2020 OFA Virtual Workshop

DISTRIBUTED ASYNCHRONOUS OBJECT STORAGE (DAOS)

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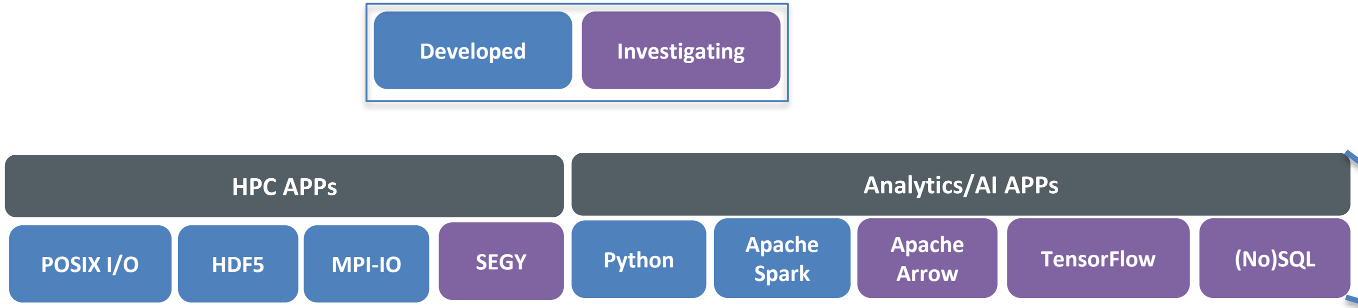
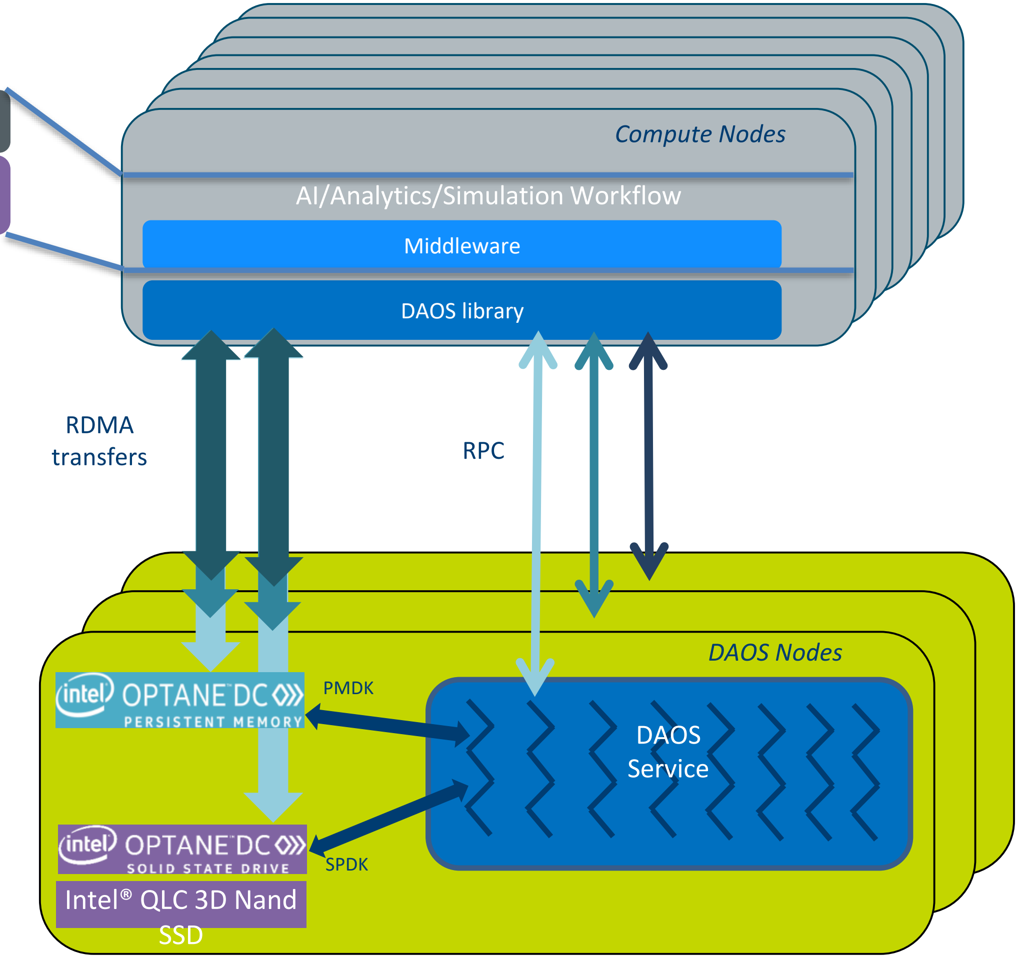
OUTLINE

- **DAOS overview**
- **Lessons learned building DAOS using OFI / libfabric**
- **Brainstorm – opportunities to further leverage networks/fabrics**

DAOS ARCHITECTURE OVERVIEW

DAOS ARCHITECTURE:
CLIENT LIBRARY AND INTERFACES

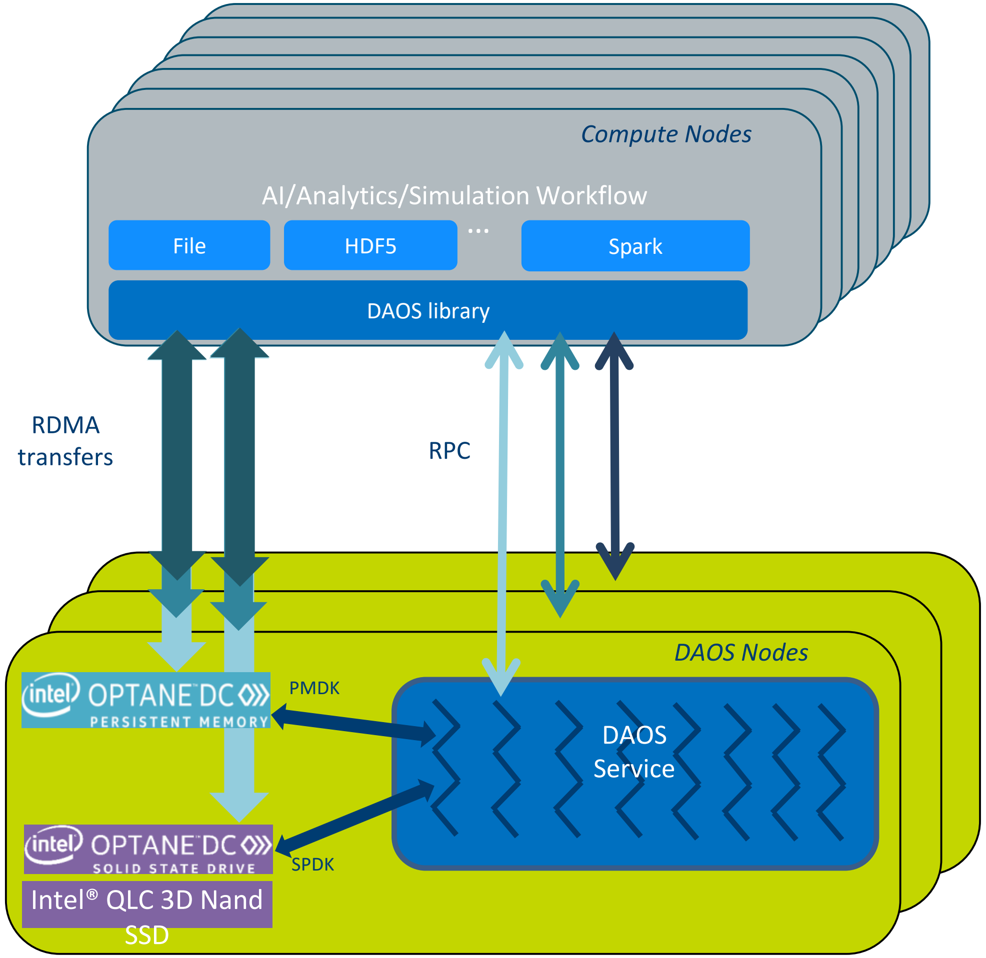




- **POSIX I/O – namespace distributed over servers**
  - DAOS Filesystem (libdfs) – apps / frameworks may link directly
  - FUSE Daemon – transparent access to DAOS, involves syscalls
  - I/O Interception Library – OS bypass for read/write operations
- **MPI-IO Support**
  - MPI-IO Driver uses DAOS array API (+ libdfs for collective open)
- **Python Bindings**
  - Export key-value store objects
  - Integrate with dictionaries: iterator, direct assignment, etc.

DAOS ARCHITECTURE:
HIGH PERFORMANCE COMMUNICATIONS

- **RDMA (iWARP, RoCE, IB, OPA) + scalable collectives**
- **User-space networking, libfabric (via CART / Mercury)**
  - RPC via tagged messages: **fi_tsend / fi_trecv**
  - Bulk transfer via RDMA: **fi_readmsg / fi_writemsg**
  - End-to-end OS bypass: low-latency, high-message-rate in I/O path
- **Clients / applications link with DAOS lib**
  - No: context switch, locking, caching, or data copy
  - No need for dedicated cores
- **Servers initiate RDMA**
  - PM access over fabric:
    - Zero-copy RDMA to PM ; mmap'ed via PMDK
    - Memory consistency / flush done in server *code* after RDMA
  - NVMe SSD access over fabric:
    - RDMA into DRAM ; then SPDK for I/O to device

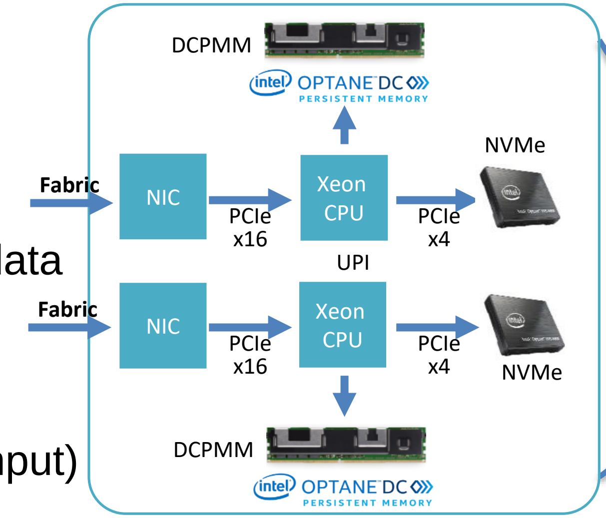


DAOS ARCHITECTURE:

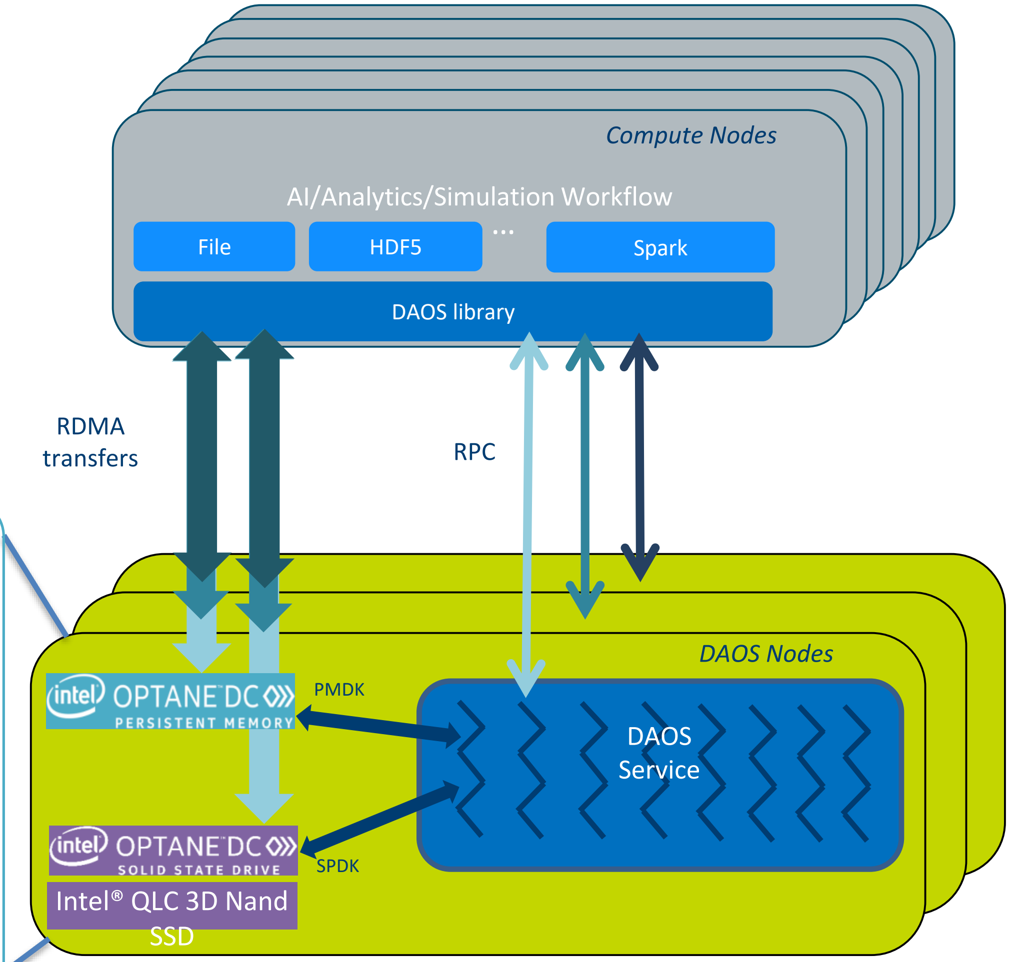
STORAGE SERVERS – TWO-LEVEL DATA PLACEMENT

- **Algorithmic placement**
  - Identify servers to store data replicas or shards
  - **Client-calculated** jump consistent hash based on key, object class (e.g., replicated, striped)
  - Fault domains taken into account – reduce impact of server loss (e.g., if a whole domain fails)

- **One tier, two media types:**
  - **Server-selected** media
  - Data Center Persistent Memory (DCPMM)
    - PM ← app small, byte-granular data, metadata
    - PM ← DAOS metadata
  - NVMe (*NAND, Intel® Optane™) SSD
    - SSD ← app-only bulk data (for high throughput)
    - SSD ← (aggregation of small data in PM)



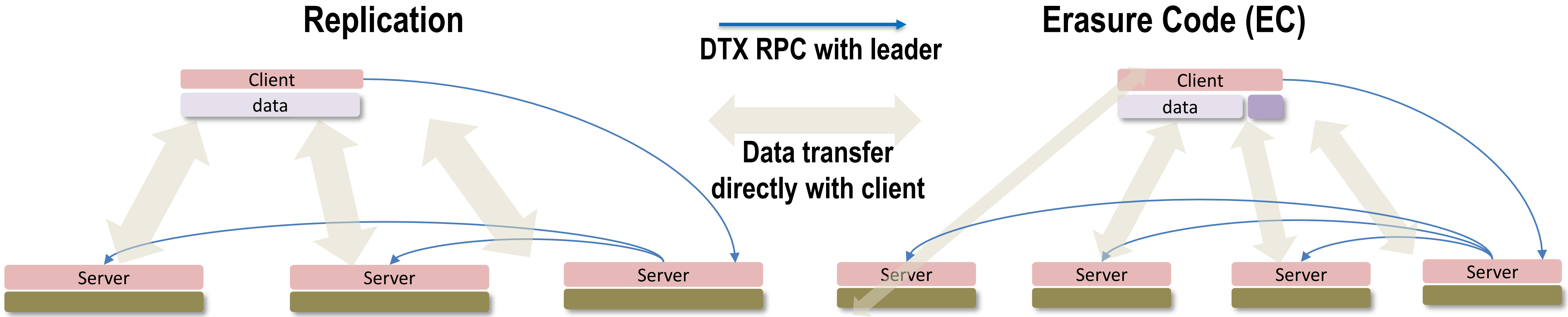
Dual-Socket DAOS Nodes (DNs)
Intel® Xeon servers with DCPMM & NVMe SSDs



DATA PROTECTION AND SELF-HEALING / REBUILD

COMMON PROPERTIES OF REPLICATION AND ERASURE CODE (EC)

- **Leader server chosen to manage distributed transaction protocol (DTX)**
  - Chosen algorithmically based on key – no single leader node bottleneck
- **Degraded mode – client I/O satisfied by surviving servers**
  - Non-blocking protocol for server fail-out
- **Self-healing / rebuild (online recovery)**
  - Declustered – per object, select alternate server storage to restore original degree of replication
    - Many alternate nodes in parallel – pull object data from surviving servers
  - Throttled – to control impact to serving ongoing client I/O requests

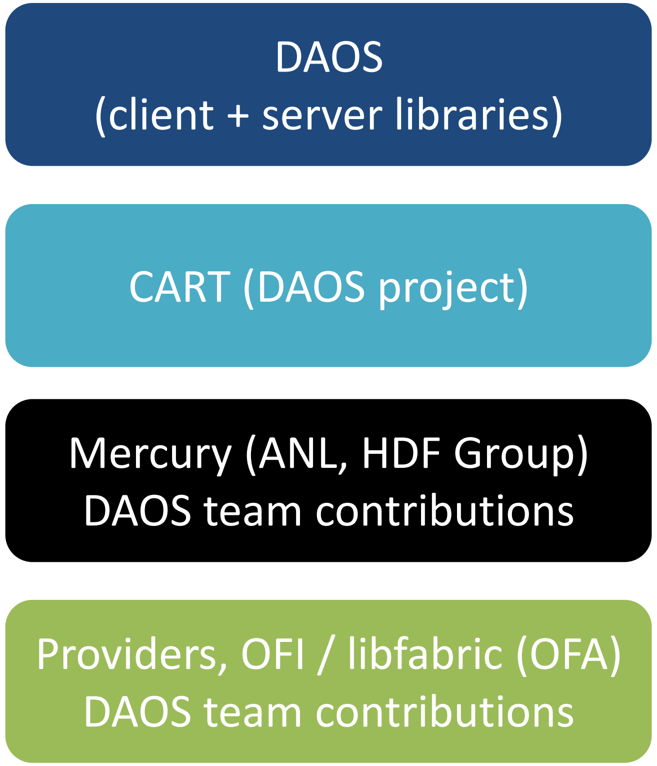


DAOS TO LIBFABRIC

VIA CART, MERCURY RPC MIDDLEWARES

- **CART: Collective Adaptive Reliable Transport**
  - P2P RPC reliability, built over Mercury RPC:
    - Timeout detection / retry
    - Flow control
    - SWIM protocol for fault detection / reaction
  - Collective RPC – broadcast, barrier, incast variable (IV)
    - Reliability: group versioning as membership expands or contracts

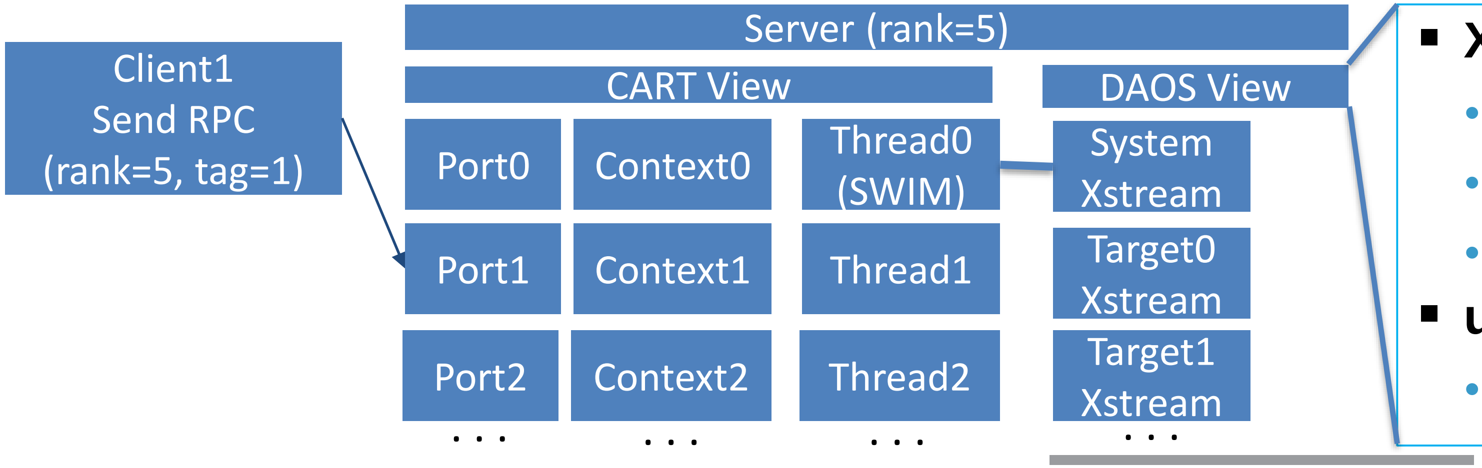
- **Mercury: P2P RPC between targets, pluggable OFI providers**



CART RANKS AND TAGS/CONTEXTS

AND ASSOCIATION WITH DAOS SERVER NODE RESOURCES

- **Rank: Unique 32-bit identifier assigned to each process in a ‘set’ (e.g., DAOS server)**
- **Tag: Number identifying a context/port on the node**
- **Server can create multiple CART contexts, process them independently.**
- **Allows different priorities of executions depending on context receiving a given RPC**



- **Xstream: execution stream (pthread)**
  - System xstream (e.g., for DAOS metadata tasks)
  - 1 Thread / target (often configured based on #cores)
  - Helper threads for target background tasks e.g., rebuild
- **user-level threads (argobots)**
  - Context switching in user-space

CART RPCS

POINT-TO-POINT (P2P)

Timeouts – 3 levels

- All RPCs, per context, per RPC
- Can resend on timeout

Flow Control (Max RPCs in flight to a target)

- Initiated RPCs > limit put on a queue, processed after others complete or timeout

Inline vs. Bulk Transfers

- Messages < ‘eager size’ use send, inline with RPC
- Messages > ‘eager size’ use RDMA either internally (CART/HG) or explicitly (bulk API)

Progress-based model

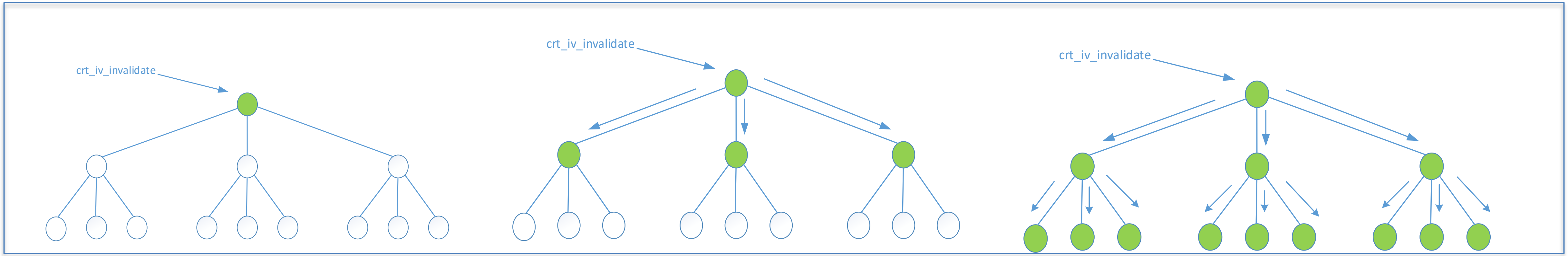
- No actions occur until crt_progress() called (near other calls, or in separate thread)
  - RPC create / send does not perform communication – happens when crt_progress() invoked on the CART context.
- Callback functions invoked from the context of the crt_progress() function
  - E.g., RPC handling (server), RPC reply received (client), bulk transfer completion

CART RPCS
COLLECTIVE

- **Barrier synchronization**
- **Broadcast**
- **Shared Incast Variables (IV)**
  - Scalable Fetch, Update, Invalidate ops
  - Example use: scalable read cache

- **Optional rank filtering for collective over (sub)group**
- **Request propagated through K-ary tree**
- **Reply aggregation**
- **Chained bulk transfer support**
- **Group versioning, error on receiver / sender mismatch**

<u>Example: broadcast used within IV invalidate</u>



LESSONS LEARNED: BUILDING DAOS UPON OFI / LIBFABRIC

CLIENT/SERVER VS MPI MODEL OF USAGE

- **DAOS client/server model, different application lifecycles**
  - Client endpoint addresses can end up being reused – differentiate between 2 client runs reusing same endpoint address
  - Server resources dedicated to a client need to be released on client disconnect
    - Examples: Address Vector (AV) table entry, bounce buffers, memory registrations (MR), …
    - Additional challenges on abrupt disconnect (client failure)

- **MPI usage tends to be more of "launch everything at once, do a job and exit"**
  - Servers: dynamically expand / contract system ; and members of sub-groups associated with storage pools

- **DAOS utilizes multiple contexts, with different type of workloads**
  - Background fault detection protocols e.g., SWIM
  - DAOS metadata activities and request handling
  - I/O processing and background activity (e.g., self-healing / rebuild)

- **DAOS requires multi-tenancy support:**
  - Server can run as a different user (possibly root) compared to clients – some providers do not support this model

SCALABILITY

- **Number of issues found during scalability testing**
  - MR cache: seeing some buffer overwrites / corruption (that do not occur when disabling MR cache)
  - Race conditions: DAOS multi-threaded request processing. Have seen issues in some providers
  - Resource leaks: AV table entries, mem registrations, buffers
    - Additional challenge, concurrent cleanup with MPI-based clients (near simultaneous disconnects)

- **Connection-oriented providers and resource pre-allocation**
  - RXM-based providers pre-allocate resources per client based on FI_UNIVERSE_SIZE
    - CQ size, bounce buffers
  - Address entry in AV table (populated by fi_av_insert())
  - Some resources such as AV table size can be implemented in HW with strict limits on maximum size
  - As a result server has to manage ‘clients’ by evicting stale/old/LRU entries

- **Connection-less RXD provider considered:**
  - Does not require persistent connection – scales higher than connection-oriented providers
  - DAOS cannot use it for now due to no RDMA support - poor performance

TESTING

- **Providers tend to be in various states of stability**

- **Currently sockets provider is main one in DAOS CI**
  - Sockets provider is not performant ; and not actively maintained
  - DAOS would like to move to OFI_RXM;TCP provider, however facing stability issues for now

Wishlist items

- **More automated tests using available providers**
  - With combinations of common / provider-specific variables – e.g., with/without shared rx buffers (FI_OFI_RXM_USE_SRX)

- **Longevity tests**

- **Performance tests**

- **Valgrind/Thread/memory sanitizer tests:**
  - DAOS has a few valgrind memory suppressions for issues seen in providers

POTENTIALLY INTERESTING FABRIC FEATURES

POTENTIAL AREAS OF EXPLORATION - BRAINSTORM

- **Multiple interface solutions on client – e.g., single virtual / bonded interface**
  - A process uses one interface today – with many processes / node (e.g., MPI ranks) interface use can be distributed
  - A single, highly threaded process needs a mechanism to use all interfaces (e.g., for performance and/or fault resilience)
  - Each system (e.g., MPI, DAOS) needs to solve the problem on its own – possible wish list item for OFI / libfabric

- **Lower-latency client-initiated RDMA to server persistent memory:**
  - Smaller scale, special cases assumed
  - Array + Map Conceptual API: preallocated, registered PM

- **Network e.g., switch configured and enforced traffic classes/QoS, traffic management.**
  - current approach: enforce proportion of normal vs. background I/O (e.g., self-healing) through user-level thread scheduling.

- **Network telemetry to diagnose / optimize DAOS service performance**

- **Network offloaded checksum, erasure code, etc.**

RESOURCES

Resource	URL
Source Code on GitHub	https://github.com/daos-stack/daos
Documentation	https://daos-stack.github.io/
Community Mailing List	https://daos.groups.io/
DAOS Solution Brief	https://www.intel.com/content/www/us/en/high-performance-computing/overview.html

OPENFABRICS ALLIANCE

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THANK YOU

Kenneth Cain, Software Engineer

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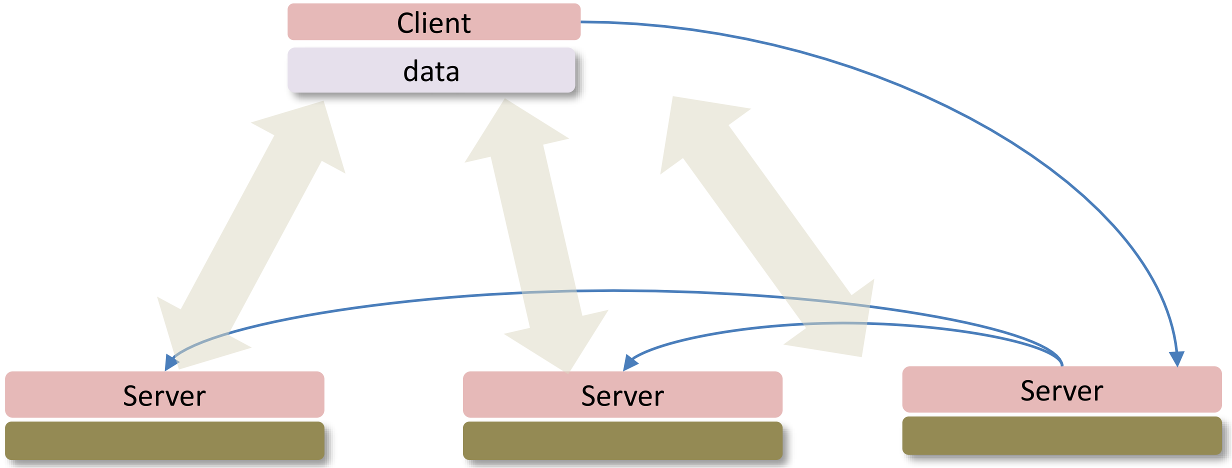
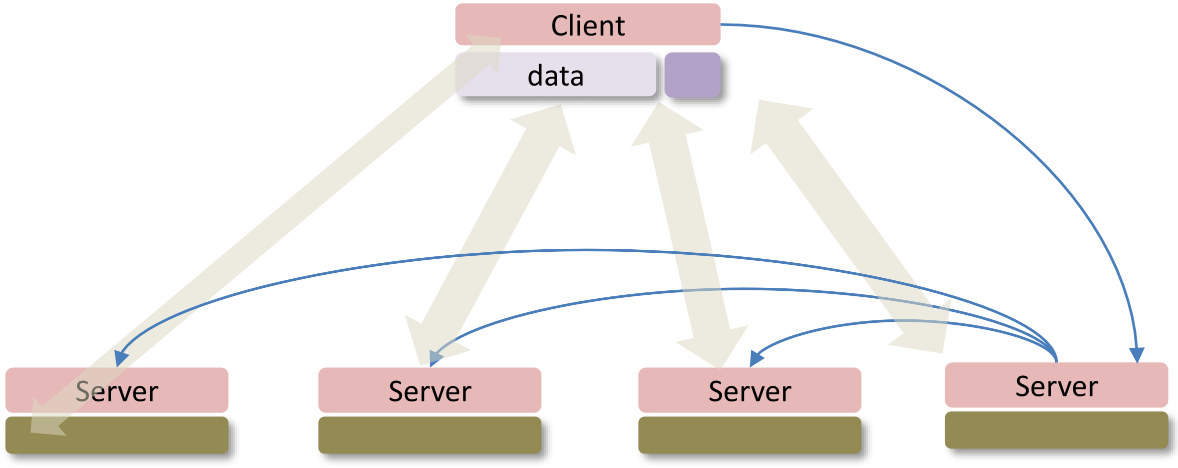
BACKUP SLIDES

DATA PROTECTION AND SELF-HEALING / REBUILD

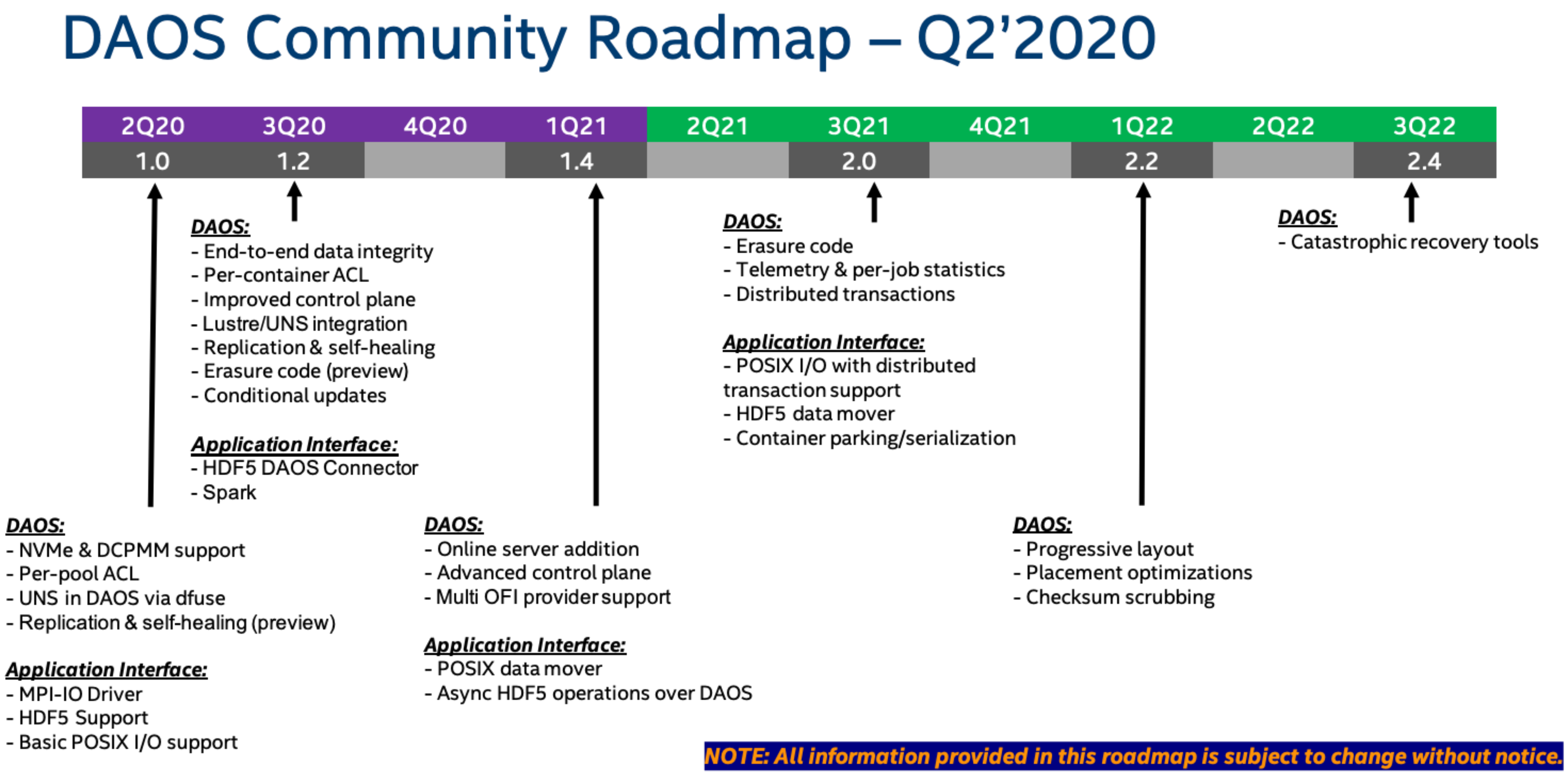
- **Data replication in DAOS**
  - Primary-slave
  - Distributed transaction for atomicity
- **Degraded mode**
  - Client issue I/O requests to surviving server(s)
- **Self-healing / rebuild (online recovery)**
  - Server-side exchange / data reconstruction



- **Erasure code in DAOS**
  - Client compute EC on full stripe write
  - Replication, server merge/encode for partial write
- **Degraded mode**
  - Client-side inflight data reconstruction
- **Self-healing / rebuild (online recovery)**
  - Server-side exchange / data reconstruction



DAOS COMMUNITY ROADMAP



DAOS PERFORMANCE

IO-500 BENCHMARKS

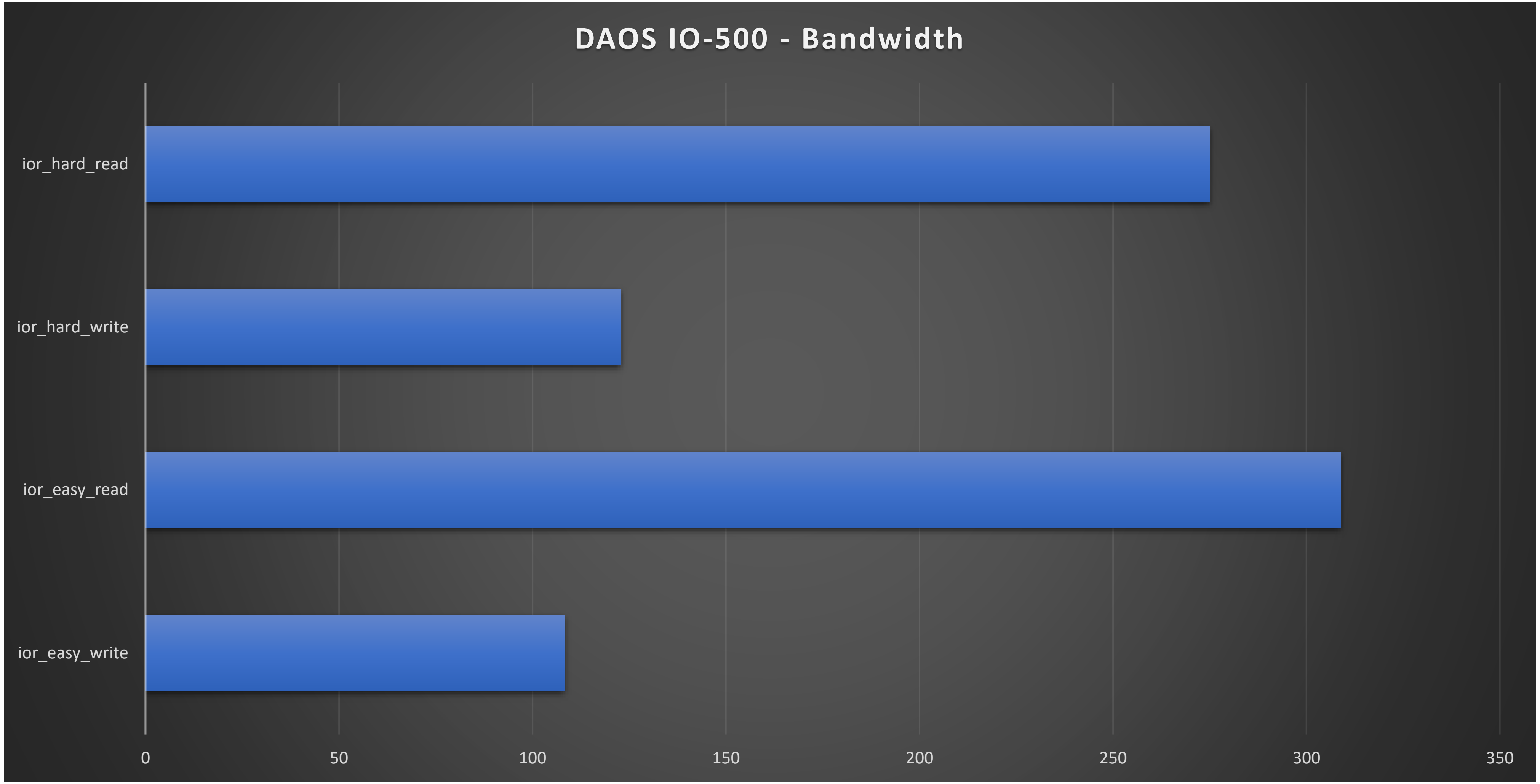
IO-500 Benchmarks

- **IOR**
  - Easy: any IOR pattern to show best-case performance without any explicit caching
  - Hard: single shared file with transfer 47008 bytes!
  - Separate Write and Read/verify runs.
- **mdtest**
  - Easy: private directory per process with empty files
  - Hard: shared directory with 3901-byte files
  - Separate write, read, stat, and delete runs
- **Find**
  - scan namespace created with IOR and mdtest

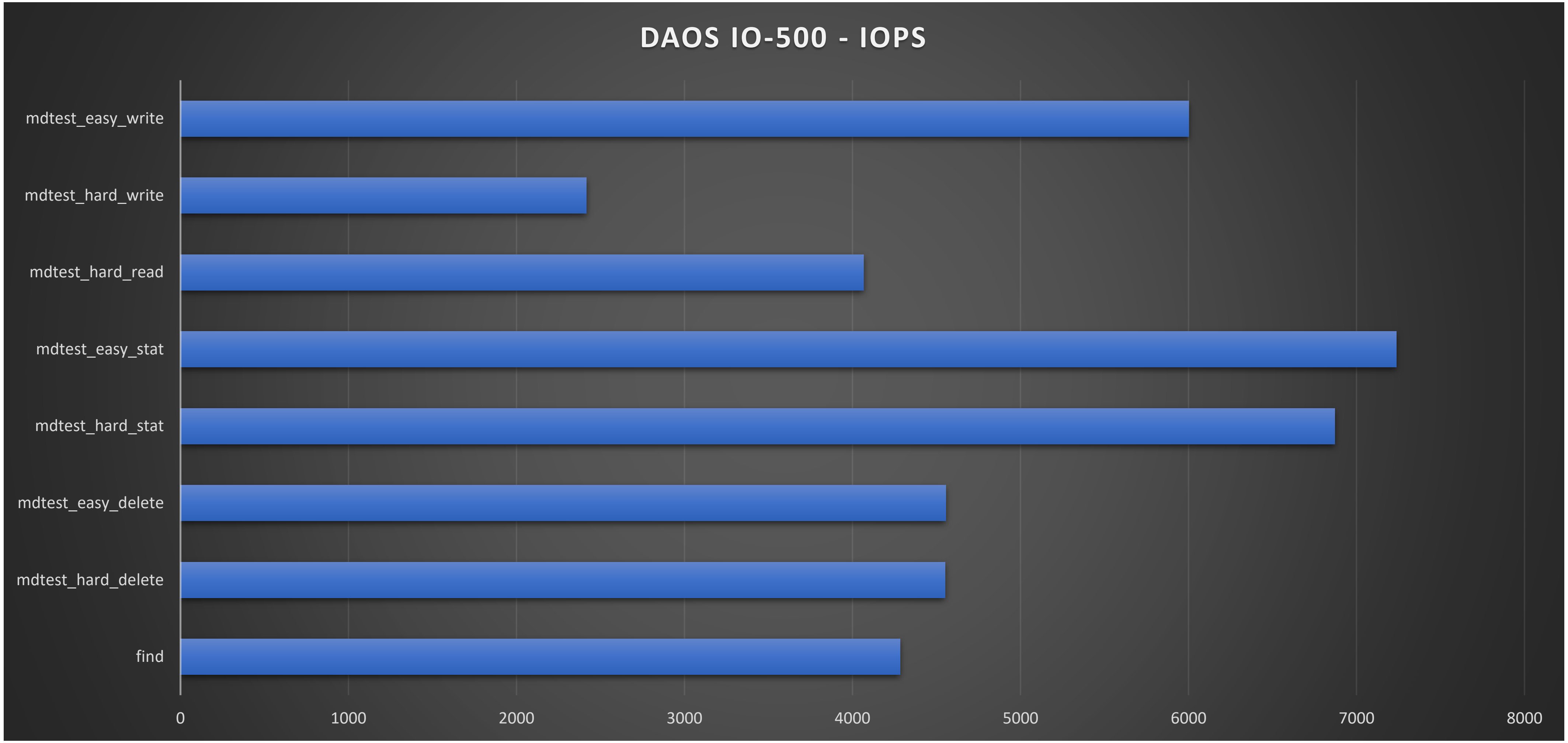
DAOS Testbed

- **10, 26 Compute nodes**
  - 10 node x 31 ranks/node (10 node challenge)
  - 26 node x 28 ranks/node (open challenge)
  - 2x BDW CPU
    - Xeon® E5-2699 v4 @2.2GHz
    - 22 cores per CPU
  - 2x Intel® Omni-Path® 100 adaptors
- **24x Storage nodes**
  - 2x CLX CPU
    - Xeon® Platinum 8260L @ 2.4GHz
    - 24 cores per CPU
  - 12x Optane® DC Persistent Memory DIMMs
    - 500GB each for a total of 3TB
    - Configured in app-direct/interleaved mode
  - 2x Intel® Omni-Path® 100 adaptors

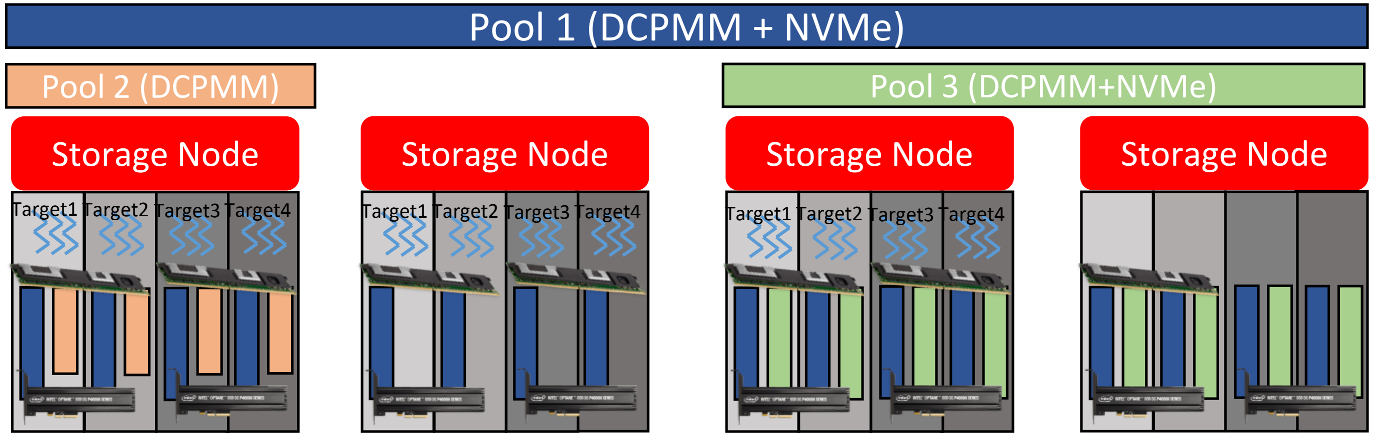
DAOS & IO-500: BANDWIDTH

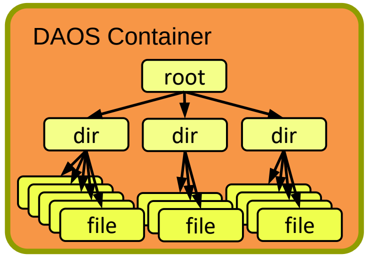


DAOS & IO-500: IOPS

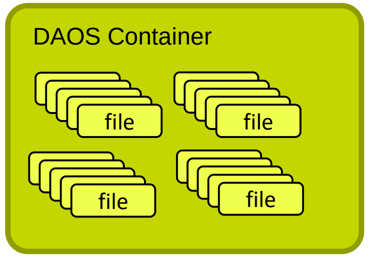


POOLS AND CONTAINERS

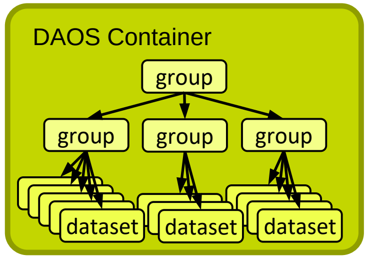




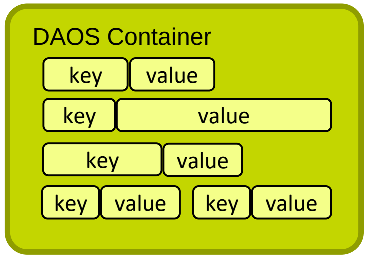
Encapsulated POSIX Namespace



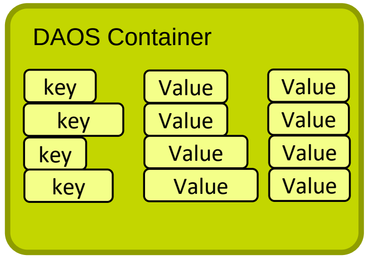
File-per-process



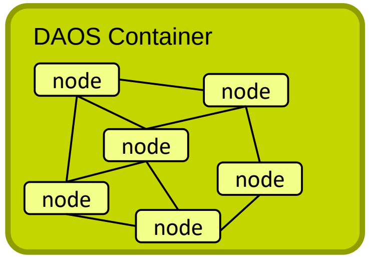
HDF5 « File »



Key-value store



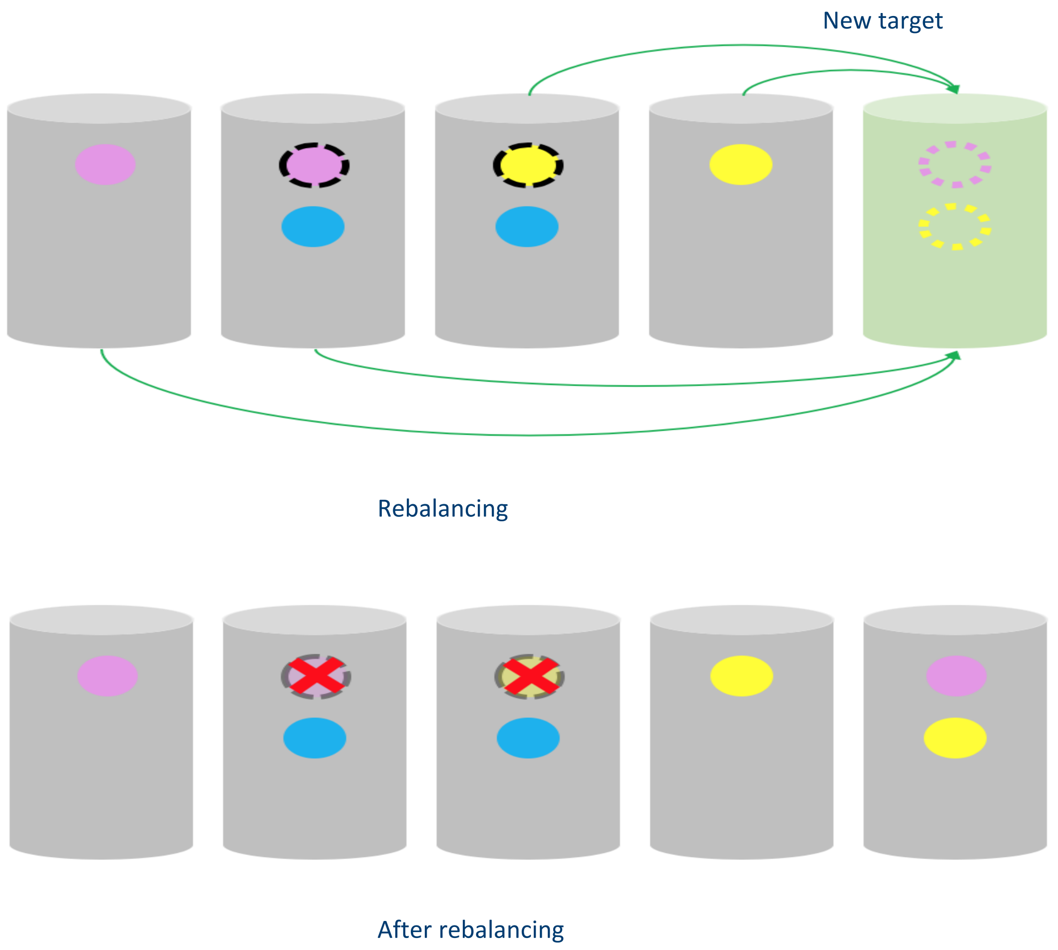
Columnar Database



Graph

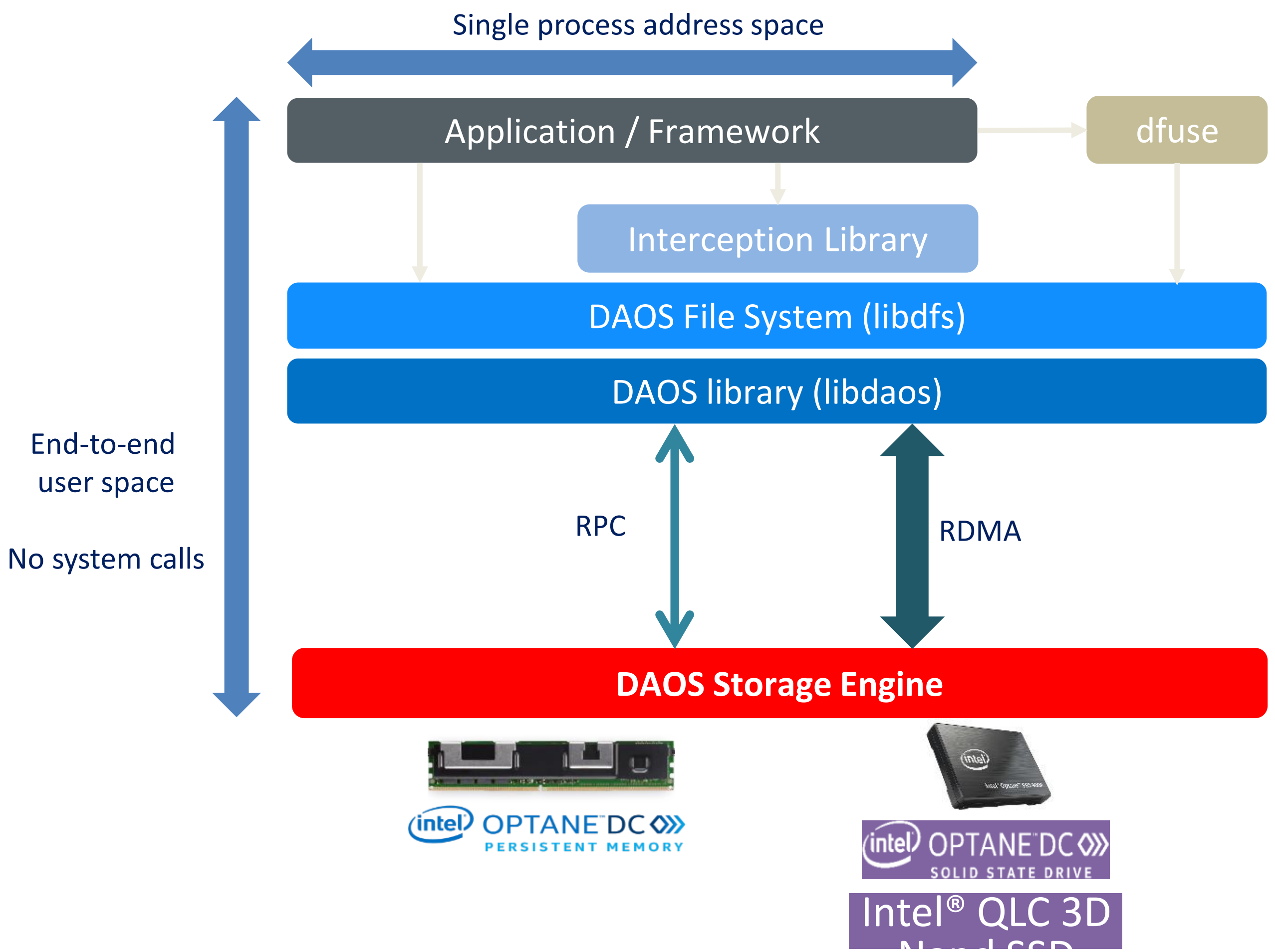
STORAGE TARGET REINTEGRATION / ADDITION

- **Reintegrate recovered target to the pool**
  - Add temporarily excluded storage targets back to the pool
    - Replaced: empty storage target
    - Not replaced: retained data but lagging behind
  - Migrate data back to the reintegrated targets
- **Expand the pool size**
  - Add more nodes/devices to the system
  - Rebalance data within the pool
- **Online data rebalance**



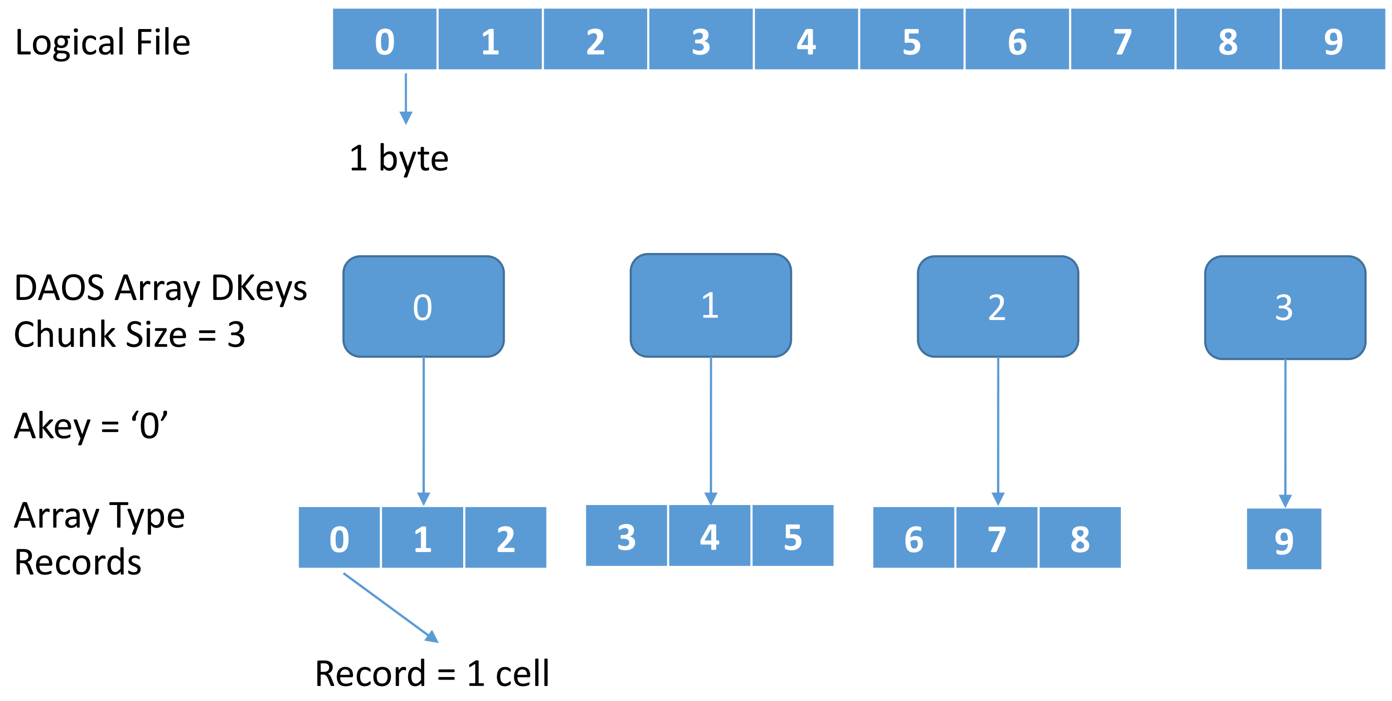
POSIX I/O SUPPORT

- **DAOS File System (libdfs)**
  - Encapsulated POSIX namespace
  - Application/framework can link directly with libdfs
    - ior/mdtest backend provided
    - MPI-IO driver leveraging collective open
    - TensorFlow, …
- **FUSE Daemon (dfuse)**
  - Transparent access to DAOS
  - Involves system calls
- **I/O interception library**
  - OS bypass for read/write operations



MPI-IO DRIVER FOR DAOS

- **The DAOS MPI-IO driver is implemented within the I/O library in MPICH (ROMIO)**
  - Added as an ADIO driver
  - Portable to Open-MPI, Intel MPI, etc.
  - Merged in upstream mpich
  - 1 MPI File = 1 DAOS Array Object

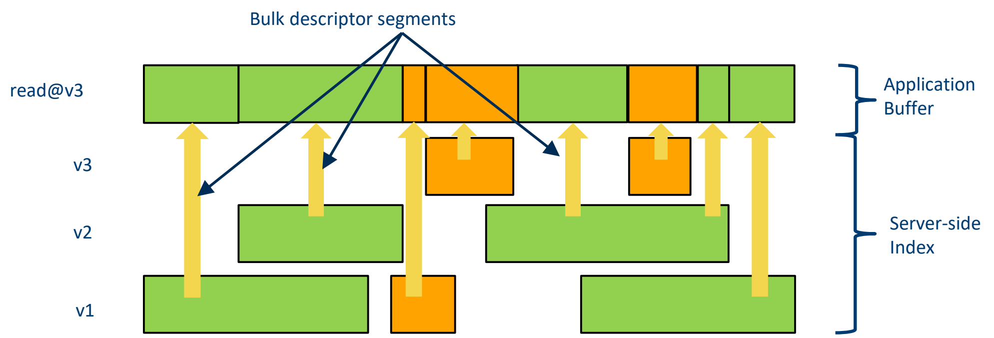


Application works seamlessly by just specifying the use of the driver by appending “daos:” to the path.

FINE-GRAINED I/O

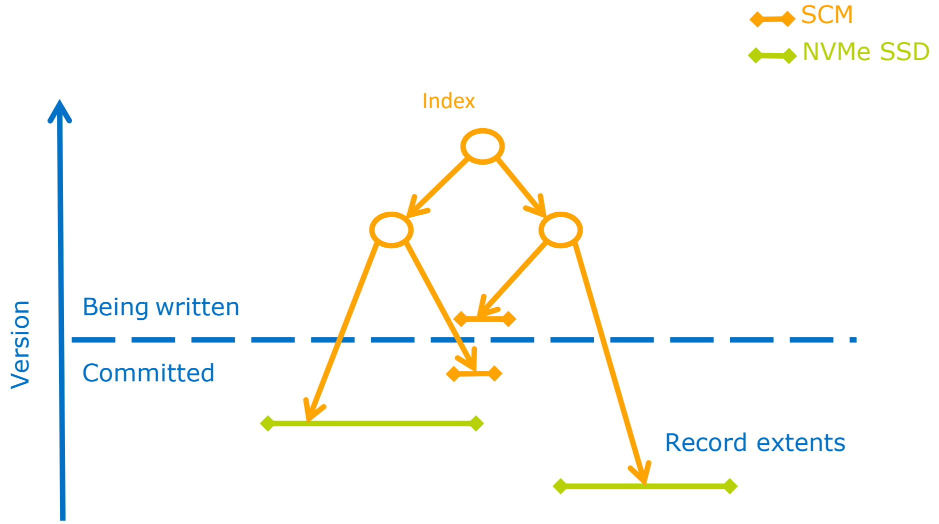
Mix of storage technologies

- **Storage Class Memory (AEP / Optane DC pmem)**
  - DAOS metadata & application metadata (6% min)
  - Byte-granular application data
- **NVMe SSD (*NAND, Optane SSDs)**
  - Cheaper storage for bulk data (e.g. checkpoints)
  - Multi-KB



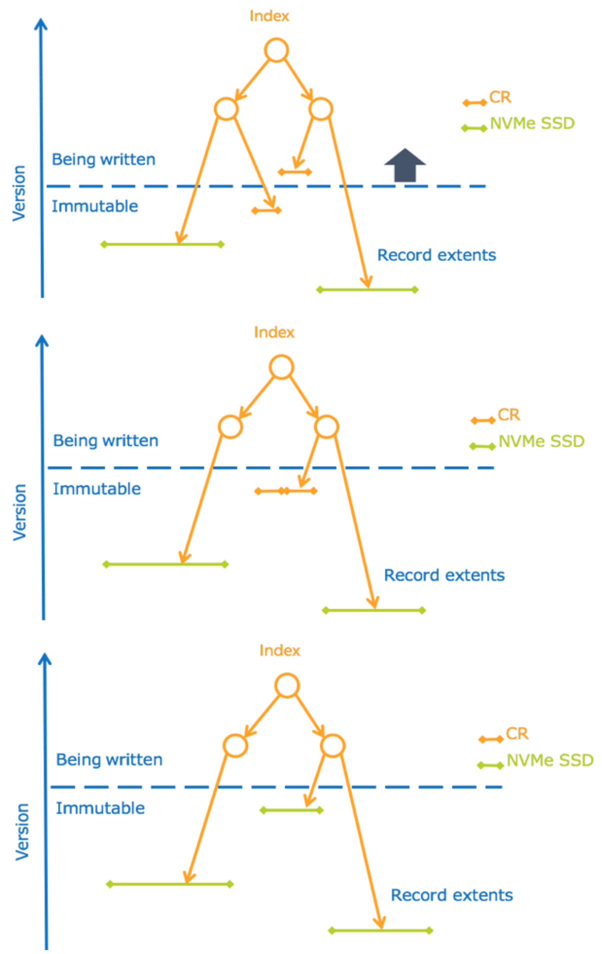
I/Os logged / inserted into persistent index

- **Non-destructive write & consistent read**
- **No alignment constraints**
- **No read-modify-write**

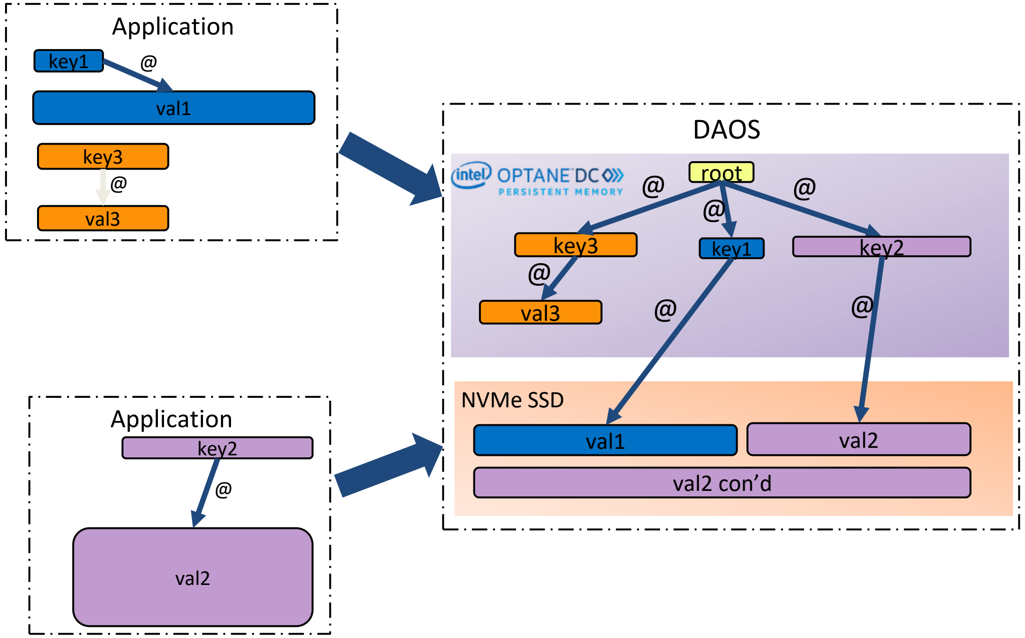


DATA AGGREGATION

- **Merge small extents in DCPMM, migrate to NVMe SSD**
- **Merge extents in NVMe SSD to larger extent**
- **Reclaim old snapshots**
  - Overwrites: delete old version
  - Punch/delete: delete whole subtree
- **EC aggregation**
  - Compute parities for partial writes



ADVANCED STORAGE MODEL



- **Native support for structured, semi-structured & unstructured data models**
  - Built on top of DCPMM
  - Unconstrained by POSIX serialization
  - Custom attributes
  - Data access time orders of magnitude faster (µs)
  - Scalable concurrent updates & high IOPS
  - Non-blocking
  - Enable in-storage computing