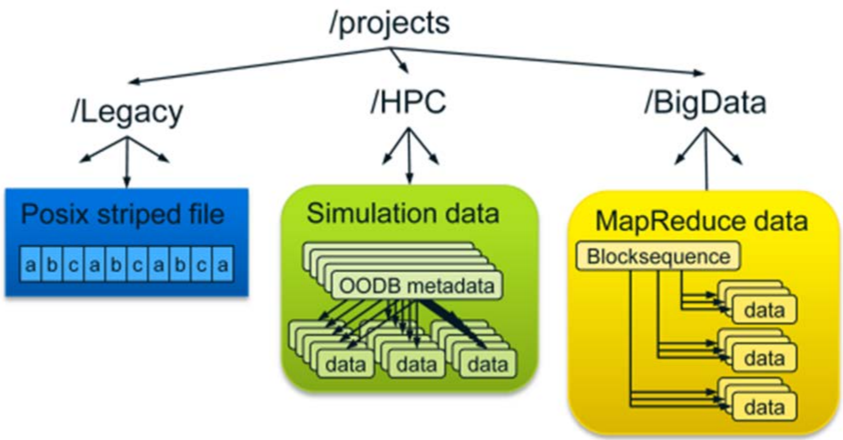
Explicit control

- Persist & prestage APIs / JCL
- System resource manager driven migration
  - Rebalance & minimize interference

Transparent caching

- Write-back & demand cache
- Prefetch guided by usage metadata
- Residence maps

Top level I/O APIs



POSIX Containers

- POSIX namespace over DAOS-HA objects
  - Dynamically sharded directories & files
- Private POSIX namespaces
  - Library for parallel applications and middleware targeting POSIX
- System POSIX namespace
  - Parallel server exporting shared namespace

DAOS for application programmers

- Simplified APIs
- Distributed Persistent Memory

High level HPC object databases

- Complex application datatypes & metadata
- HDF5 + derivatives / ADIOS / SciDB etc…

Big Data

- HDFS compatibility layer
  - Hadoop ecosystem
- Spark / Graph Analytics etc…

NVRAM Storage Revolution

Cost-effective storage & fabric integration

- Challenge: Extreme scale-out
  - Amdahl's law
  - Fault Tolerance
- Reward: Storage @ full fabric bandwidth
  - O(1000) increase in data velocity

Byte-granular data access @ uS latency

- Challenge: Deliver benefit to applications
  - Software overhead of conventional storage & communications stacks
- Reward: Ultra fine-grain access
  - Remove constraints on applications
  - Enable new programming models

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