DAOS: A New Storage Paradigm for Exascale

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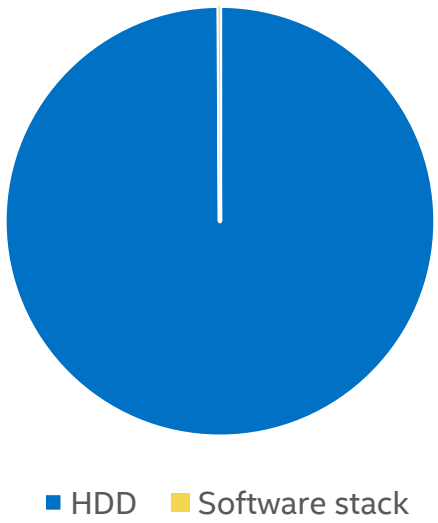
Challenge: I/O Latency



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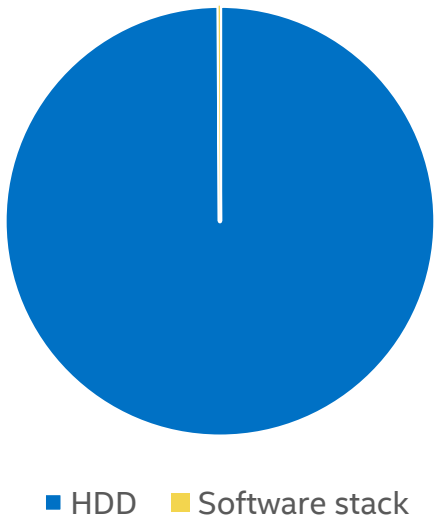

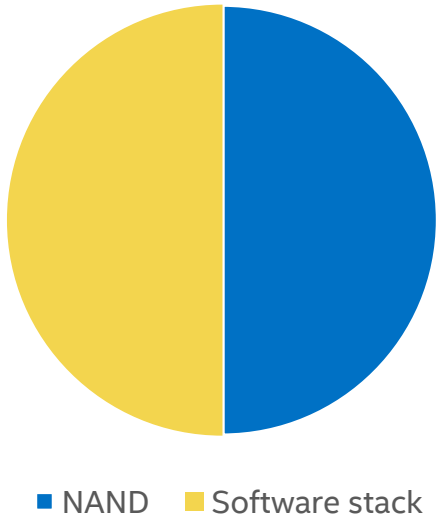

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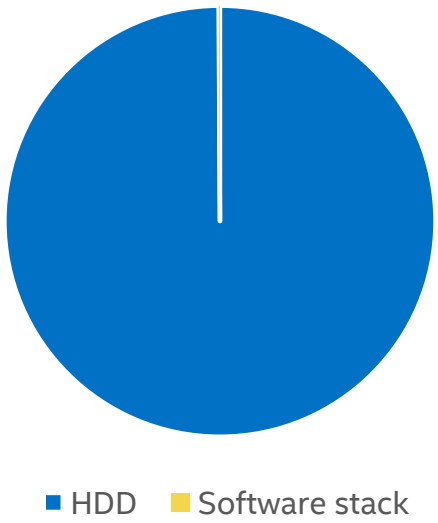

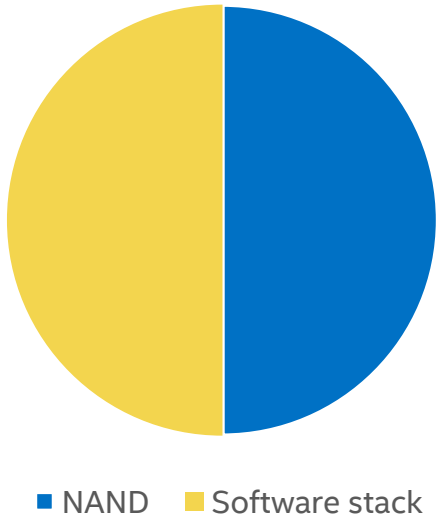

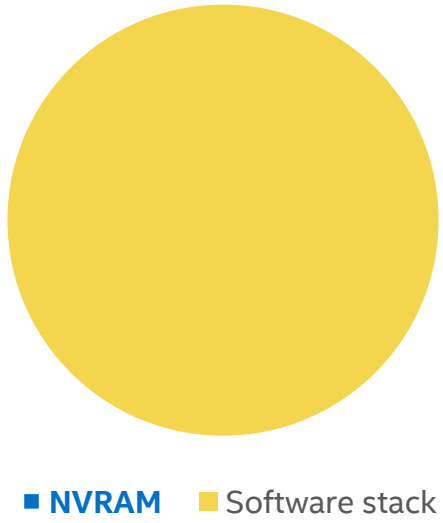

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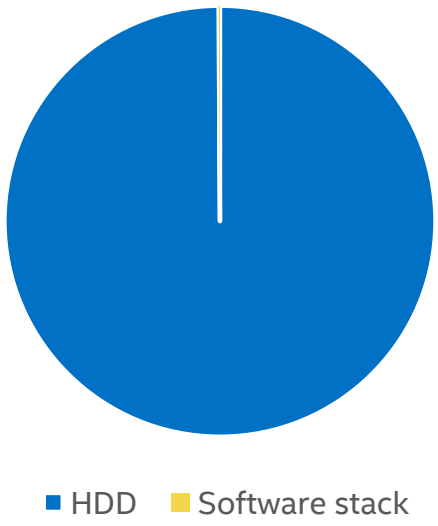
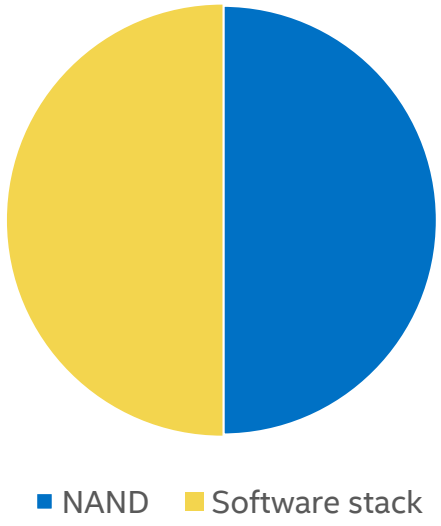
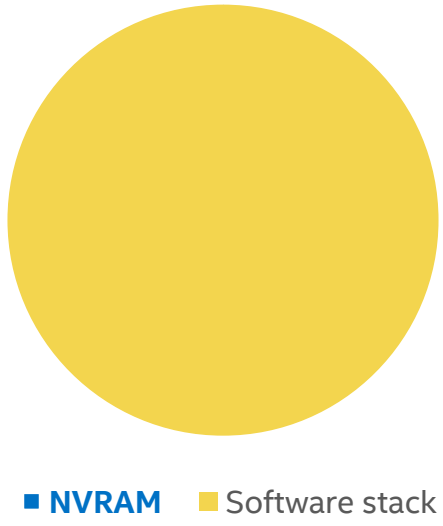
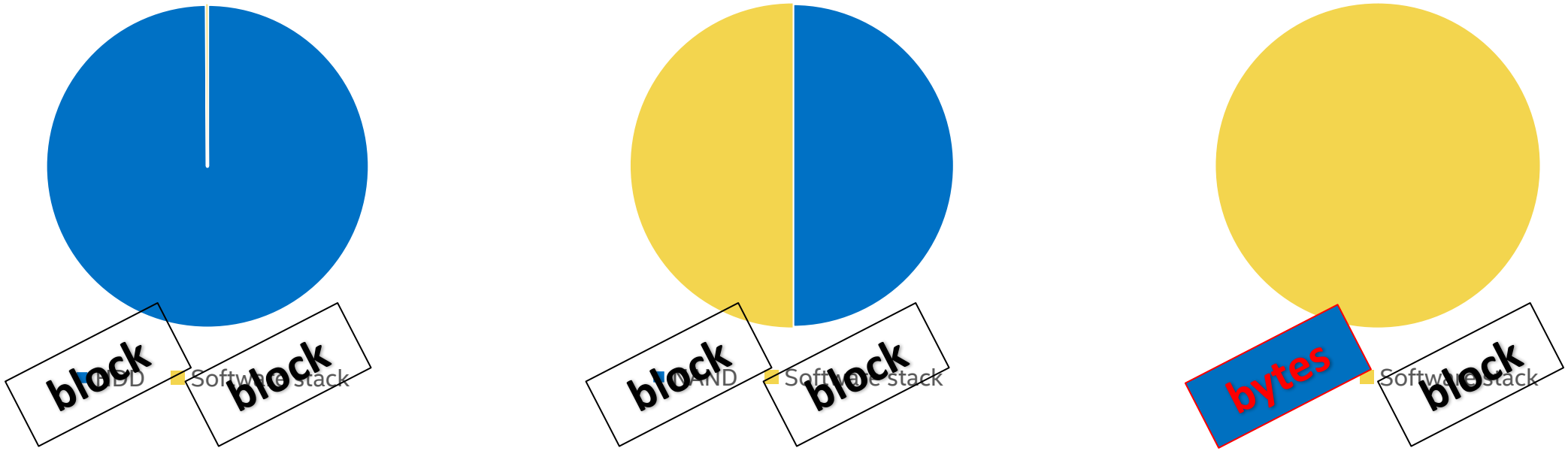






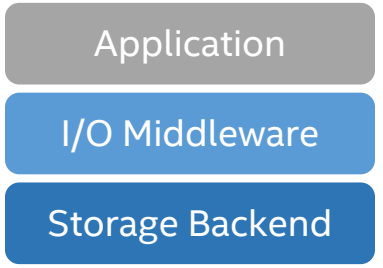
Traditional storage stack entirely **masks** low latency of **NVRAM**!

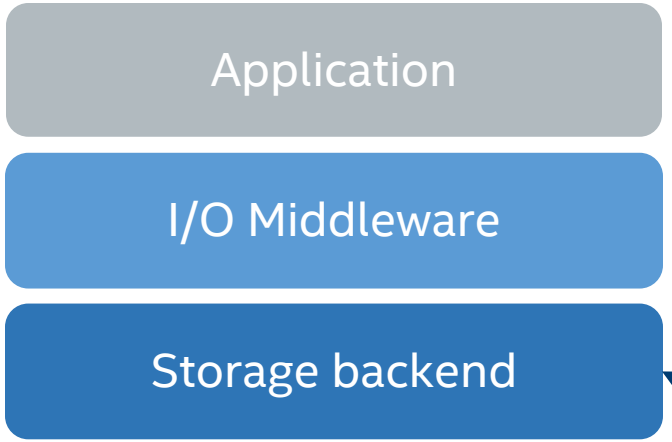
Challenge: Access Granularity



Traditional storage stack entirely **masks**
low latency & capabilities of **NVRAM**!

ESSIO Storage Stack





New storage API (*DAOS*) provides extended capabilities and low-latency I/O to middleware

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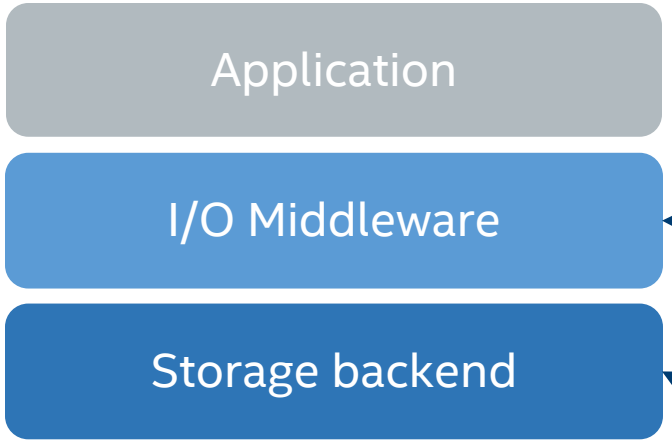

Port I/O middleware (*HDF5, ADIOS, …*) to new storage backend and **augment** API to take advantage of new capabilities

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Application
I/O Middleware
Storage Backend

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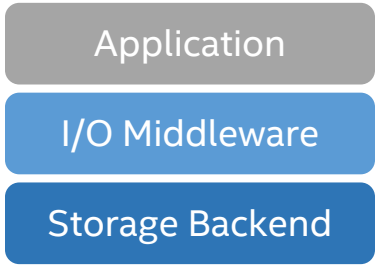

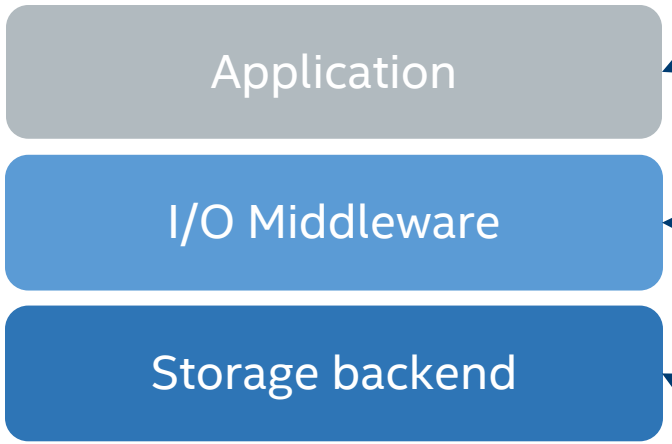

Evaluate applications (*HACC, ACME, CLAMR)* and new programming model (*Legion*) over enhanced I/O middleware

Port I/O middleware (*HDF5, ADIOS, …*) to new storage backend and **augment** API to take advantage of new capabilities

New storage API (*DAOS*) provides extended capabilities and low-latency I/O to middleware

Distributed Asynchronous Object Storage

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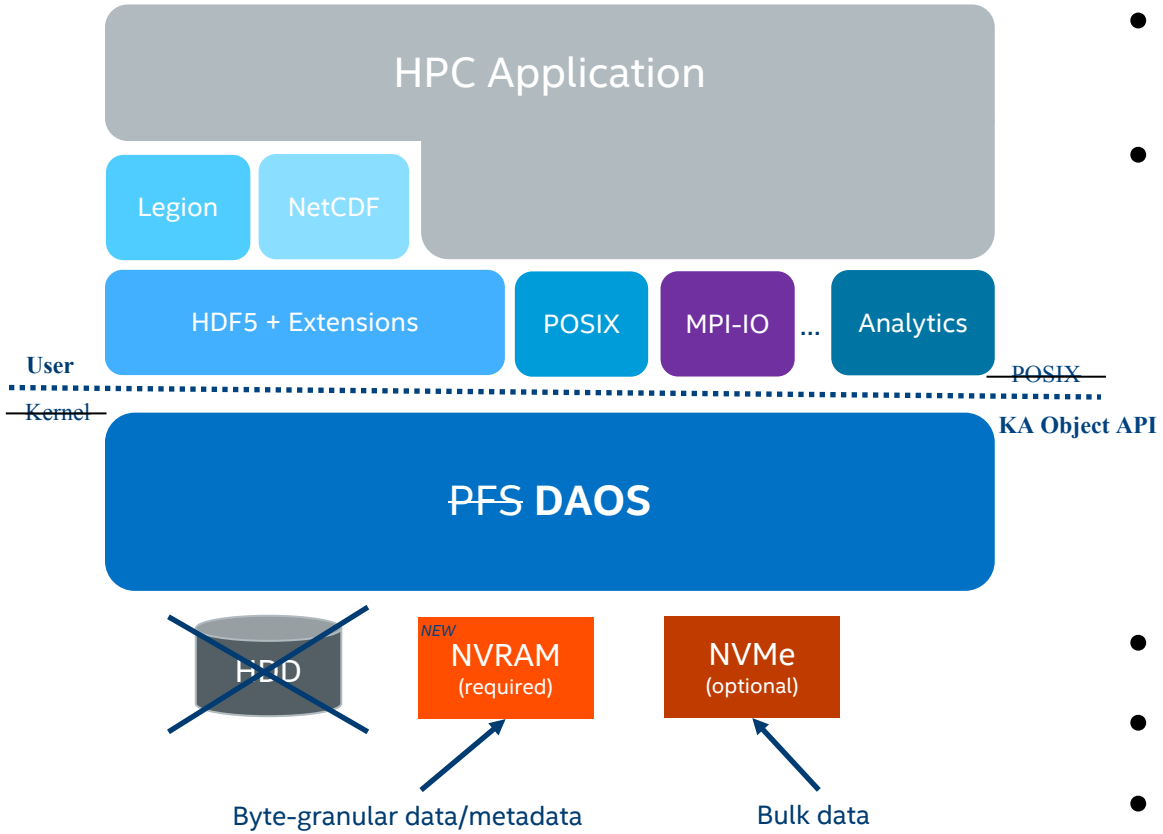
I/O Middleware
Storage Backend



- Storage stack designed for NVRAM & NVMe storage technologies with integrated fabric
- Advanced backend storage API providing:
  - New storage model based on key-array objects
  - Ultra-low latency & non-blocking I/O
  - Distributed transactions & snapshots
  - Extreme scalability & resilience
  - Native support for producer/consumer pipeline
  - Ad-hoc concurrency control mechanism
  - Query & indexing
- Resource/workflow manager integration
- Software defined storage platform
- Integrated multi-tier support

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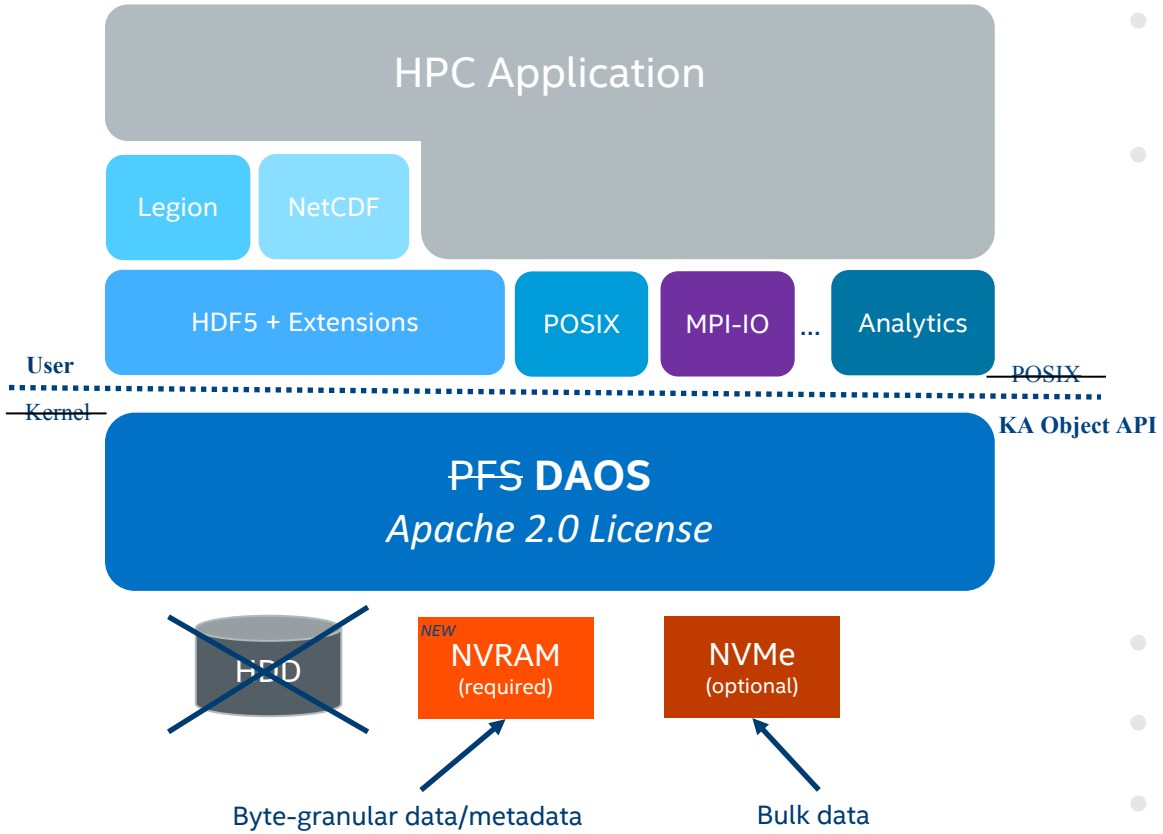

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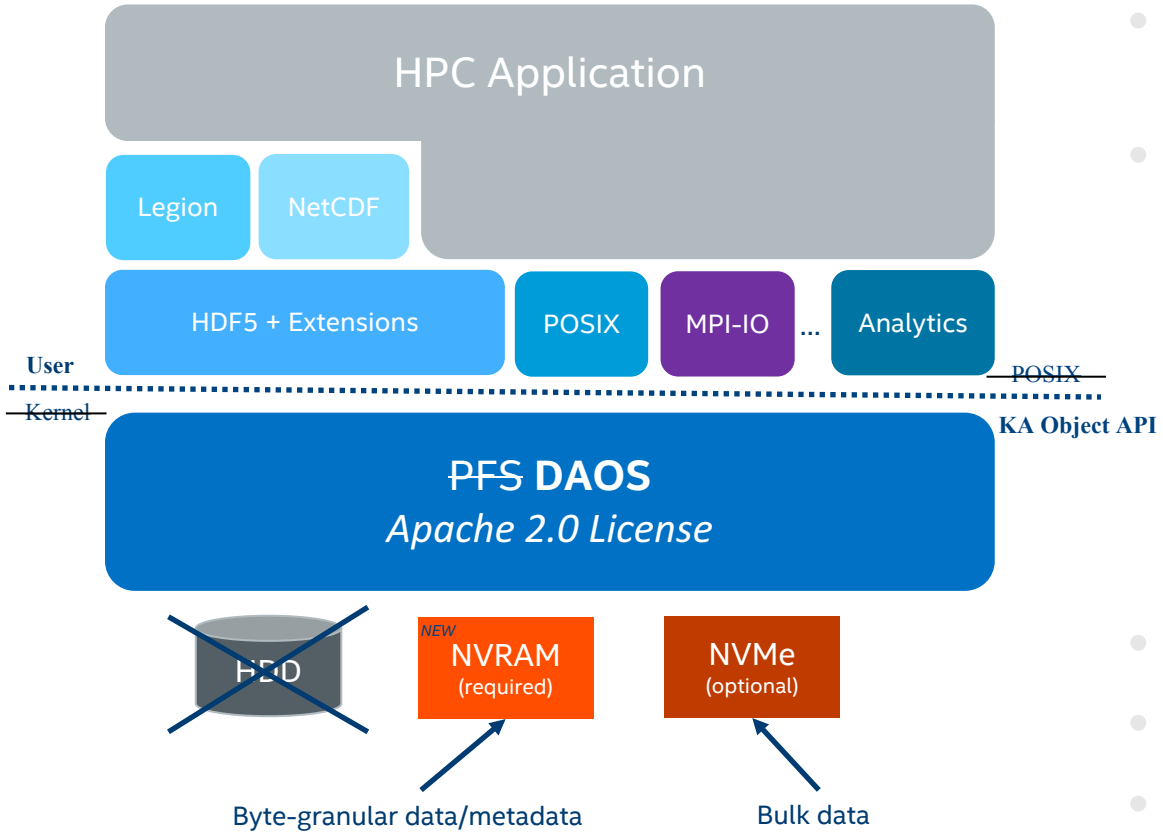

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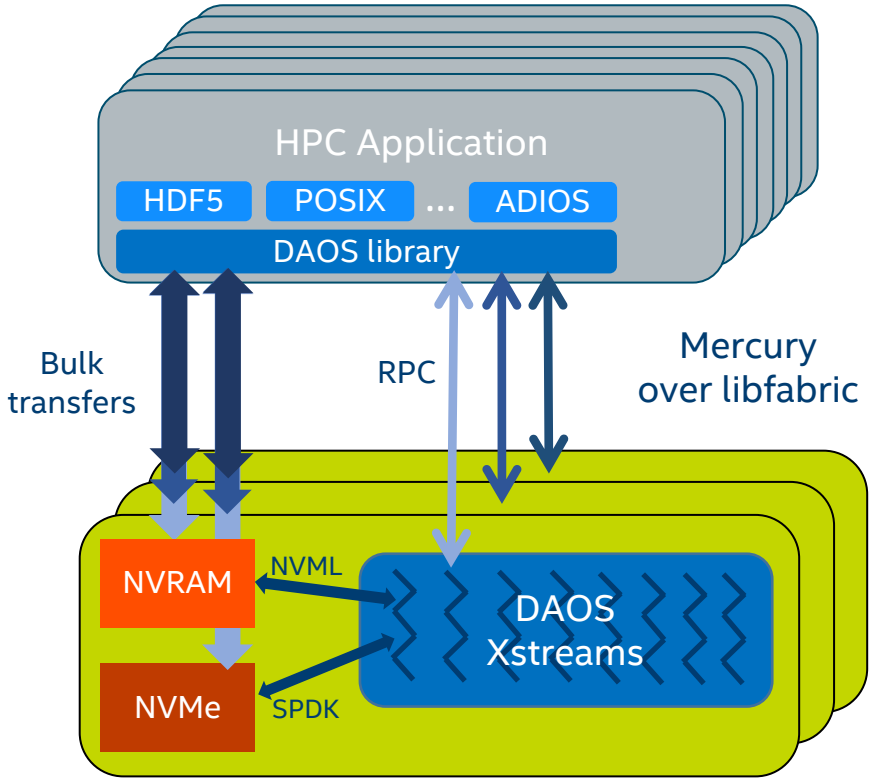
Community Project
https://github.com/daos-stack

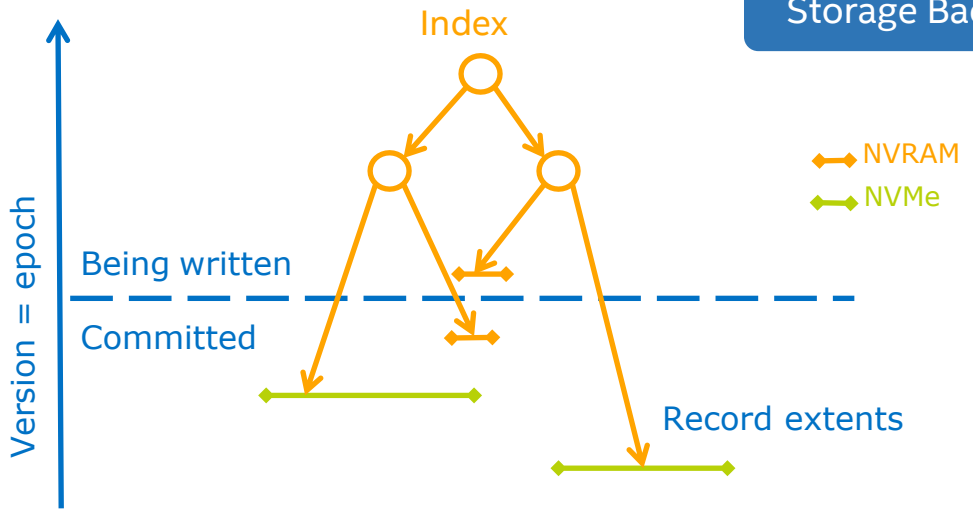
Lightweight Storage Stack

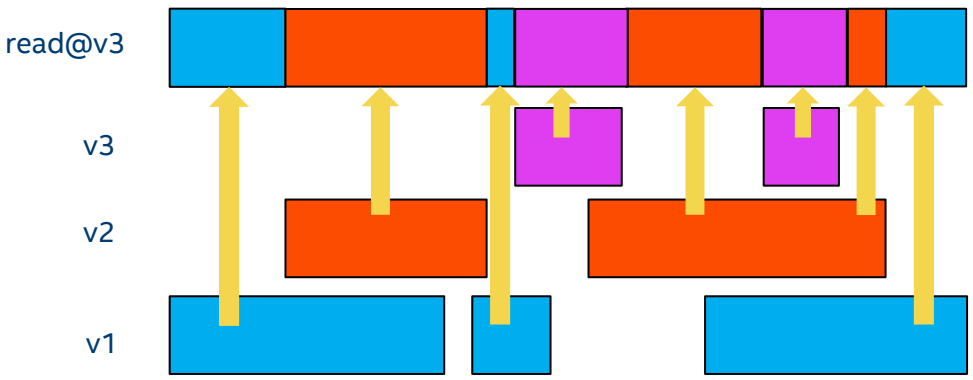
- Mercury userspace function shipping
  - MPI equivalent communications latency
  - Built over libfabric
- Applications link directly with DAOS lib
  - Direct call, no context switch
  - No locking, caching or data copy
- Userspace DAOS server
  - Mmap non-volatile memory (NVML)
  - NVMe access through SPDK/BlobFS
  - User-level thread with Argobots



Ultra-fine grained I/O

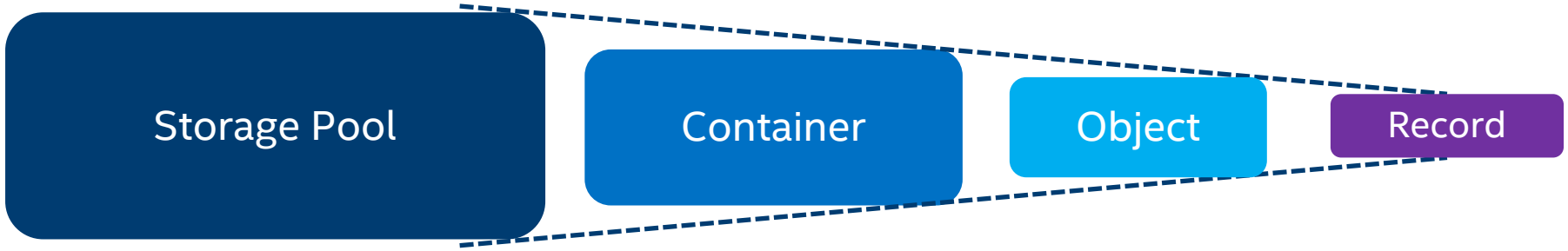
- Mix of storage technologies
  - NVRAM
    - DAOS metadata & application metadata
    - Byte-granular application data
  - NVMe
    - Cheaper storage for bulk data
    - Multi-KB
- I/Os are logged & inserted into persistent index
  - All I/O operations tagged/indexed by version
    - Non-destructive write & consistent read
  - No alignment constraints
    - no read-modify-write





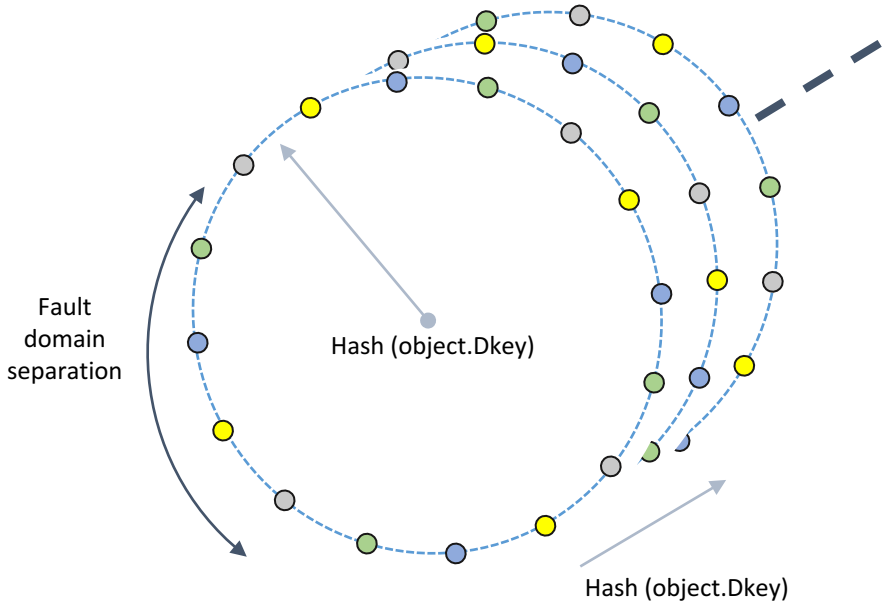
DAOS Storage Model

- Storage Pool
  - Reservation of distributed storage within a tier
  - Integration with resource manager
- Container
  - Aggregate related datasets into manageable entity
  - Distributed across entire storage pool
  - Unit of snapshot/transaction
- Object
  - Collection of related arrays/values with own distribution/resilience schema
  - Key-array store with flexible multi-level key
    - fine-grain control over colocation of related data
- Record
  - Arbitrary binary blob from single byte to several Mbytes



Scalability & Resilience

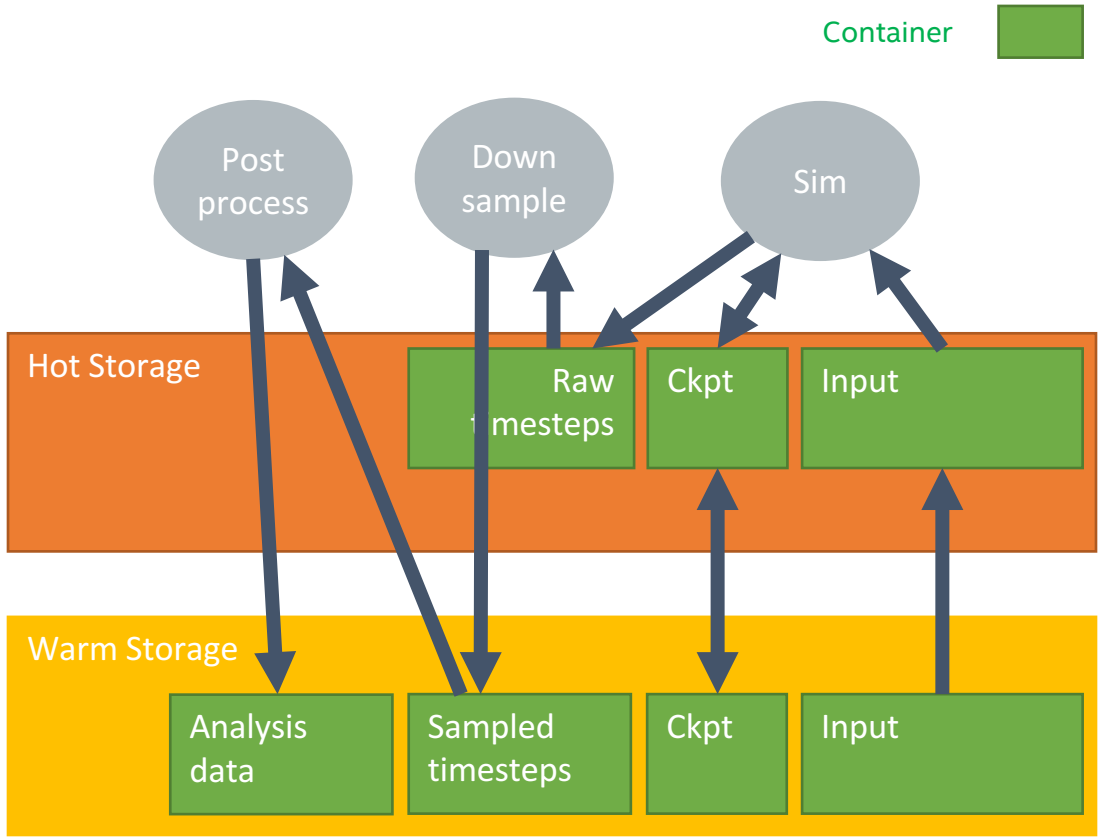
- Scalable communications
- Scalable I/O
- Shared-nothing distribution & redundancy schema



- Storage system failure
  - Failed target(s) evicted
  - Automated online rebuild & rebalancing
- End-to-end integrity
  - Checksums can be provided by I/O middleware
  - Stored and verified on read & scrubbing
- Application failure
  - Scalable distributed transaction exported to I/O middleware
  - Automated recovery to roll back uncommitted changes

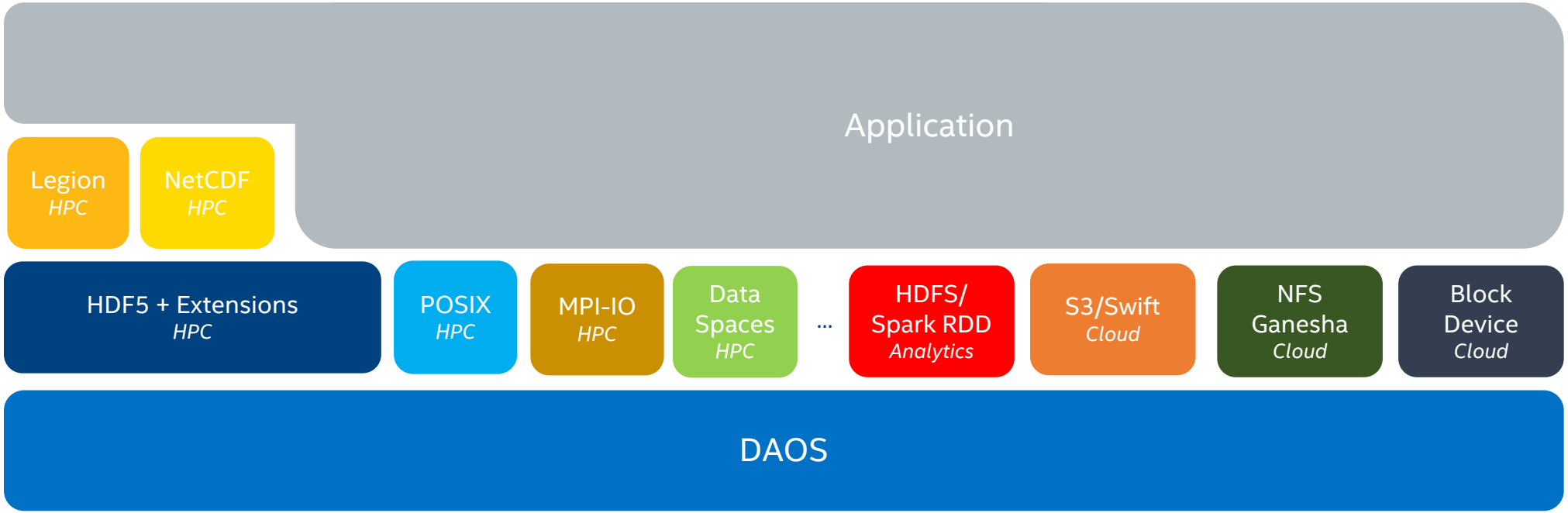
New Workflow Methodologies

- Simplify application & workflow development
  - Transparently span multiple tiers
  - Support producer/consumer pipeline
  - Simplified data management
    - Aggregated related dataset into manageable entitiers, i.e. DAOS container
    - Snapshots
- Integration with resource manager
  - Storage management & job monitoring
  - Data-aware scheduling



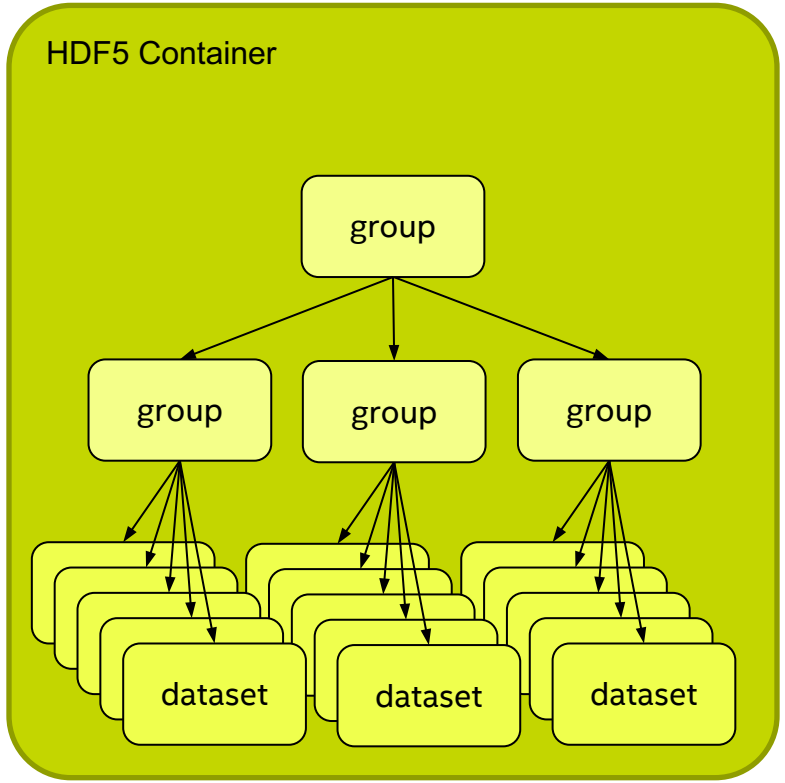
DAOS Ecosystem

Application
I/O Middleware
Storage Backend

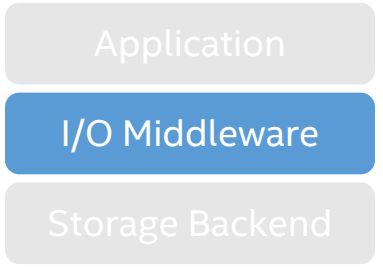


HDF5

- HDF5 file = DAOS container
- DAOS VOL Plugin with smooth migration path
  - Minimal application changes
  - Application no longer needs to explicitly control transactions
    - HDF5 library manages DAOS transactions internally
      - Consistency from H5Fopen() to H5Fflush()/H5Fclose()
    - User-controlled transactions available as extension
- Ported two high-level HDF5-based I/O libraries
  - *NetCDF4*
  - Parallel I/O (*PIO*)



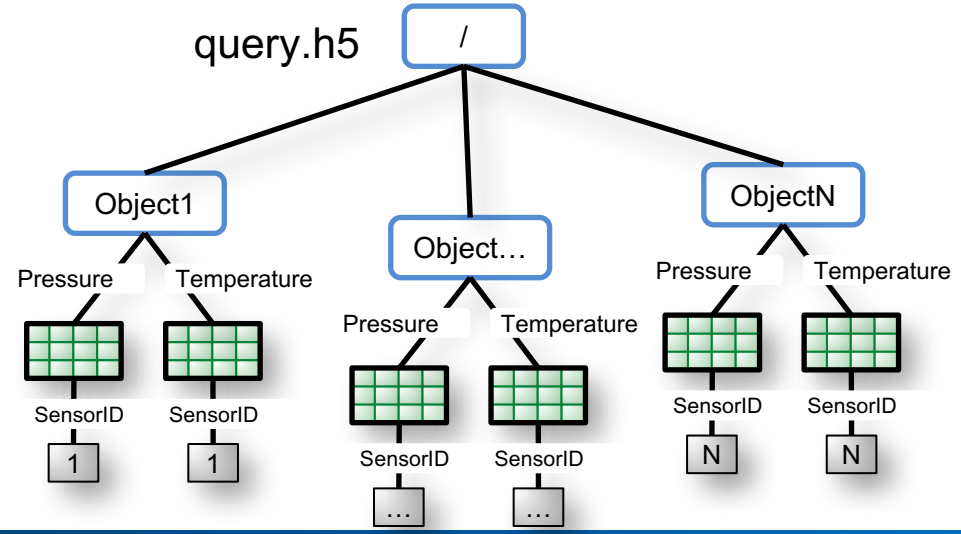
HDF5 Extensions

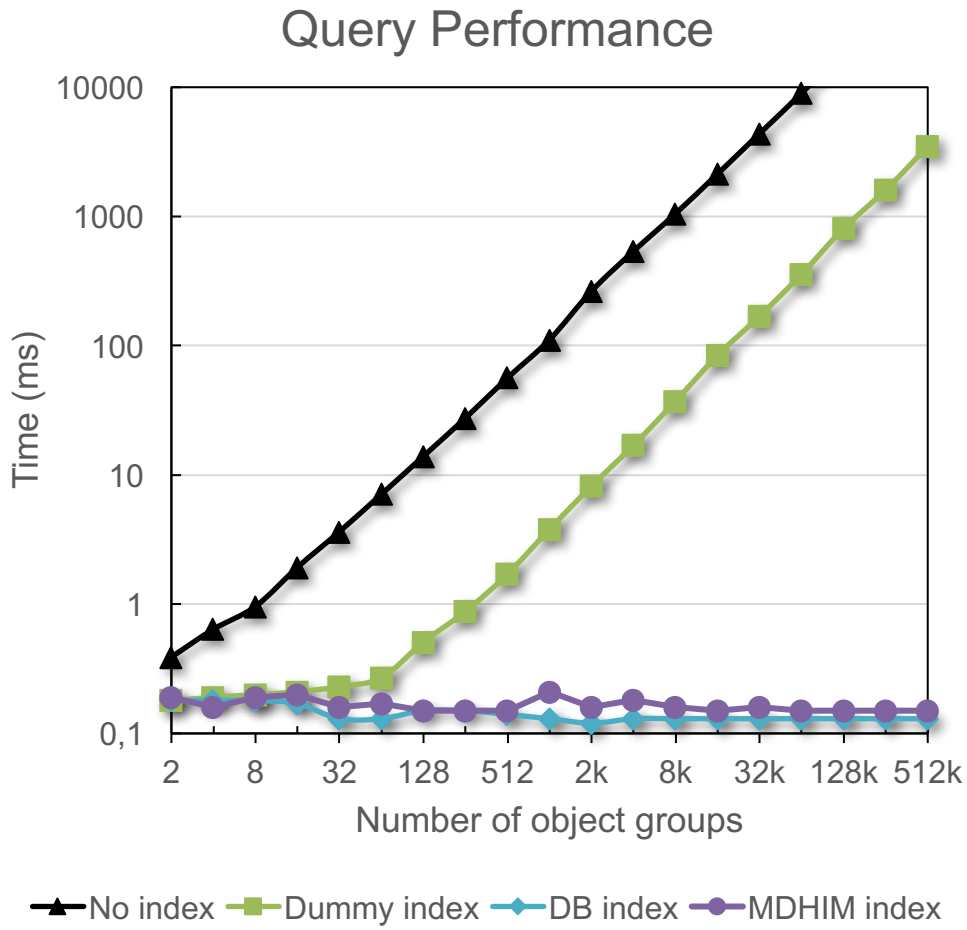


- Asynchronous I/O
  - Focus on ease-of-use
    - Operations still synchronous by default
    - Dependencies tracked by library
  - Extend API with HDF5 “context”
    - Structure for managing and monitoring multiple operations
    - Application can test/wait on individual operations if desired
- End-to-end data integrity
  - Applications can provide checksum buffer to HDF5
    - Receive checksum on write, return value on read
    - Optional
  - HDF5 passes down to DAOS
    - Stored & verified on read/scrubbing
- User-controlled transactions
  - Finer grained control of atomic updates to an HDF5 file
  - Export transaction capabilities to applications through HDF5 API
  - Can pipeline transactions
  - Loosely-coupled execution
- Snapshots
  - Create/open/destroy persistent snapshot of an HDF5 file

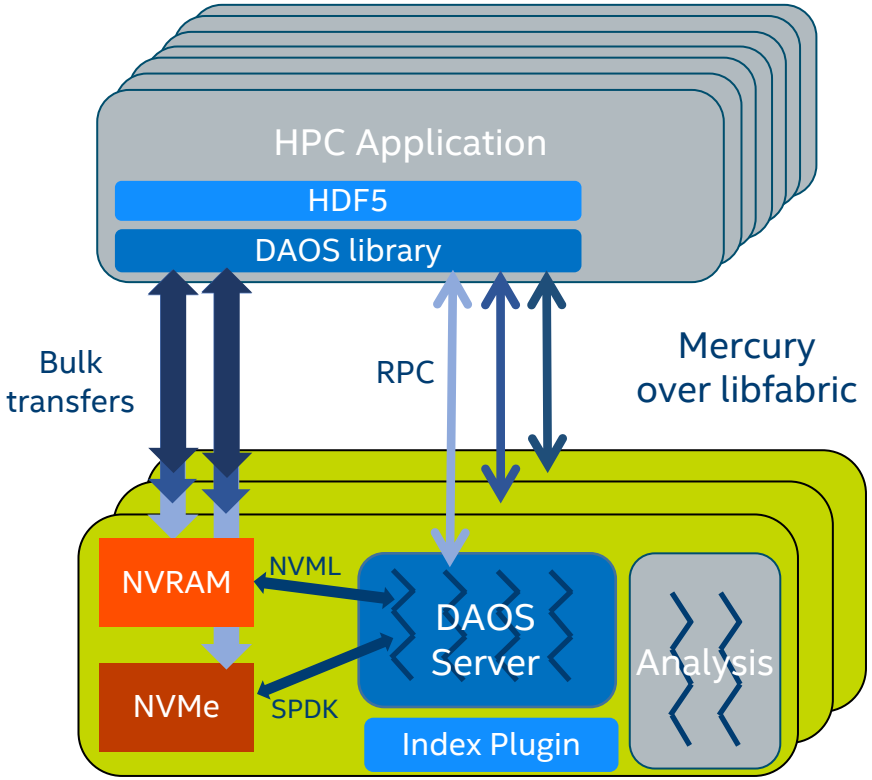
Query & Indexing

- Query API (H5Q)
  - View created in memory
  - Support cross-container queries
- Index API (H5X) accelerates generation of view
  - Data Index (FastBit)
  - Metadata Index (Berkeley DB / MDHIM)
  - Plugin framework





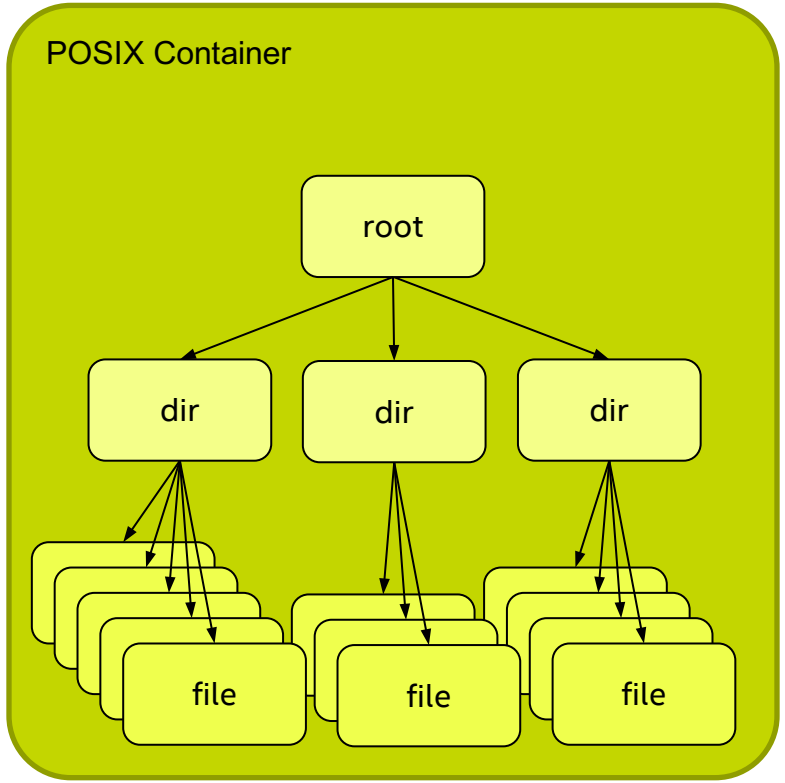
Data Analysis



- Analysis shipping
  - Send user-defined Python script to storage service
  - Execute MapReduce-like operations where data is located
  - Send results back to caller

POSIX Namespace Encapsulation

- POSIX Namespace = DAOS container
  - Full OS bypass for both data & metadata
- Application-private namespace
  - Highly scalable metadata operation
  - Relaxed POSIX compliance



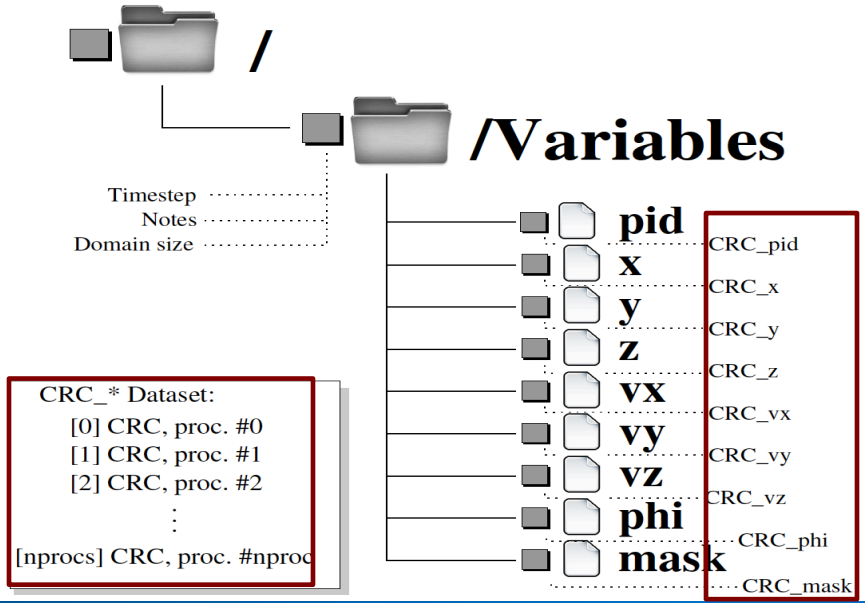
Legion on ESSIO Stack

- *Legion* attaches to HDF5 files using low-level Realm runtime
  - Realm maps memory objects to HDF5 file/objects
- New DAOS capabilities featured in Legion
  - Multiple independent container handles
  - Flexibility with epoch updates from independent container handles
  - Ability to read from un-committed epochs within a container handle
- Using *Legion* with DAOS
  - Individual tasks can be scheduled independently
  - Tasks can complete at various time
  - Legion can schedule different phases of I/O based on data dependency
    - May have reading and writing tasks run concurrently on the same logical region

HACC

Hardware/Hybrid **A**ccelerated **C**osmology **C**ode

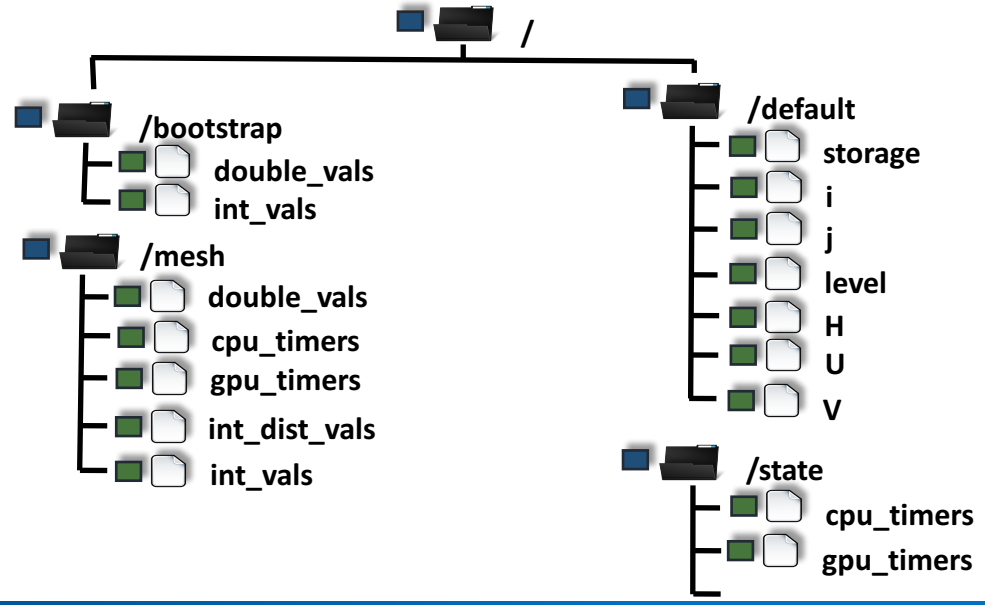
- Updated to store application metadata in HDF5 container
- Ported to rely on end-to-end data integrity feature from the ESSIO stack
- Improved fault tolerance by storing transactional checkpoints



CLAMR

Ce**l**l-Based **A**daptive **M**esh **R**efinement

- Updated to use HDF5 instead of POSIX I/O
- Added restart capabilities using HDF5
- Demonstrated CLAMR restart capabilities over the ESSIO stack



Questions?

Contact: johann.lombardi@intel.com

Resources:

- Git repository
  - https://github.com/daos-stack
- High Level Design (HLD) document
  - https://wiki.hpdd.intel.com/download/attachments/36966823/MS54_CORAL_NRE_DAOSM_HLD_v2.3_final.pdf?version=1&modificationDate=1460746910000&api=v2