ESSIO
Extreme Scale Storage & I/O

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Emerging trends

Increased computational power…

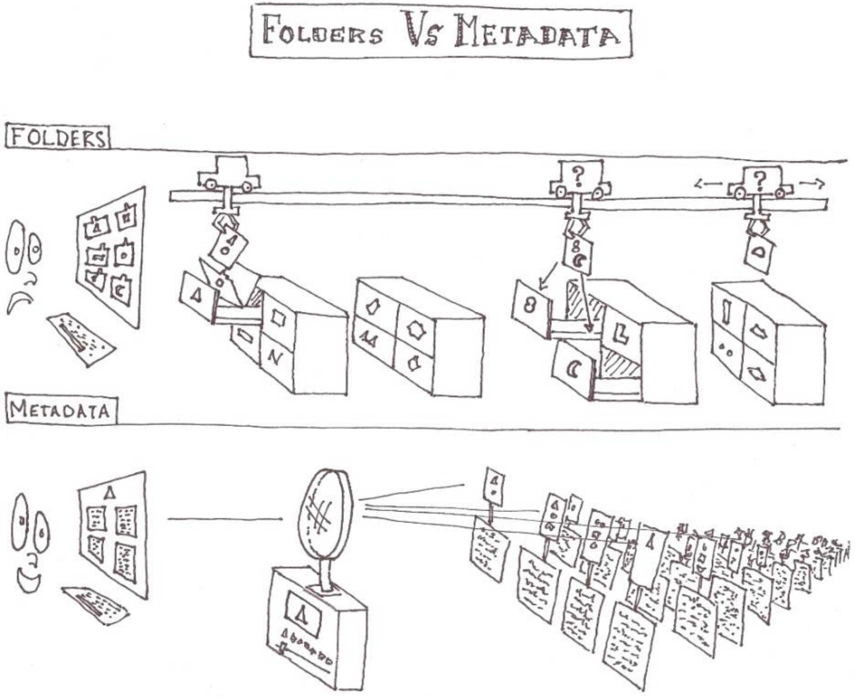
- Huge expansion of data volumes & metadata complexity
- Complex to manage and analyze

…achieved through parallelism…

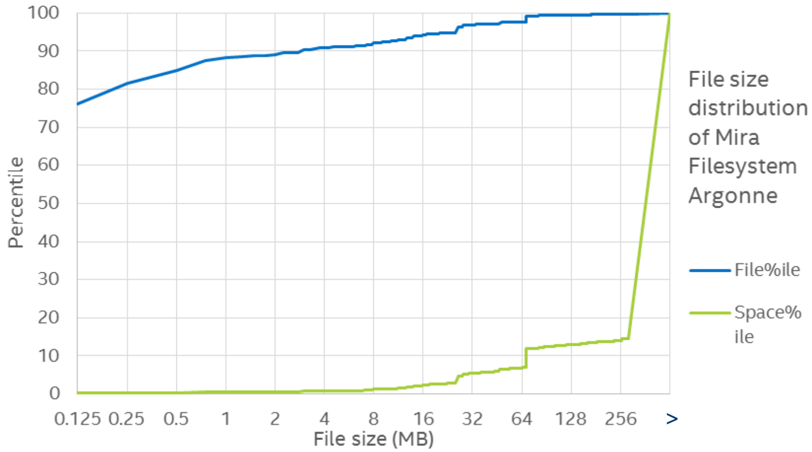
- 100,000s nodes with many millions of cores
- Routine, frequent hardware & software failures
- Extreme scalability challenge

…with tiered storage architectures

- Economics of performance v. capacity



Emerging trends



Vast majority of storage objects are tiny…

- Kilobytes and smaller
- Trending to larger proportion of system capacity
- High performance => Billions of IOPs @ lowest possible latency
- Resilience => Replication improves concurrency/scalability @ acceptable storage overhead
- **Poorly supported by today's filesystems**

…but vast majority of space is used by large storage objects

- Megabytes and larger
- High performance => efficient streaming @ Terabytes per second
- Resilience => Erasure codes required for space efficiency & limit system cost

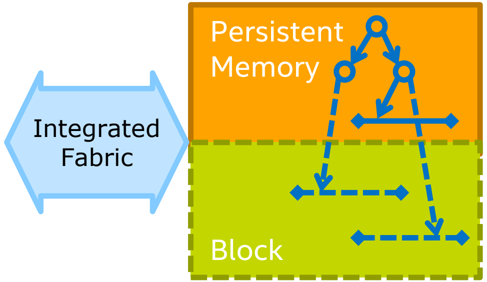
Disruptive change

3D XPoint™ + Intel® Omni-Path Architecture

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

Conventional storage software

- High overhead
  - 10s µS lost to communications S/W
  - 100s µS lost to F/S & block I/O stack
- Block/page granular & alignment sensitive
  - False sharing limits scalability



Exascale storage

- Low overhead
  - OS bypass comms + storage
- Byte granular & alignment insensitive
  - Ultra low latency enables fine granularity
- Persistent Memory
  - All metadata & fine-grained application data
- Block storage
  - NAND: High performance bulk data
  - Disk: High capacity cold data

Project History

DOE Fast Forward Storage & I/O

- 2 year project – prototype demonstrated June 2014
- Intel / HDF Group* / EMC* / DDN* / Cray*
- Prototype Exascale tiered storage system
  - IOD – based on PLFS (performance tier)
  - DAOS – based on Lustre* / ZFS* (long term storage)

DOE Extreme Scale Storage & I/O

- 2 year project – prototype to be demonstrated June 2017
- Intel / HDF Group
- Unified storage model over all storage tiers
- Working with DOE labs to port and evaluate applications

Exascale storage requirements

Routine failures – MTTI O(hours)

- Application failure
  - Complex data models have complex consistency / cleanup requirements
  - Application development intractable without system consistency guarantees
- Storage system failure
  - Fail-out resilience to simplify & cost-reduce storage hardware
  - End-to-end integrity checks required to eliminate silent data/metadata corruption
  - Workflow driven resilience schemas
    - None (cheapest) / Replication (high performance) / Erasure Codes (space efficient)

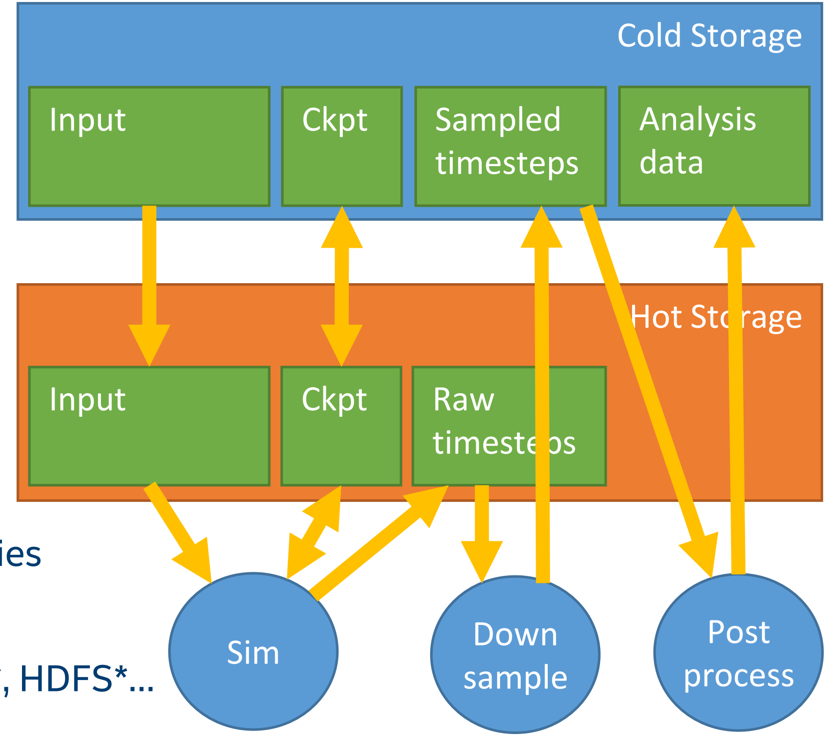
Unprecedented scalability

- Shared-nothing, lockless distribution schemas
- Arbitrary alignment and granularity without sacrificing consistency

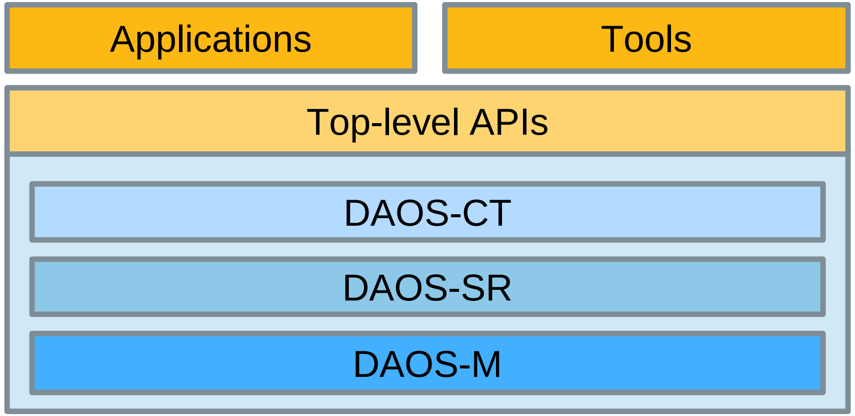
Exascale storage requirements

Simplify application & workflow development

- Transparently span multiple storage tiers
  - From cheap high capacity storage to expensive performance storage
- Support producer/consumer workflow pipelines
  - Simplify coordination between jobs sharing data
  - Connect jobs at any storage tier
- Simplify data management
  - Snapshots
  - Aggregate related datasets into manageable entities
- Support multiple storage APIs & data models
  - POSIX, HDF5*, pNetCDF*, ADIOS*, Legion*, Spark*, HDFS*…



Distributed Asynchronous Object Storage



Multiple Top Level APIs

- Domain-specific APIs
- High-level data models

DAOS-CT: Caching and Tiering

- Transparent caching
- Efficient staging

DAOS-SR: Sharding and Resilience

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

DAOS-M: Memory class object storage

- Ultra-low latency / fine grain object I/O
- Multi-version concurrency control
- Global consistency model

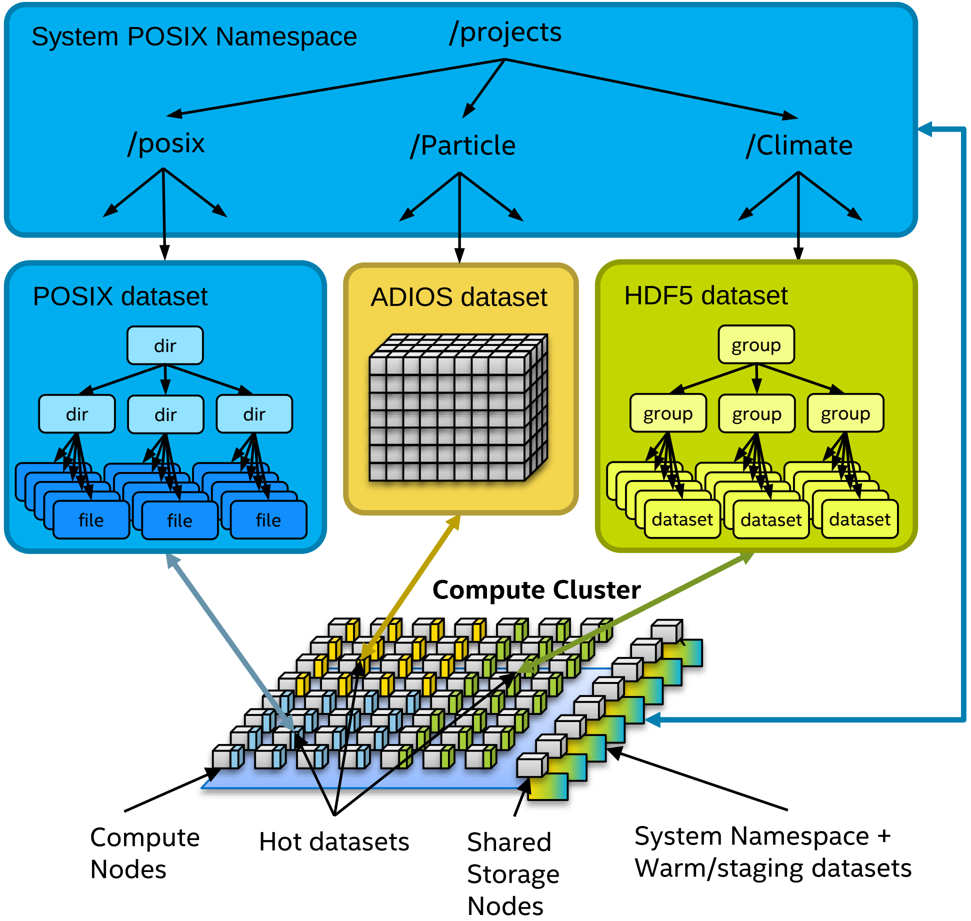
Global Namespaces

Containers

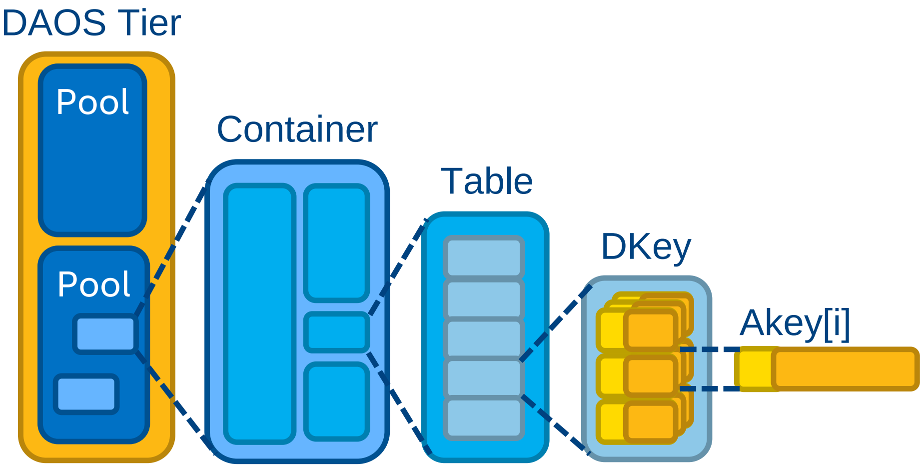
- Shared System Namespace
  - "Where's my stuff"
- Private Namespaces
  - "My stuff"
  - Entire simulation datasets

Multiple Schemas

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



DAOS Storage Model



Storage Pool

- Reservation of storage within a tier

Container

- Related data & metadata distributed across an entire storage pool

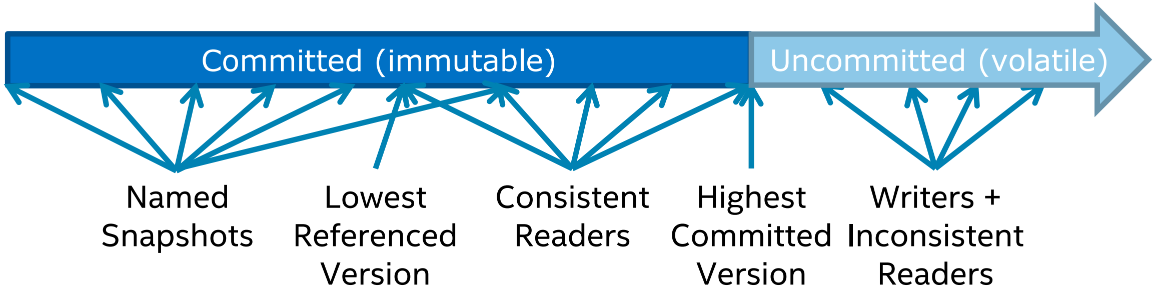
Table

- Collection of related arrays/values with own distribution/resilience schema
- Dkey determines placement
- Akey selects named array
- Index [lo…hi] selects array extent

Array Element

- Arbitrary binary blob
  - Single byte to several Mbytes
  - Atomic unit of versioning
- Non-destructive write: log blob@version
- Consistent read: blob@(max(version <= v))

Transactions



Why

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

How

- Versioned storage
  - Non-destructive (logging) write
  - Snapshot consistency on read
  - Maximize concurrency/asynchrony/scalability
- Process groups
  - Arbitrary numbers of collaborating processes
  - Leader commit/snap/migrate
- Conflict resolution in top-level client library
  - No system-imposed, worst-case serialization

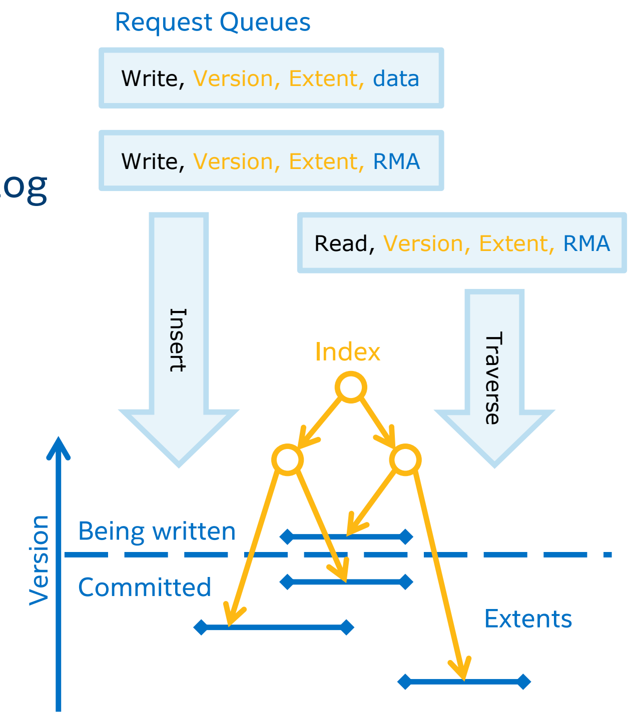
DAOS-M fundamental operations

Write (version, {array elements})

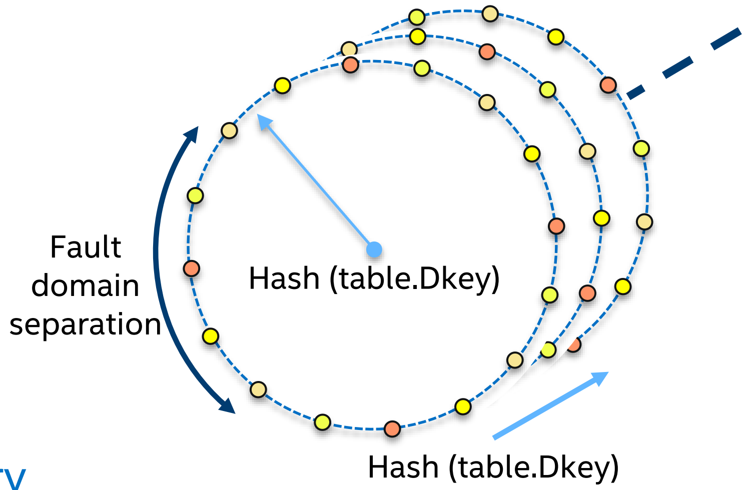
- Insert set of array elements with given version into searchable log
  - Allocate extent buffer in NVRAM
  - RDMA READ client data
  - Insert into persistent index
- Commutative – writes may arrive in any order

Read (version, {array elements})

- Return array element values with highest version <= given
  - Traverse index to create gather descriptor
  - RDMA WRITE client data
- Committed version => Immutable, consistent snapshot across storage nodes



Sharding & Resilience



Algorithmic layout metadata

- Scales with # storage nodes
- Consistent hash randomizes placement
  - Disperses fault domains
- Multiple hash rings for declustering*

Explicit layout metadata

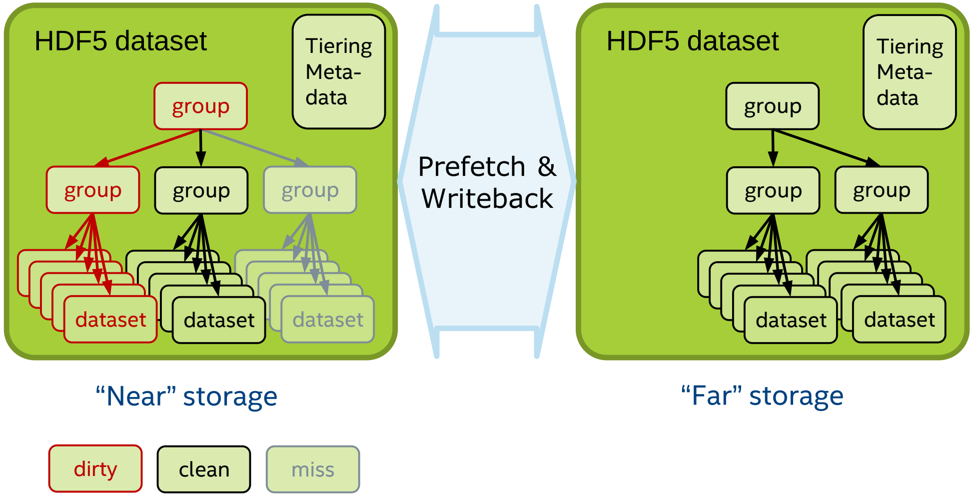
- Scales with volume of data
- Layout responsive to usage
  - Progressive & locality driven layouts
- Stored using algorithmic layout (bootstrap)

Recovery

- Failed target evicted & recover targets selected on each ring
- Storage targets hosting shards of damaged tables send table IDs to recovery targets
- Recovery targets “pull” data from peers until rebuild complete
- Clients may now read from recovery targets

* Concept developed in collaboration with Argonne National Laboratory, see preliminary work in *P. Carns et al, “Consistent Hashing Distance Metrics for Large-Scale Object Storage,” Poster at the ACM/IEEE SuperComputing Conference (SC’15), Nov. 2015.*

Caching & Tiering



Staging controls

- Prestage populates cache
  - Select using top-level data abstraction
    - POSIX directory subtrees
    - HDF5 query/view
- Persist flushes committed data
- Staging optimized to aggregate & stream I/O on lower performance tier

Transparent caching

- Fetch-on-miss / policy driven eviction
- Slowly evolving working sets

Data migration

- Resharding between tiers
  - Maintains distributed object semantics
  - Tier-appropriate resiliency schemas
- Transactional

Storage Revolution

Cost-effective storage & fabric integration

- Challenge: Extreme scale-out
  - Scalability (Amdahl's law)
  - Fault Tolerance
- **Reward: 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: Efficient ultra fine-grain I/O**
  - Simplify applications & enable new programming models