EXPLORING HIGH PERFORMANCE STORAGE WITH DAOS

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Aims

- Understand object storage hardware and software
- Learn about DAOS and filesystems on DAOS
- Learn about DAOS lower-level APIs and using them for your applications
- Get hands on with DAOS and high performance storage hardware
- Learn how to program, and design, for object storage systems

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Aims cont.

- Understand/think about your application data requirements
  - Both storage and discovery
- Thinking about different ways you undertake I/O or storing data
- Move beyond bulk, block-based, I/O paradigms

Format

- Lectures and practicals
- Slides and exercise material available online:
  - https://github.com/adrianjhpc/ObjectStoreTutorial
  - Exercises will be done on remote system (NEXTGenIO)
  - We will provide access for these

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Timetable

- 08.30 Introduction
- 08.40 Object storage and storage approaches
- 09.20 Practical: Benchmarking different storage approaches
- 09.30 DAOS programming APIs
- 10.00 Break
- 10.30 DAOS programming APIs, filesystems, and examples
- 11.30 Practical: Using DAOS for applications
- 11.50 Performance, design, and summary
- 12.00 Finish

Object Storage

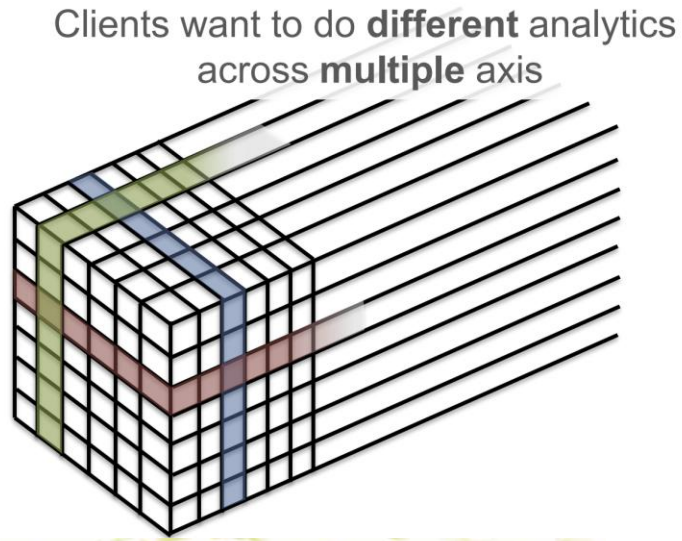
- Design and performance considerations are the challenge
  - Programming against the interfaces is (relatively) easy(ish)
  - Direct use often straight forward (i.e. filesystem interfaces)
  - More intelligent functionality takes more work/more specialised
- Design for functionality
  - When to store, when transactions should happen, what granularity I/O operations should be, what failures can you tolerate, etc..
- Design for performance
  - Memory size, I/O, data access costs, etc...

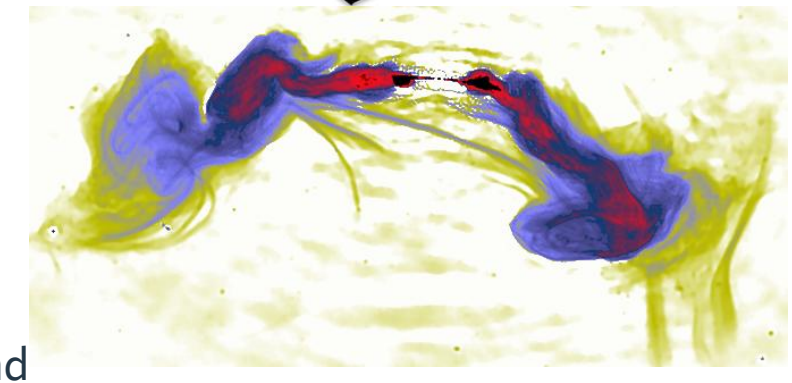
Object storage

- Data stored in unstructured objects
  - Data has identifier
  - Size and shape can vary
  - Metadata can also vary
- Originally designed for unstructured data sets
  - Bunch of data with no specific hierarchy required
- Can also enable efficient/fast access to data in different structures
  - Supports different creation, querying, analysis, and use patterns

Object storage

- Can enable efficient/fast access to data in different structures
  - Supports different creation, querying, analysis, and use patterns
- Granular storage with rich metadata
  - Data retrieval leverages metadata
  - **Build structure on the fly**
- Weather/climate
  - Pursuing optimal I/O for applications
    - Weather forecasting workflows
  - End-to-end workflow performance important
  - Simulation (data generation) only one part
    - Consumption workloads different layout/pattern from production
- Radio astronomy
  - Data collected and stored by antenna (frequency and location) and capture time
  - Reconstruction of images done in time order
  - Evaluation of transients or other phenomenon undertaken across frequency and location





Summary

- Please don't hesitate to ask questions!
- We have a practical sessions
  - Login account will remain active for you to try out using DAOS after the tutorial (not really enough time to finish them during the tutorial today)
  - Email a.jackson@epcc.ed.ac.uk to get an account on the system we will use for practical/try out sessions (if you use the subject "Object store account" that will help us respond to the emails)

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OBJECT STORES AND I/O APPROACHES

Hardware and Software interfaces

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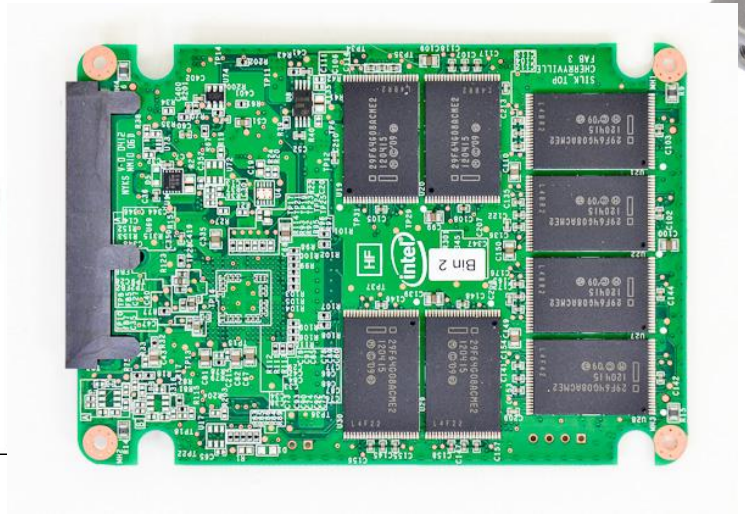
Storage



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Filesystems

- Lots of ways to store data on storage devices
- Filesystems have two components:
  - Data storage
  - Indexing
- Data stored in blocks
  - Chunks of data physically stored on hardware somewhere
- Indexing is used to associate names with blocks

  - File names are the index
  - Files may consist of many blocks
- Variable sized nature of files makes this a hard problem to solve

Filesystems

- Different ways of defining how inodes → blocks, and how directories, filenames, etc… are structured
  - As well as alternative approaches (i.e. log-structured filesystem)
  - Extended functionality (replication, distribution, backup, erasure coding, etc…)
- These are what differentiate filesystems, i.e.:
  - ext*: ext3, ext4
  - xfs
  - zfs
  - btrfs
  - etc…
- Maybe be important for performance or required functionality but the default can be used by most

Parallel filesystems

- Build on local filesystem but provide
  - Aggregated distributed local filesystem
  - Custom approach to define how inodes → blocks, and how directories, filenames, etc... are structured
  - Relaxed consistency (potentially) for concurrent writing
- i.e. Lustre:
  - Open-source parallel file system
  - Three main parts
    - Object Storage Servers (OSS)
      - Store data on one or more Object Storage Targets (OST)
      - The OST handles interaction between client data request and underlying physical storage
      - OSS typically serves 2-8 targets, each target a local disk system
      - Capacity of the file system is the sum of the capacities provided by the targets (roughly)
      - The OSS operate in parallel, independent of one another
    - Metadata Target (MDT)
      - One(ish) per filesystem
      - Storing all metadata: filenames, directories, permissions, file layout
      - Stored on Metadata Server (MDS)
  - Clients
    - Supports standard POSIX access

POSIX I/O

- Standard interface to files
  - Linux approach
  - Based on systems with single filesystem
  - open, close, write, read, etc...
- Does not support parallel or HPC I/O well
  - Designed for one active writer
  - Consistency requirements hamper performance
  - Has a bunch of functions that can impact performance, i.e. locking (flock, etc...)
- Some filesystems/approaches relax POSIX semantics to improve performance
  - Moving beyond filesystems allows other semantics to be targeted

Object storage

- Filesystems use Files
  - container for blocks of data
  - lowest level of metadata granularity (not quite true)
- Object stores use Objects
  - container for data elements
  - lowest level of metadata granularity
- Allows individual pieces of data to be:
  - Stored
  - Indexed
  - Accessed separately
- Allows independent read/write access to “blocks” of data

Object storage

- Generally restricted interface
  - Put: Create a new object
  - Get: Retrieve the object
- Removes the requirements for lots of functionality r.e. POSIX style I/O
- Traditionally objects are immutable
  - Once created cannot be changed
  - This removes the locking requirement seen for file writes
  - Makes updates similar to log-append filesystems, i.e. copy and update
  - Can cause capacity issues (although objects can be deleted)
- Object ID generated when created
  - Used for access
  - Can be used for location purposes in some systems

Object stores

- Often helper services and interfaces
  - Manage metadata
  - Permissions
  - Querying
  - Etc...
- Distribution and redundancy etc... part of the complexity
  - Often eventual consistency
- Lots of complexity in implementations
- Commonly use web interfaces as part of the Put/Get interface

S3 – Simple Storage Service

- AWS storage service/interface
  - Defacto storage interface for a range of object stores
- Uses a container model
  - Buckets contain objects
  - Buckets are the location point for data
  - Defined access control, accounting, logging, etc...
  - Bucket names have to be globally unique
- Buckets can be unlimited in size
  - Maximum object size is 5TB
  - Maximum single upload is 5GB
- A bucket has no object structure/hierarchy
  - User needs to define the logic of storage layout themselves (if there is any)
- Fundamental operations corresponding to HTTP actions:
  - http://bucket.s3.amazonaws.com/object
  - POST a new object or update an existing object.
  - GET an existing object from a bucket.
  - DELETE an object from the bucket
  - LIST keys present in a bucket, with a filter.

S3

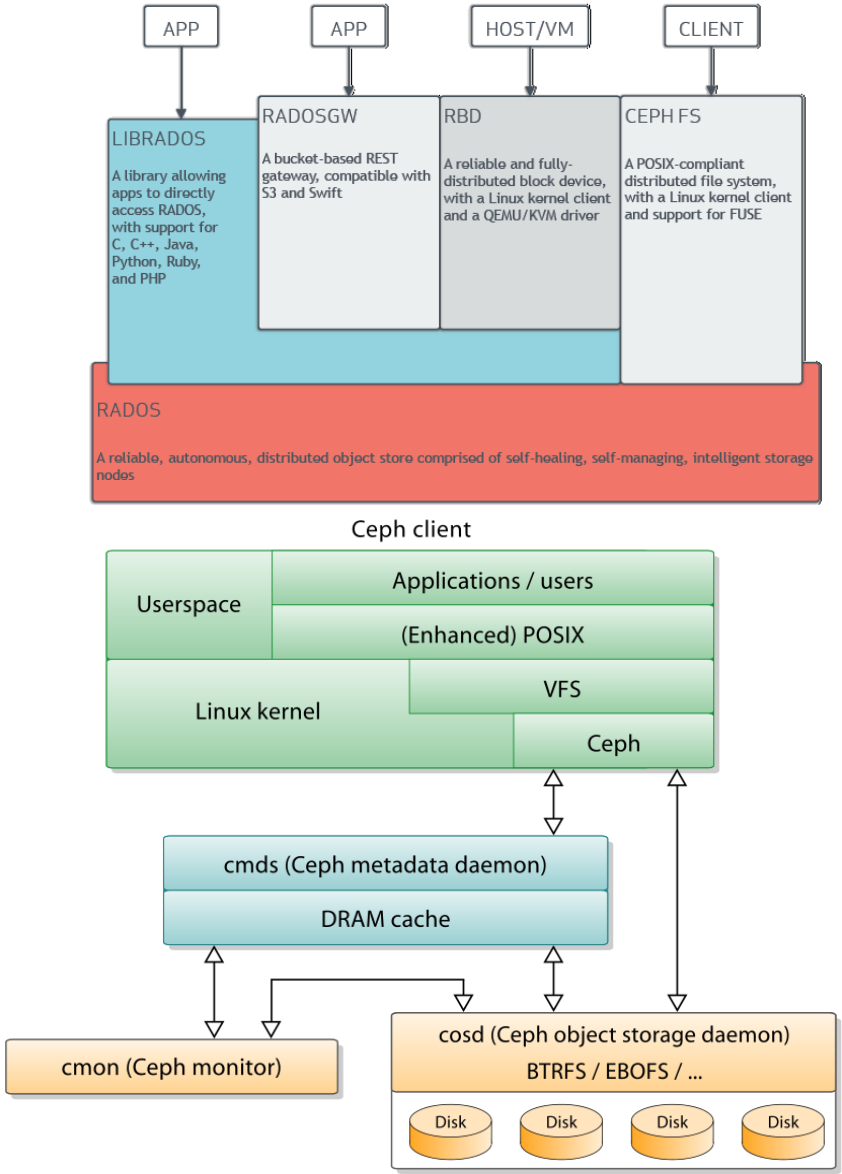
- Objects are combination of data and metadata
- Metadata is name – value pair (key) identifying the object
  - Default has some other information as well:
    - Date last modified
    - HTTP Content-Type
    - Version (if enabled)
    - Access Control List (if configured)
  - Can add custom metadata
- Data
  - An object value can be any sequence of bytes (up to 5TB)
  - Multi-part upload to create/update objects larger than 5GB (recommended over 100MB)

S3 Consistency Model

- Strong RAW (read after write) consistency
  - PUT (new and overwrite) and DELETE operations
  - READ on metadata also strong consistency
  - Across all AWS regions
- Single object updates are atomic
  - GET will either get fully old data or fully new data after update
  - Can't link (at the S3 level) key updates to make them atomic
- Concurrent writers are *racy*
  - No automatic locking
- Bucket operations are eventually consistent
  - Deleted buckets may still appear after the delete has occurred
  - Versioned buckets may take some time to setup up initially (15 minutes)

Ceph

- Widely used object store from academic storage project
- Designed to support multiple targets
  - Traditional object store: RadosGW → S3 or Swift
  - Block interface: RBD
  - Filesystem: Ceph FS
  - Lower-level object store: LibRados
- Distributed/replicated functionality
  - Scale out by adding more Ceph servers
  - Automatic replication/consistency
    - replication, erasure coding, snapshots and clones
- Supports striping
  - Has to be done manually if using librados
- Supports tiering
- Lacking production RDMA support



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NVRAM

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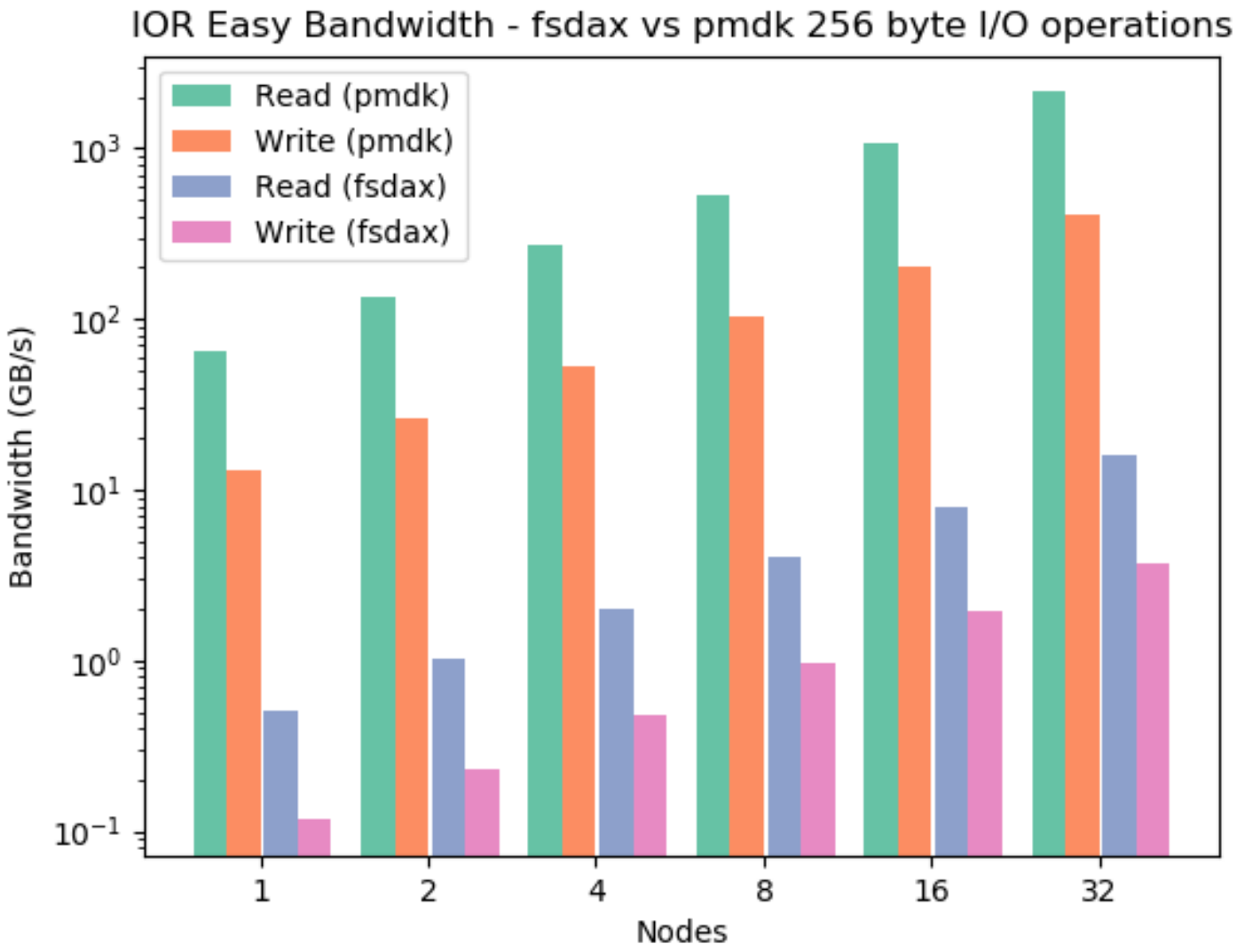
Optane



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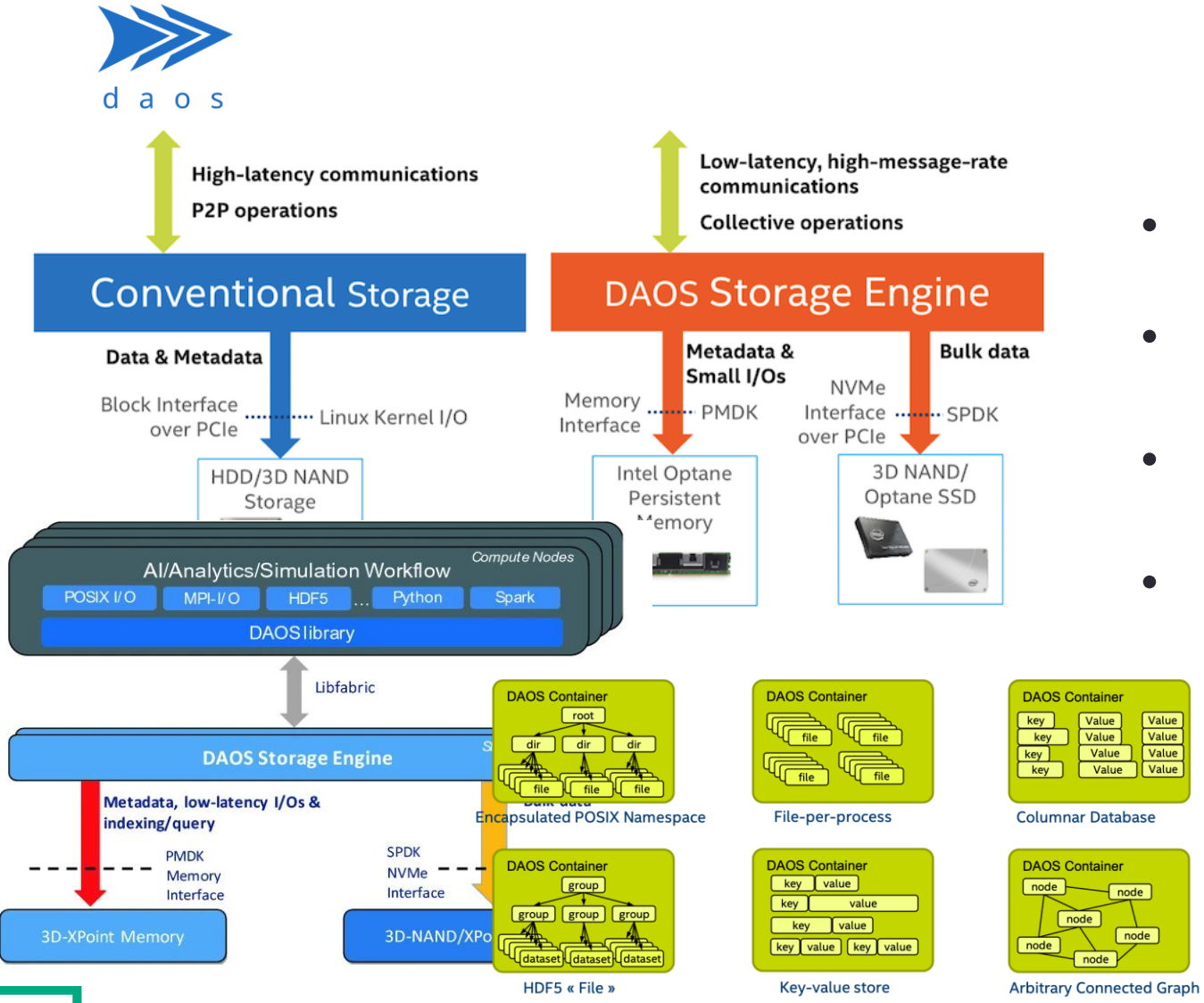

- Native object store on non-volatile memory and NVMe devices and designed for HPC
- Pools
  - Define hardware range of data
- Containers
  - User space and data configuration definitions
- Objects
  - **Multi-level key-array** API is the native object interface with locality
  - **Key-value** API provides a simple key and variable-length value interface. It supports the traditional put, get, remove and list operations.
  - **Array API** implements a one-dimensional array of fixed-size elements addressed by a 64-bit offset. A DAOS array supports arbitrary extent read, write and punch operations.

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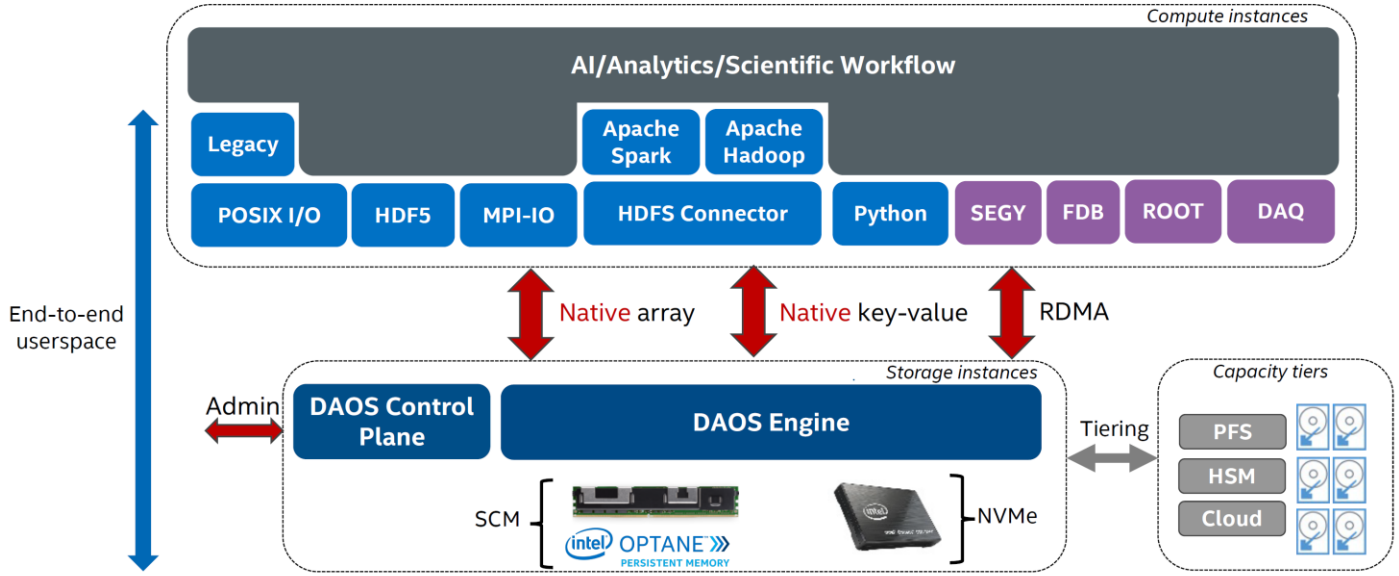
daos

- Range of storage interfaces
  - Native object store (libdaos)
  - Filesystem (various approaches)
  - Raw block device
  - MPI-I/O (ROMIO)
  - HDF5
  - PyDAOS
  - Spark/Hadoop
  - TensorFlow I/O
- DAOS systems built from DAOS servers
  - One per socket, has own NVMe and NVRAM
  - Scale system by adding more servers (in node or across nodes)
  - Metadata and data entirely distributed/replicated (no metadata centralisation)
  - RAFT-approach used for consensus across servers



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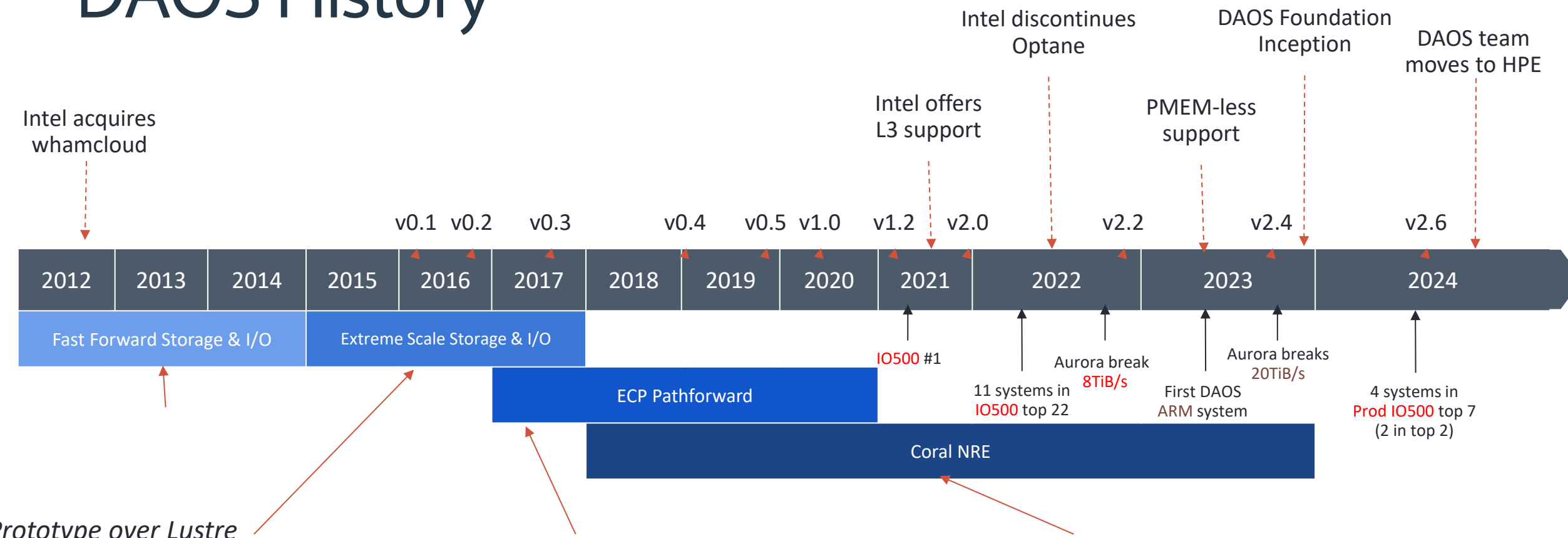
DAOS History



Prototype over Lustre

- Build over ZFS OSD
- DAOS API over Lustre

Standalone prototype

- OS-bypass
- Persistent memory via PMDK
- Replication & self healing

DAOS embedded on FPGA

- Disaggregated I/O
- Monitoring
- NVMe SSD support via SPDK

DAOS Productization for Aurora

- Hardening
- 10+ new features
- Support for extra AI/Big data frameworks

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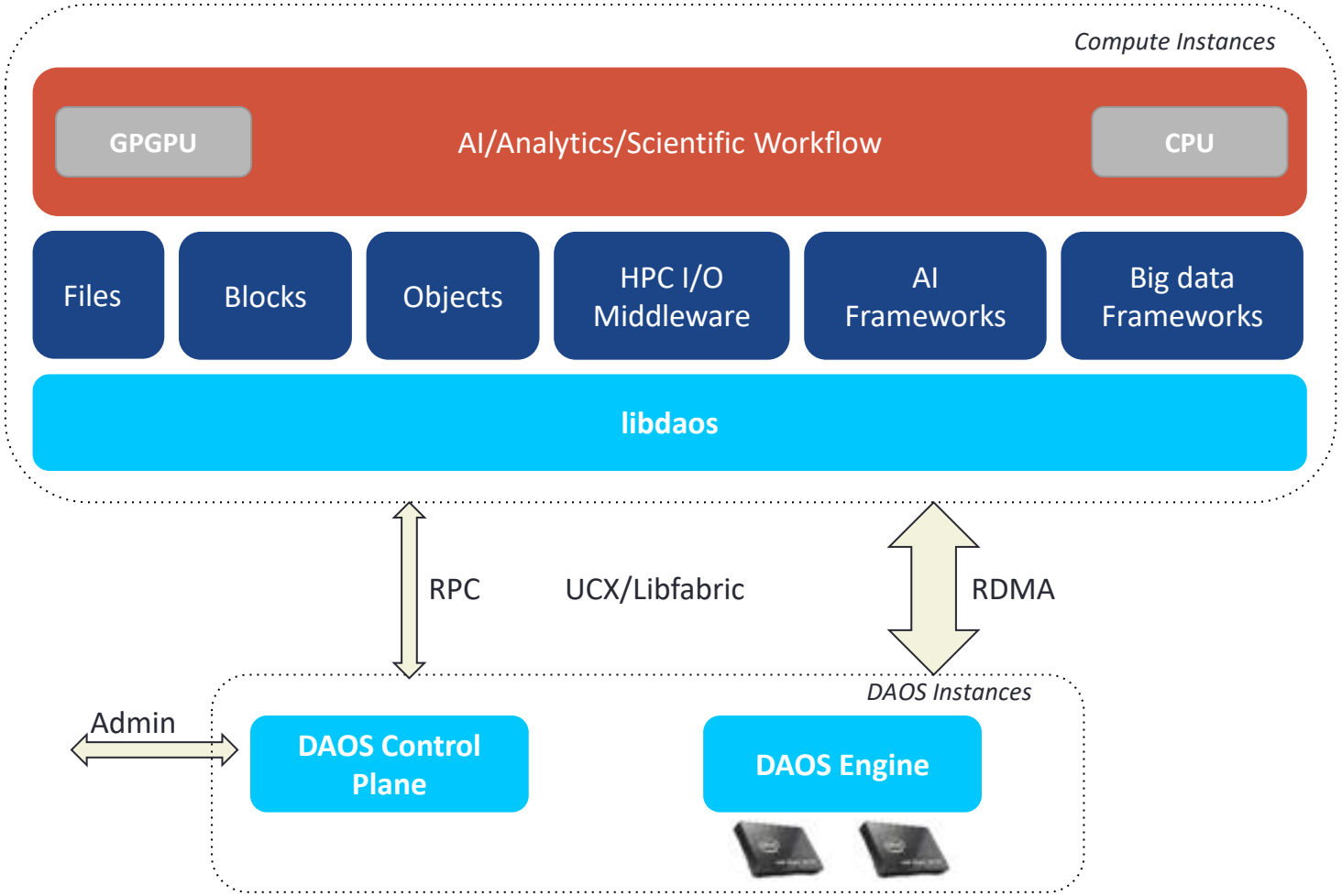
DAOS: Nextgen Open Storage Platform

- Platform for innovation
- Files, blocks, objects and more
- Full end-to-end userspace
- Flexible built-in data protection
  - EC/replication with self-healing
- Flexible network layer
- Efficient single server
  - O(100)GB/s and O(1M) IOPS per server
- Highly scalable
  - TB/s and billions IOPS of aggregated performance
  - O(1M) client processes
- Time to first byte in O(10) µs



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DAOS Design Fundamentals

- No read-modify-write on I/O path (use versioning)
- No locking/DLM
- No client tracking or client recovery
- No centralized (meta)data server
- No global object table
- Non-blocking I/O processing (futures & promises)
- Serializable distributed transactions
- Built-in multi-tenancy
- User snapshot

Scalability & Performance

High IOPS

Unique Capabilities

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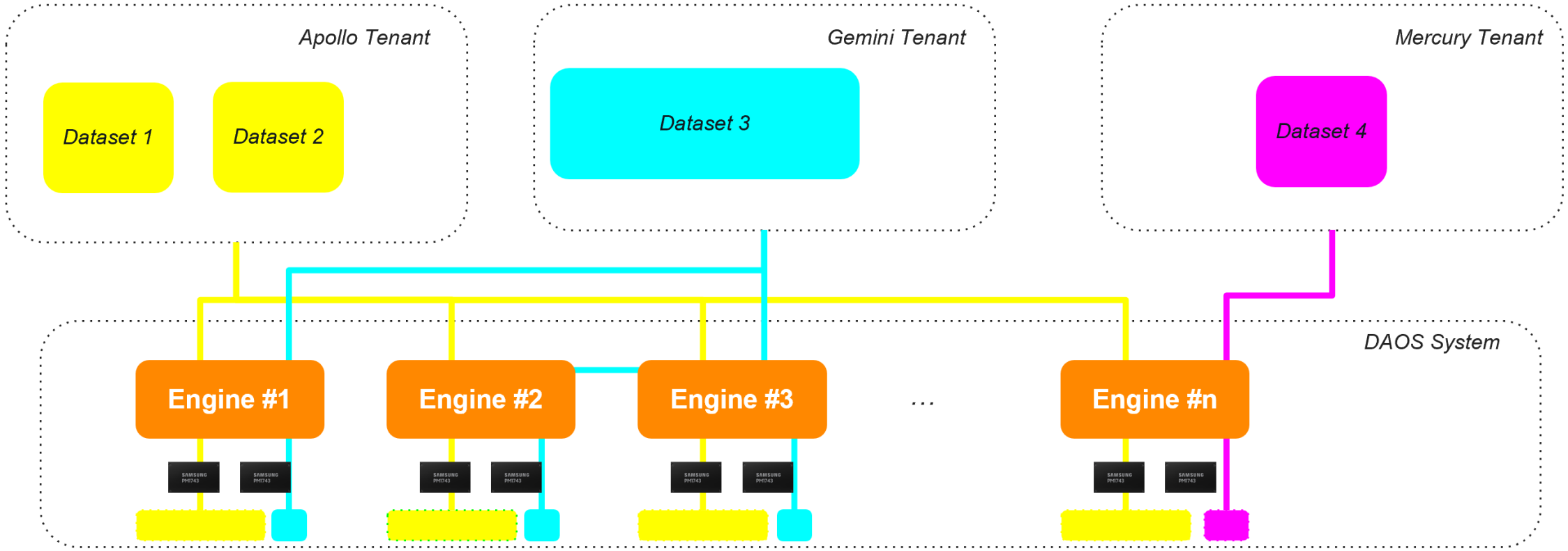
Flexibility in data space creation and operation



Pool 1	Apollo Tenant	100PB	20TB/s	200M IOPS
Pool 2	Gemini Tenant	10PB	2TB/s	20M IOPS
Pool 3	Mercury Tenant	30TB	80GB/s	2M IOPS

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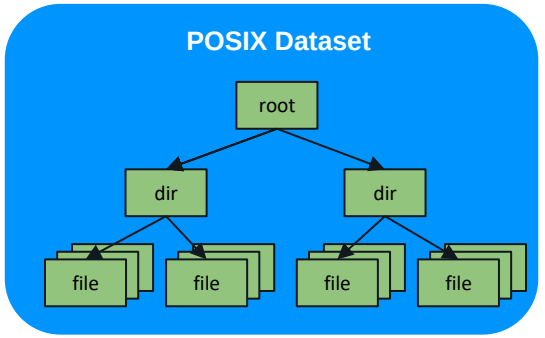
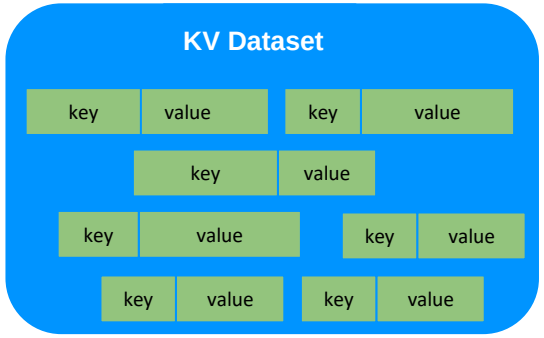
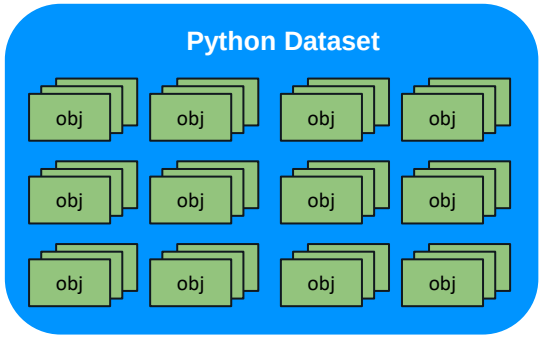
Beyond files

- New data model not based on files and file based approaches
- Introduce notion of dataset
- Basic unit of storage
- Datasets have a type
- POSIX datasets can include trillions of files/directories
- Advanced dataset query capabilities
- Unit of snapshots
- ACLs/IAM per dataset







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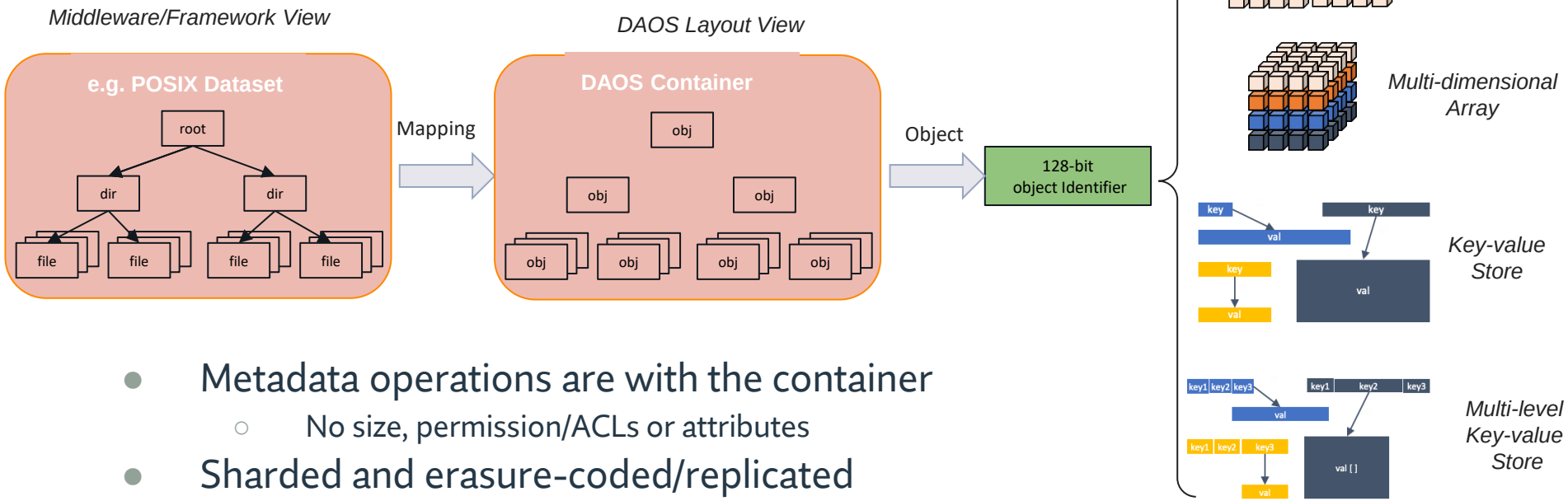
Objects

- Objects are the final level of storage for DAOS



  - Metadata operations are with the container
    - No size, permission/ACLs or attributes
  - Sharded and erasure-coded/replicated
  - Algorithmic object placement
  - Very short Time To First Byte (TTFB)

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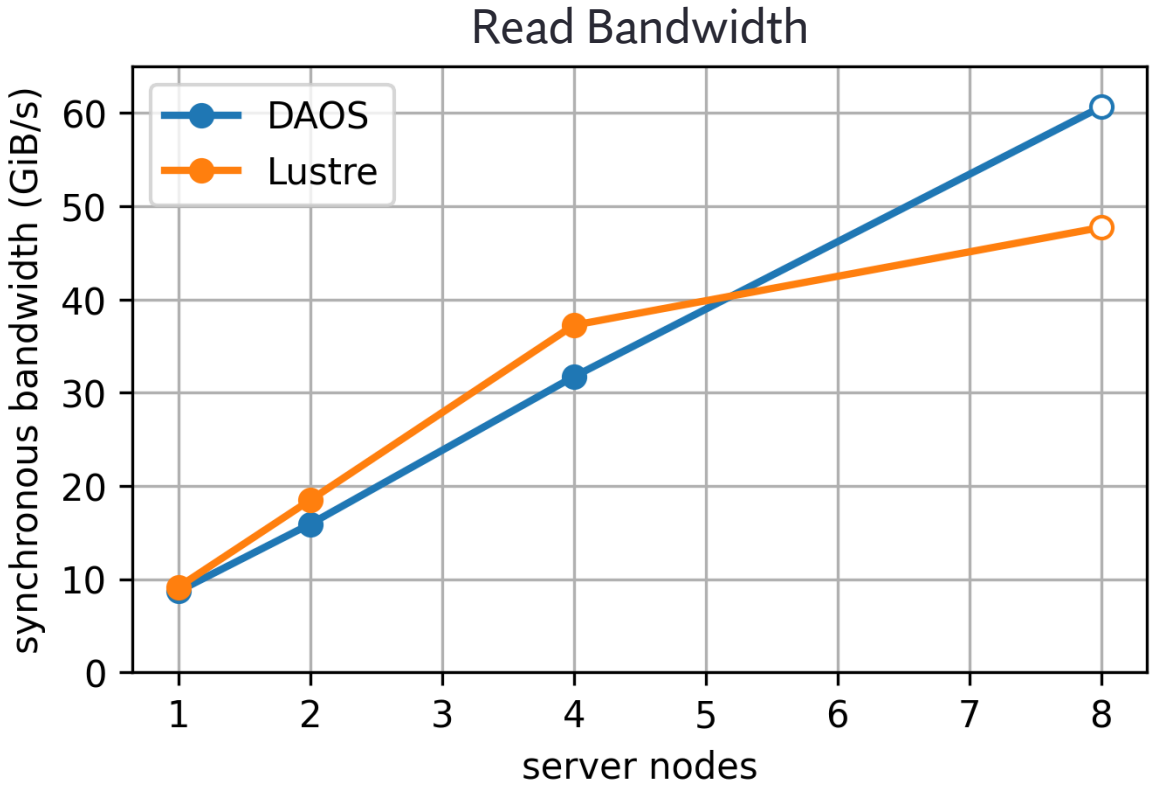
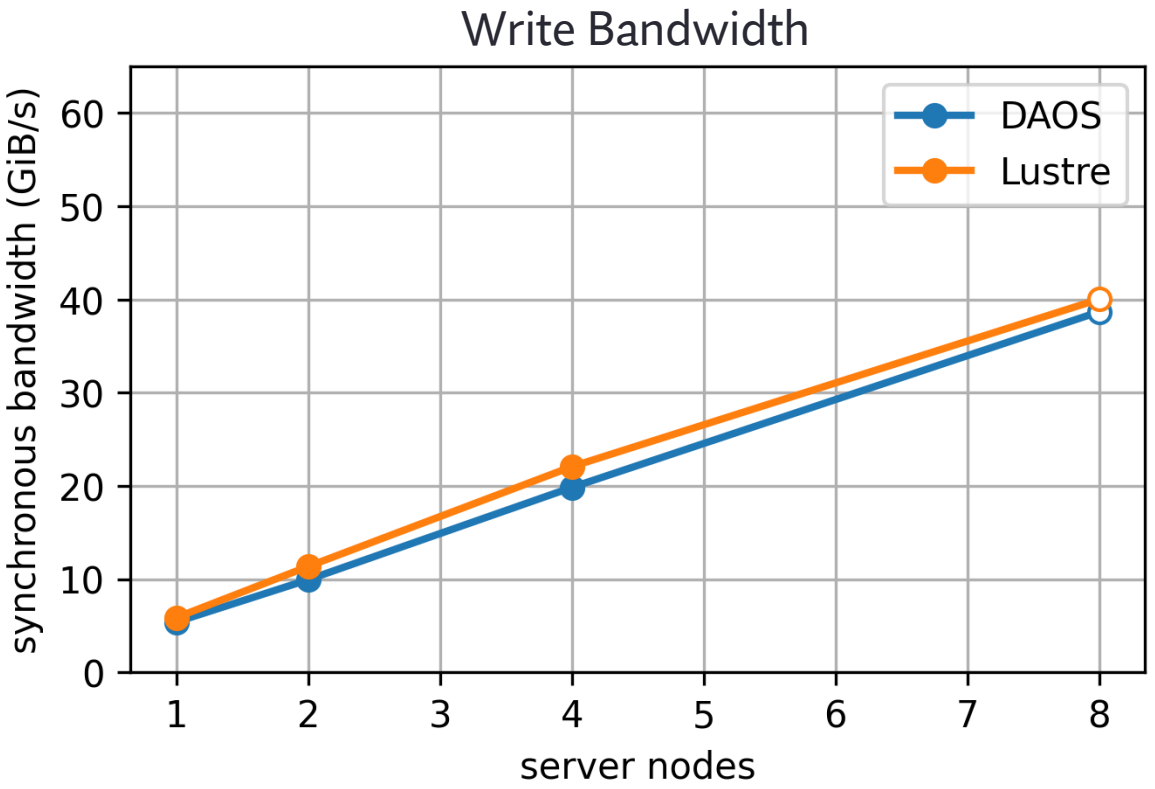
DAOS Performance

- Comparing Lustre and DAOS on the same hardware
  - IOR bulk synchronous I/O





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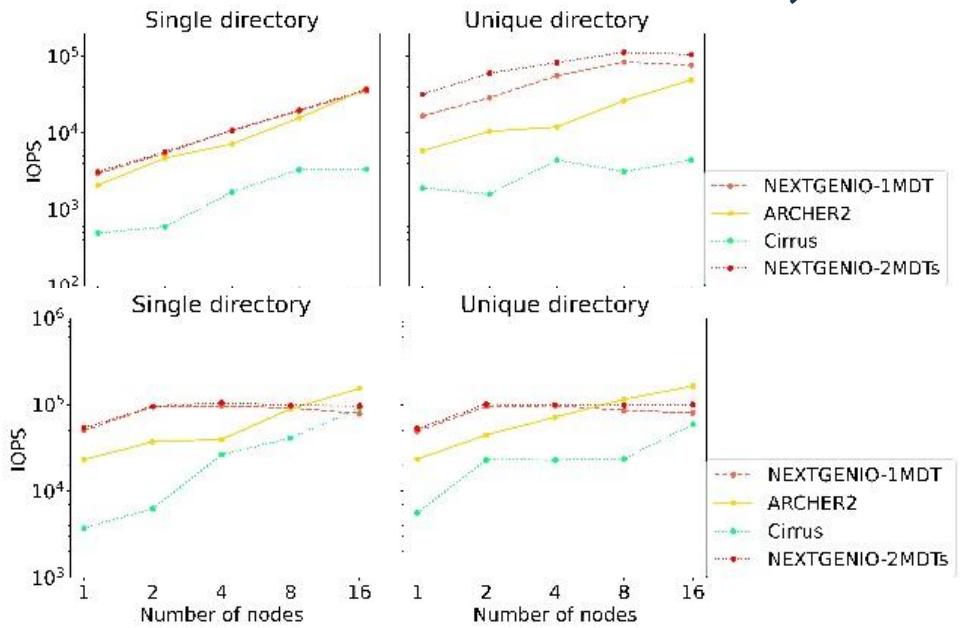
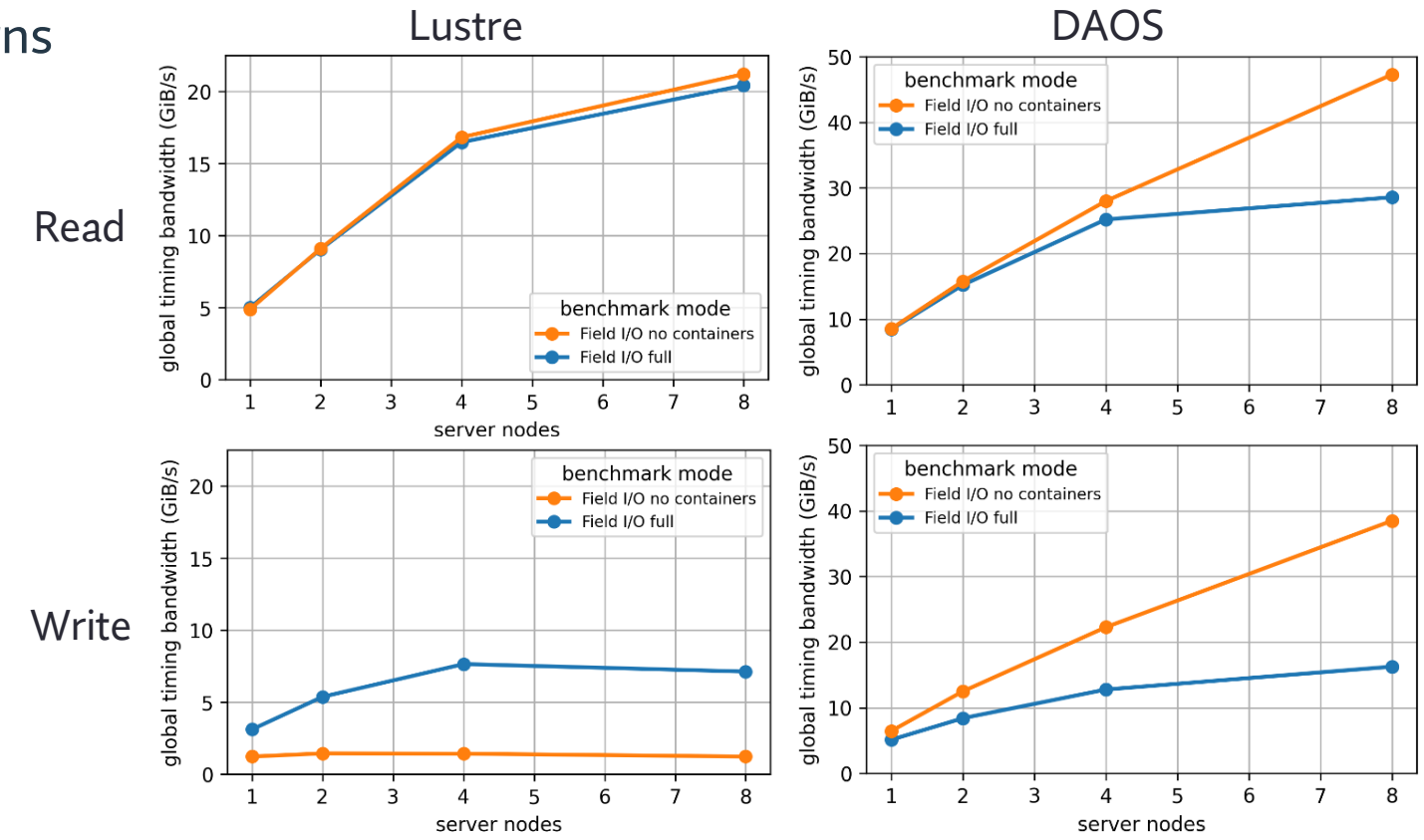
DAOS performance

- Separate read and write steps
  - More “object like” access patterns
  - Weather field -> Object or file





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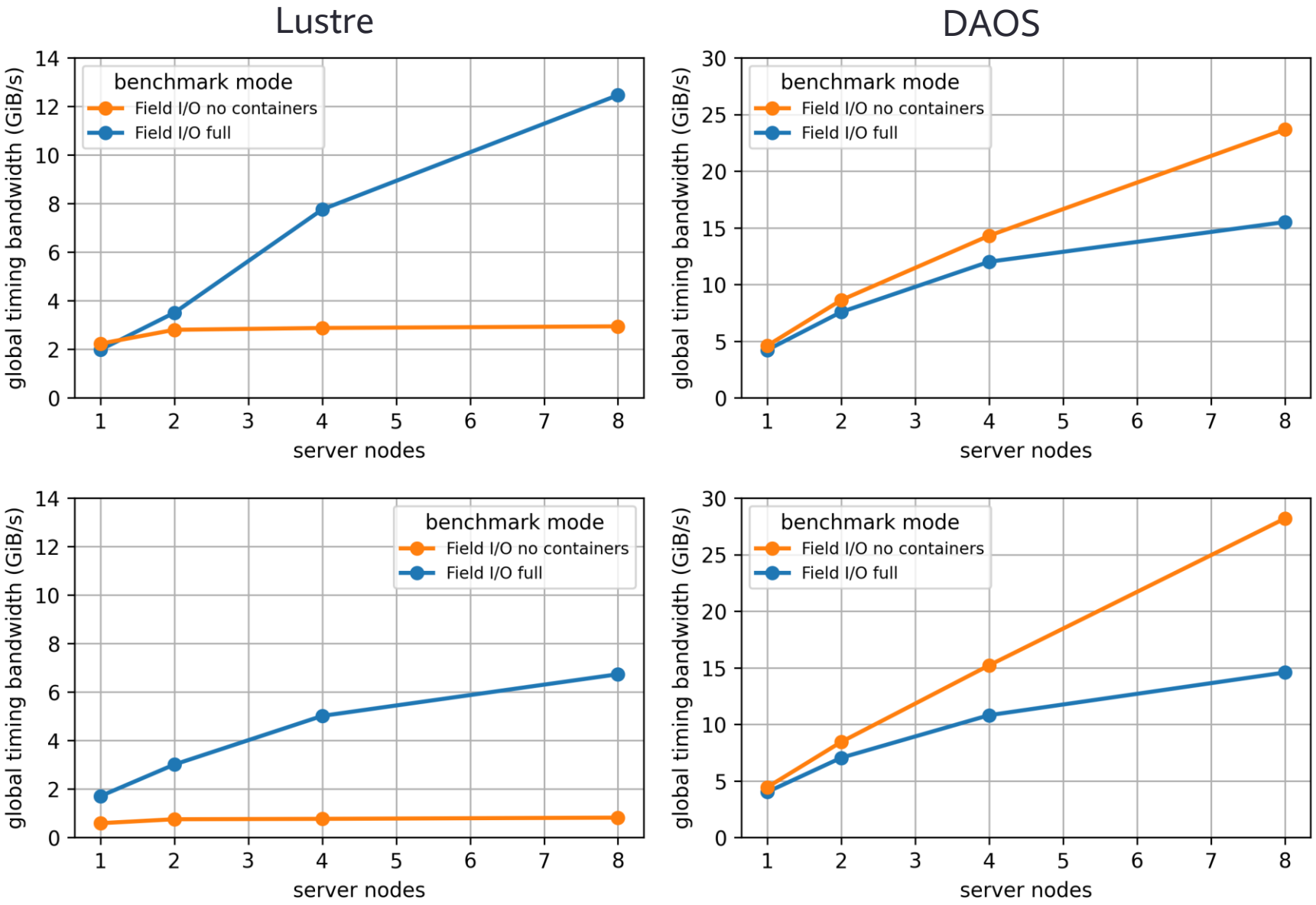
DAOS performance

- Contending read and write workers
  - Containers represent filesystem or object store structure



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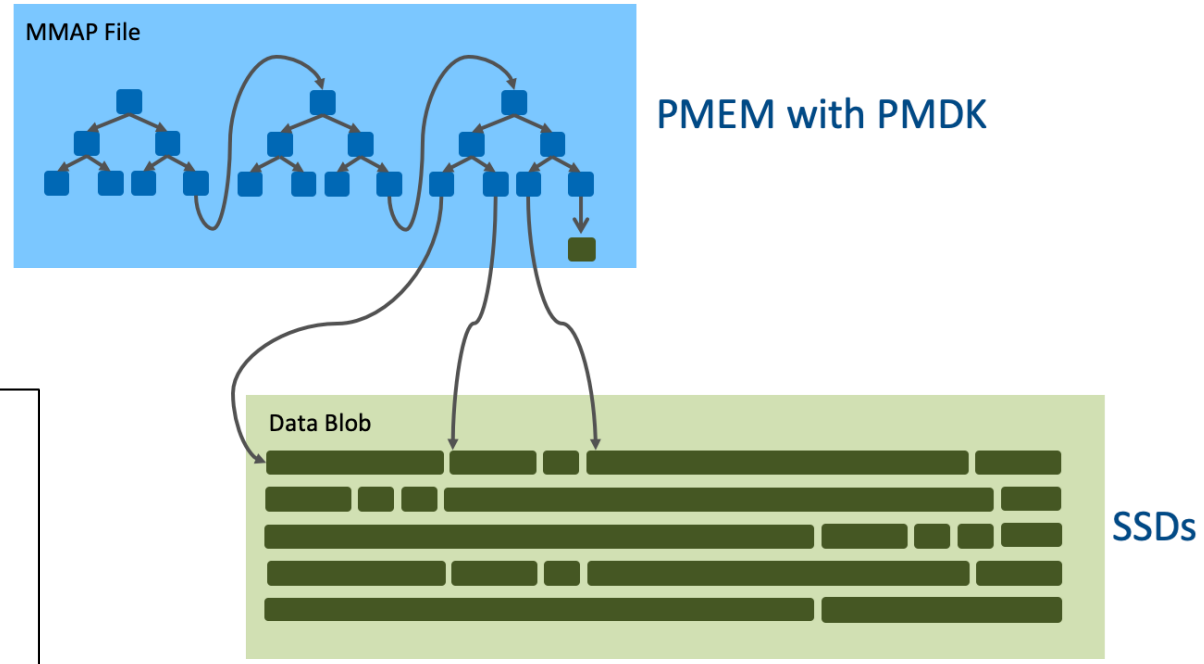
DAOS beyond NVRAM/Optane/PMem



- Persistent metadata
- Require Intel Optane PMEM (or NVDIMM-N)
- App Direct mode
- Mode used on Aurora

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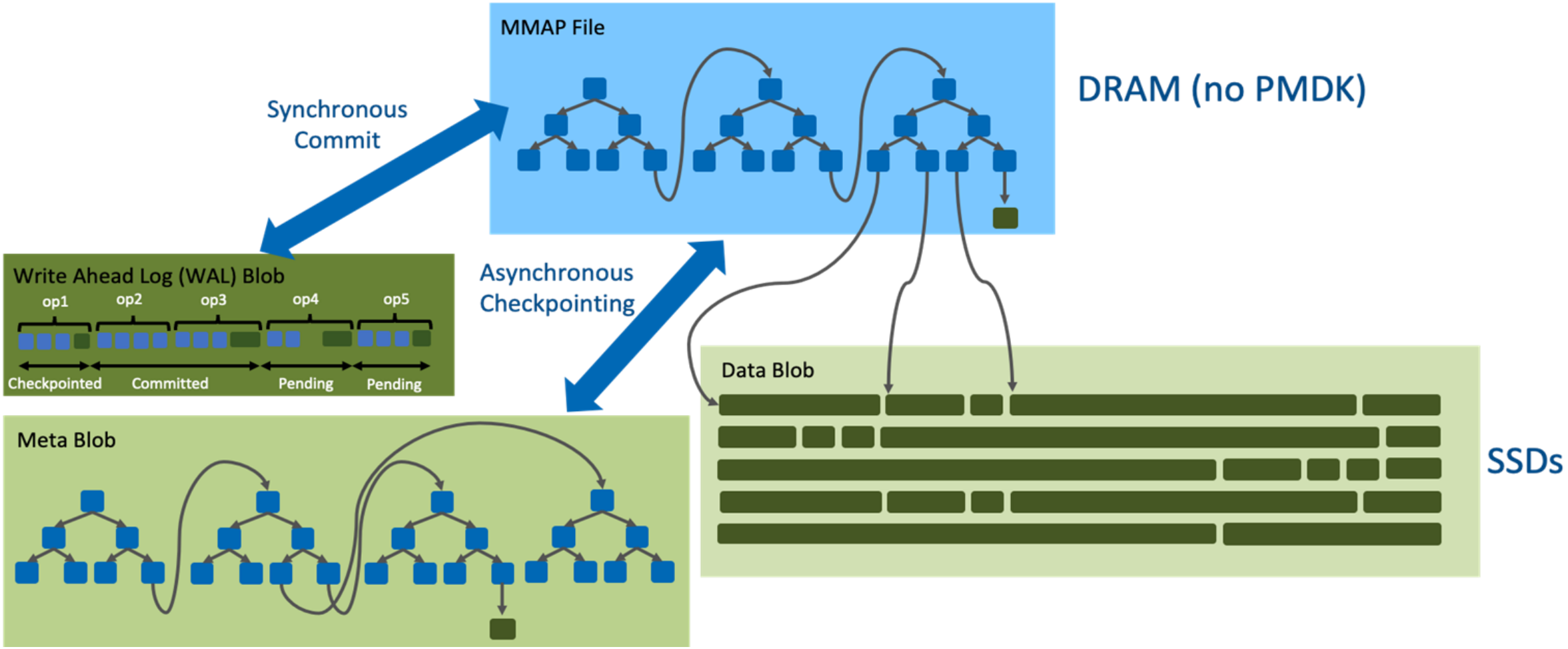
DAOS beyond NVRAM/Optane/PMem



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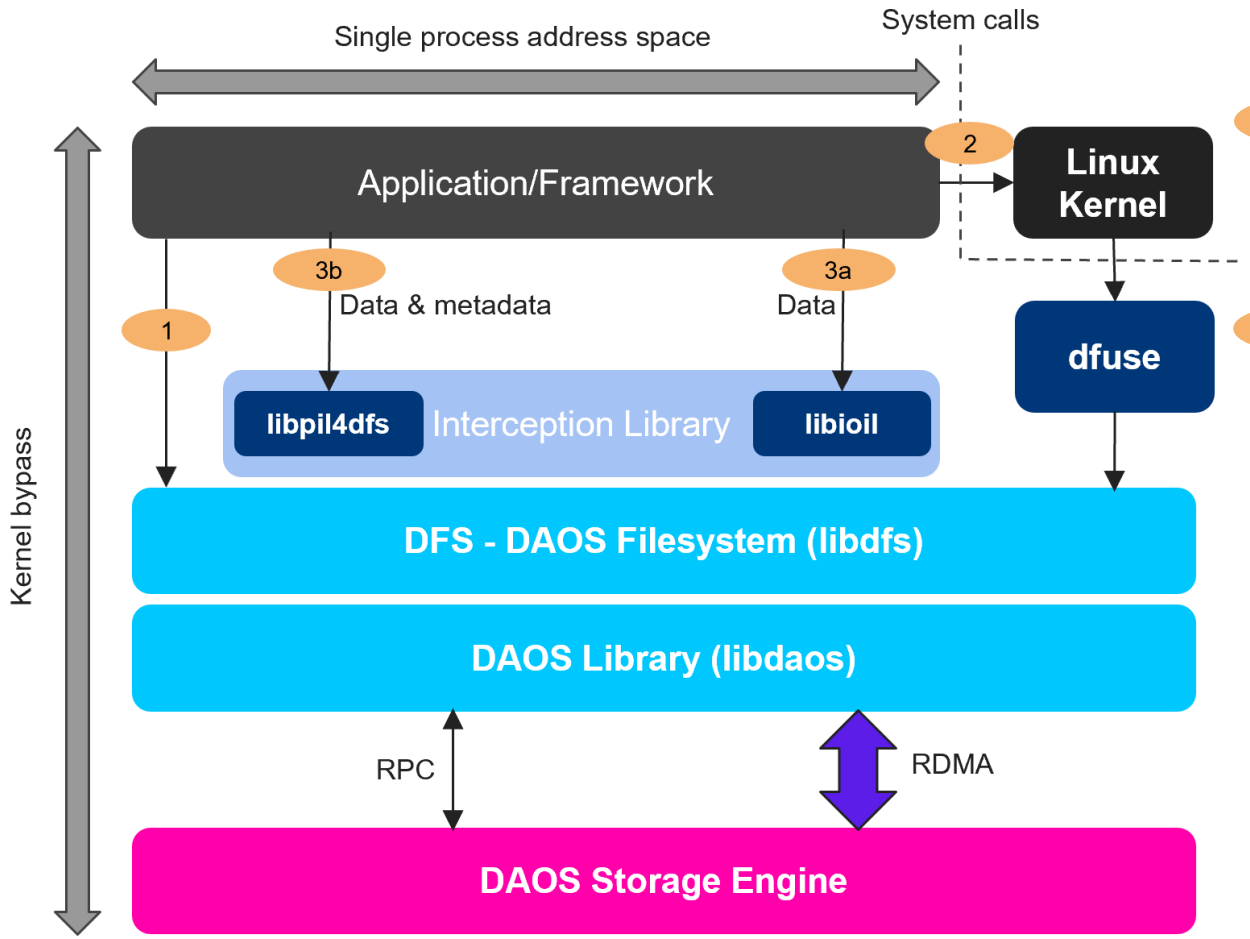
DAOS access approaches



1. Userspace DFS library with API like POSIX
   - **Require** application changes
   - Low latency & high concurrency
   - No caching
2. DFUSE daemon to support POSIX API
   - **No** application changes
   - VFS mount point & high latency
   - Caching by Linux kernel
3. DFUSE + Interception library
   - **No** application changes
   - 2 flavours using LD_PRELOAD
   - 3a libioil
     - (f)read/write interception
     - Metadata via dfuse
   - 3b libpil4dfs
     - Data & metadata interception
     - Aim at delivering same performance as #1 w/o any application change
     - mmap & binary execution via fuse

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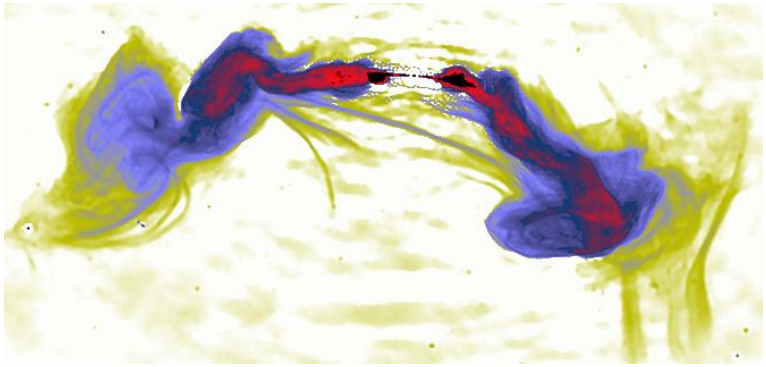
Object stores

- High performance object stores offer:
  - Server-side consistency by default
    - reducing round trip messaging for some operations
  - Distributed metadata functionality
    - no single performance bottleneck
  - Small object size performance
    - non-kernel space I/O operations so don't have interrupt/context switch performance issues
    - designed for faster hardware and for large scale operation
  - Decoupled metadata from data
  - In-built redundancy control/configuration
  - Multi-versioning and transactions to reduce contention/provide consistency tools
  - Scaling across storage resources
  - Searching/discovery across varying data dimensions

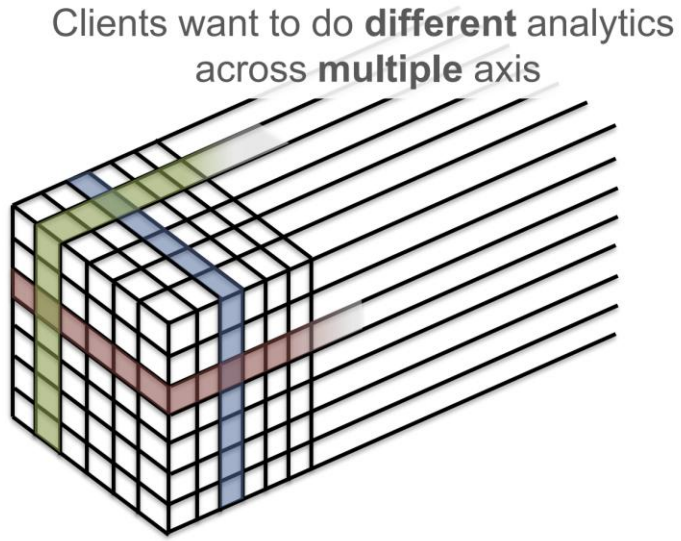
Object stores

- Object can have as much or as little complexity as you want
  - Single array
  - Single key-value
  - Nested object containing table of entries
  - etc..
- High performance object stores can't....
  - Beat filesystems for bulk I/O with low metadata overheads
  - Support high performance alternative functionality without porting effort
  - Eliminate server side contention
  - Fix poor storage design
  - Create your data layout and indexing for you
  - Fix configuration/resource issues

- Object Stores can unlock previously expensive I/O patterns



- Enable discovery as well as storage



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Practical Setup

- https://github.com/adrianjhpc/ObjectStoreTutorial/Exercises/exercisesheet.pdf
- Take IOR source code
- Run on the EPCC system
- SSH details will be sent
- You will get a username
  - ngguestXX
  - Password and key

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Tutorial on the DAOS API

Kenneth Cain, Mohamad Chaarawi, Jerome Soumagne HPE
Adrian Jackson (EPCC, The University of Edinburgh)

May 5, 2025

Presentation Outline

- Pools:
  - Connect, disconnect
- Containers:
  - Create, destroy, open, close
- Objects: access APIs based on type
  - Flat KVS
  - Global array
  - Multi-level KVS
- POSIX Support:
  - DFS API (for modified applications to use daos)
  - dfuse mount, interception libraries (for unmodified applications to use daos)
  - Best practices

DAOS API Usage, Program Flow

- Initialize DAOS stack
- Connect to a Pool
- Create / open a container
- Access an object in the container through the unique OID
  - Open object
  - update/fetch/list
  - Close object
- Close / disconnect from container & pool, finalize DAOS stack

Program Flow – Initialize DAOS, Connect to a Pool

- First (typically): initialize DAOS, connect to your pool:

```
int daos_init(void);
int daos_pool_connect(const char *pool, const char *sys,
      unsigned int flags, daos_handle_t *poh,
      daos_pool_info_t *info, daos_event_t *ev);
```

Note: pool already exists

Administrator used daos management utility "dmg" to create a pool – e.g.,

```
dmg pool create
--size=10TB mypool
```

- MPI program: connect from 1 rank, serialize handle, then share with MPI

```
int daos_pool_local2global(daos_handle_t poh, d_iov_t *glob)
int daos_pool_global2local(daos_handle_t poh, d_iov_t *glob)
```

- Last, disconnect from your pool, finalize DAOS:

```
int daos_pool_disconnect(daos_handle_t poh, daos_event_t *ev);
int daos_fini(void);
```

Program Flow – Initialize DAOS, Connect to a Pool

- First (typically): initialize DAOS, connect to your pool:

```
int daos_init(void);
int daos_pool_connect(const char *pool, const char *sys,
      unsigned int flags, daos_handle_t *poh,
      daos_pool_info_t *info, daos_event_t *ev);
```

- MPI program: connect from 1 rank, serialize handle, then share with MPI

```
int daos_pool_local2global(daos_handle_t poh, d_iov_t *glob)
int daos_pool_global2local(daos_handle_t poh, d_iov_t *glob)
```

- Last, disconnect from your pool, finalize DAOS:

```
int daos_pool_disconnect(daos_handle_t poh, daos_event_t *ev);
int daos_fini(void);
```

const char *pool: label string

daos_handle_t: opaque handle type
- "poh" - "pool open handle"
- "coh" – "container open handle"
- "oh" – "object open handle"

daos_pool_info_t:
- capacity, free space, (im)balance
- Health, rebuild state
- Also output by `daos_pool_query()`

d_iov_t:
- Refers to a contiguous app buffer

daos_event_t: (not covered here)
- Asynchronous API invoke/test

Program Flow – Create a Container

- Using the daos tool:

```
daos cont create mypool mycont
```

```
    Container UUID : 5d33d6e0-6c8b-4bf5-bb49-c8723bf30c91
    Container Label: mycont
    Container Type : unknown

  Successfully created container 5d33d6e0-6c8b-4bf5-bb49-c8723bf30c91
```

User admin tool 'daos'

API:
- input poh from pool_connect
- output coh

Container also has a label id string

daos_prop_t: properties
- Label
- Type (POSIX, HDF5, untyped)
- Redundancy Factor (RF)

- Using the API:

```
int daos_cont_create_with_label(daos_handle_t poh, const char *label,
      daos_prop_t *cont_prop, uuid_t *uuid, daos_event_t *ev);

int daos_cont_destroy(daos_handle_t poh, const char *cont, int force, /* ev */);
```

Program Flow – Access a Container

- Need to open a container to access objects in it:

```
int daos_cont_open(daos_handle_t poh, const char *cont,
       unsigned int flags, daos_handle_t *coh, daos_cont_info_t *info, /* ev */);
```

- MPI program: connect from 1 rank, serialize handle, then share with MPI:

```
int daos_cont_local2global(daos_handle_t poh, d_iov_t *glob)
int daos_cont_global2local(daos_handle_t poh, d_iov_t *glob)
```

- Close container when done:

```
int daos_cont_close(daos_handle_t coh, daos_event_t *ev);
```

daos_cont_info_t:

- Pool UUID
- Container UUID
- # container open handles
- Metadata open/close/modify times
- RF
- …
- Also output by `daos_cont_query()`

Program Flow – Recap

```c
#include <daos.h>
int main(int argc, char **argv)
{
        daos_handle_t   poh, coh;

        daos_init();
        daos_pool_connect("mypool", NULL, DAOS_PC_RW, &poh, NULL, NULL);
        daos_cont_create_with_label(poh, "mycont", NULL, NULL, NULL);
        daos_cont_open(poh, "mycont", DAOS_COO_RW, &coh, NULL, NULL);

        /** perform object I/O - presented next */

        daos_cont_close(coh, NULL);
        daos_pool_disconnect(poh, NULL);
        daos_fini();
        return 0;
}
```

DAOS Object IDs – Types and Classes

- DAOS Object Types:
  - DAOS Flat KV – Each item having 1 string key, 1 opaque value
    - Operations: put, get, list, remove
    - Entire value collocated on 1 target, and atomic update
  - DAOS ARRAY – 1D array of fixed-size value
    - Operations: read, write, get/set size
  - DAOS Multi-Level KV – lower-level API
    - Operations: update, fetch, list
    - Multi-level keys (distribution / attribute)
    - Different value types (single value, array w/ fine-grain update)
- Object ID 128-bit space:
  - Lower 96 bits set by user
    - Unique OID allocator available in API for convenience
  - Upper 32 bits set by daos. OID Embeds:
    - Object type
    - Object class (redundancy level and type – Replication, EC, None)

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Sample Object Types (`enum daos_otype_t`)

```
/** flat KV (no akey) with hashed dkey */
    DAOS_OT_KV_HASHED,
/** Array, attributes provided by user */
    DAOS_OT_ARRAY_ATTR,
/** multi-level KV with uint64 [ad]keys */
    DAOS_OT_MULTI_UINT64,
```

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    DAOS_OT_KV_HASHED,
/** Array, attributes provided by user */
    DAOS_OT_ARRAY_ATTR,
/** multi-level KV with uint64 [ad]keys */
    DAOS_OT_MULTI_UINT64,
```

Sample Object Classes (`daos_oclass_id_t`)

```
/* Explicit layout, no data protection
 * Examples: OC_S1, OC_S2, …, OC_S32, OC_SX
 * S1 : shards=1, S2 shards=2, SX shards=all tgts
 */

/* Replicated object (OC_RP_), explicit layout:
 * <number of replicas> G<redundancy groups>
 * Ex OC_RP_2G1, 2G2..32 2GX, 3G1..32 3GX, …
 * 2G1 : 2 replicas group=1
 * 3G2 : 3 replicas groups=2, ...
 * 6GX : 6 replicas, spread across all targets
 */

/* Erasure coded (OC_EC_), explicit layout:
 * <data_cells>P<parity_cells>G<redun_groups>
 * Ex: EC_8P2G1, EC_8P2G<2..32>, EC_8P2GX,
 *     EC_16P2G1, EC_16P2G<2..32>, EC_16P2GX,
 * - 8P2G2:   8+2 EC object, groups=2
 * - 16P2GX: 16+2 EC object, all targets in pool
 * - 2P1G1:   2+1 EC object, group=1
 * - 4P2G8:   4+2 EC object, groups=2
 */
```

DAOS Object IDs – Types and Classes

- Object ID 128-bit space (Lower 96 user; upper 32 daos):
  - Object type (e.g., KV, Array, Multi-Level KV)
  - Object class (Replication, EC, None)

```
int daos_obj_generate_oid(
        daos_handle_t coh,
        daos_obj_id_t *oid,
        enum daos_otype_t type,
        daos_oclass_id_t cid,
        daos_oclass_hints_t hints, uint32_t args);
```

```
daos_obj_id_t oid;
oid.hi = 0;
oid.lo = 1;
daos_obj_generate_oid(coh, &oid,
DAOS_OF_KV_HASHED, OC_RP_2GX, 0, 0);
```

Sample Object Types (`enum daos_otype_t`)

```
/** flat KV (no akey) with hashed dkey */
    DAOS_OT_KV_HASHED,
/** Array, attributes provided by user */
    DAOS_OT_ARRAY_ATTR,
/** multi-level KV with uint64 [ad]keys */
    DAOS_OT_MULTI_UINT64,
```

Sample Object Classes (`daos_oclass_id_t`)

```
/* Explicit layout, no data protection
 * Examples: OC_S1, OC_S2, …, OC_S32, OC_SX
 * S1 : shards=1, S2 shards=2, SX shards=all tgts
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 * <number of replicas> G<redundancy groups>
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 * 2G1 : 2 replicas group=1
 * 3G2 : 3 replicas groups=2, ...
 * 6GX : 6 replicas, spread across all targets
 */

/* Erasure coded (OC_EC_), explicit layout:
 * <data_cells>P<parity_cells>G<redun_groups>
 * Ex: EC_8P2G1, EC_8P2G<2..32>, EC_8P2GX,
 *     EC_16P2G1, EC_16P2G<2..32>, EC_16P2GX,
 * - 8P2G2:   8+2 EC object, groups=2
 * - 16P2GX: 16+2 EC object, all targets in pool
 * - 2P1G1:   2+1 EC object, group=1
 * - 4P2G8:   4+2 EC object, groups=2
 */
```

DAOS KV Object – Management Operations

- Recall: KV store interface providing access operations: Put, Get, Remove, List

- Management API:

```
int daos_kv_open(daos_handle_t coh, daos_obj_id_t oid,
       unsigned int mode, daos_handle_t *oh, daos_event_t *ev);

int daos_kv_close(daos_handle_t oh, daos_event_t *ev);

int daos_kv_destroy(daos_handle_t oh, daos_handle_t th, /* ev */);
```

KV: string key → opaque/atomic value

API:

- input coh from daos_cont_open()
- Input oid from daos_obj_generate_oid()
- output object handle (oh)

DAOS KV Object – Access Operations

- Access API:

```
int daos_kv_put(daos_handle_t oh, daos_handle_t th,
      uint64_t flags, const char *key,
      daos_size_t size, const void *buf, daos_event_t *ev);

int daos_kv_get(daos_handle_t oh, daos_handle_t th,
      uint64_t flags, const char *key,
      daos_size_t *size, void *buf, daos_event_t *ev);

int daos_kv_remove(daos_handle_t oh, daos_handle_t th,
      uint64_t flags, const char *key, daos_event_t *ev);

int daos_kv_list(daos_handle_t oh, daos_handle_t th, uint32_t *nr,
      daos_key_desc_t *kds, d_sg_list_t *sgl, daos_anchor_t *anchor, /* ev */);
```

API: input oh from kv_open()

Put/get/remove values (given string key)

List keys

- Key sizes in daos_key_desc_t *kds
- Key strings in sgl

DAOS KV Object – KV Conditional Operations

- By default, KV put/get operations do not check “existence” of key before operations:
  - Put(key): overwrites the value
  - Get(key): does not fail if key does not exist, just returns 0 size.
  - Remove(key): does not fail if key does not exist.

- One can use conditional flags for different behavior:
- `DAOS_COND_KEY_INSERT`: Insert a key if it doesn't exist (fail if it already exists)
- `DAOS_COND_KEY_UPDATE`: Update a key if it exists, (fail if it does not exist)
- `DAOS_COND_KEY_GET`: Get key value if it exists, (fail if it does not exist).
- `DAOS_COND_KEY_REMOVE`: Remove a key if it exists (fail if it does not exist).

DAOS KV Object – Put/Get Example

```
/** daos_init, daos_pool_connect, daos_cont_open */

oid.hi = 0;
oid.lo = 1;
daos_obj_generate_oid(coh, &oid, DAOS_OF_KV_HASHED, OC_RP_2GX, 0, 0);
daos_kv_open(coh, oid, DAOS_OO_RW, &kv, NULL);

/** set val buffer and size */
daos_kv_put(kv, DAOS_TX_NONE, 0, "key1", val_len1, val_buf1, NULL);
daos_kv_put(kv, DAOS_TX_NONE, 0, "key2", val_len2, val_buf2, NULL);

/** to fetch, can query the size first if not known */
daos_kv_get(kv, DAOS_TX_NONE, 0, "key1", &size, NULL, NULL);
get_buf = malloc (size);
daos_kv_get(kv, DAOS_TX_NONE, 0, "key1", &size, get_buf, NULL);
daos_kv_close(kv, NULL);

/** free buffer, daos_cont_close, daos_pool_disconnect, daos_fini */
```

DAOS KV Object – List Keys Example

```
/** enumerate keys in the KV */
daos_anchor_t   anchor = {0};
d_sg_list_t     sgl;
d_iov_t         sg_iov;

/** size of buffer to hold as many keys in memory */
buf = malloc(ENUM_DESC_BUF_BYTES);
d_iov_set(&sg_iov, buf, ENUM_DESC_BUF_BYTES);
sgl.sg_nr               = 1;
sgl.sg_nr_out           = 0;
sgl.sg_iovs             = &sg_iov;
```

```
daos_key_desc_t kds[ENUM_DESC_NR];

while (!daos_anchor_is_eof(&anchor)) {
  /** how many keys to attempt to fetch in one call */
  uint32_t        nr = ENUM_DESC_NR;


  memset(buf, 0, ENUM_DESC_BUF_BYTES);
  daos_kv_list(kv, DAOS_TX_NONE, &nr, kds, &sgl,
               &anchor, NULL);

  if (nr == 0)
    continue;
  /** buf now contains nr keys */
  /** kds[] has nr key descriptors (length keys) */
}
```

DAOS Array Object – Management Operations

- 1-Dimensional Array object to manage records
  - cell_size: single array value size (bytes)
  - chunk_size: number of cells placed together in a storage target –controls striping of array regions across storage cluster

- Management API:

```
int daos_array_create(daos_handle_t coh, daos_obj_id_t oid, daos_handle_t th,
      daos_size_t cell_size, daos_size_t chunk_size, daos_handle_t *oh, /* ev */);
int daos_array_open(daos_handle_t coh, daos_obj_id_t oid, daos_handle_t th,
      unsigned int mode, daos_size_t *cell_size,
      daos_size_t *chunk_size,daos_handle_t *oh, daos_event_t *ev);

int daos_array_close(daos_handle_t oh, daos_event_t *ev);

int daos_array_destroy(daos_handle_t oh, daos_handle_t th, daos_event_t *ev);
```

DAOS Array Object – Access Operations

- Reading & writing record to an Array:

```
int daos_array_read(daos_handle_t oh, daos_handle_t th, daos_array_iod_t *iod,
      d_sg_list_t *sgl, daos_event_t *ev);
int daos_array_write(daos_handle_t oh, daos_handle_t th, daos_array_iod_t *iod,
      d_sg_list_t *sgl, daos_event_t *ev);
```

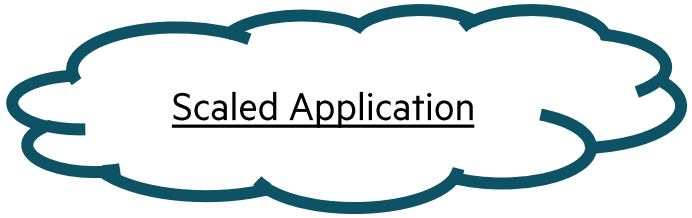
- Misc

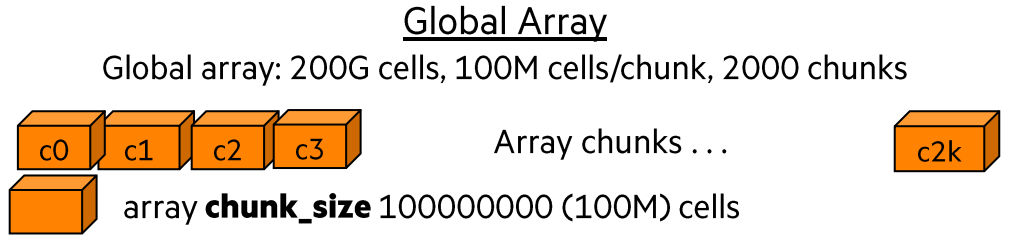
```
int daos_array_get_size(daos_handle_t oh, daos_handle_t th, daos_size_t *size, …);
int daos_array_set_size(daos_handle_t oh, daos_handle_t th, daos_size_t size, …);
int daos_array_get_attr(daos_handle_t oh, daos_size_t *chunk_size,
                        daos_size_t *cell_size);
```

DAOS Array Object – Example

```
/** create array - 1 byte/cell, NCELLS=100 million cells per chunk */
daos_array_create(coh, oid, DAOS_TX_NONE, 1, 100000000, &array, NULL);
```

`





DAOS Array Object – Example

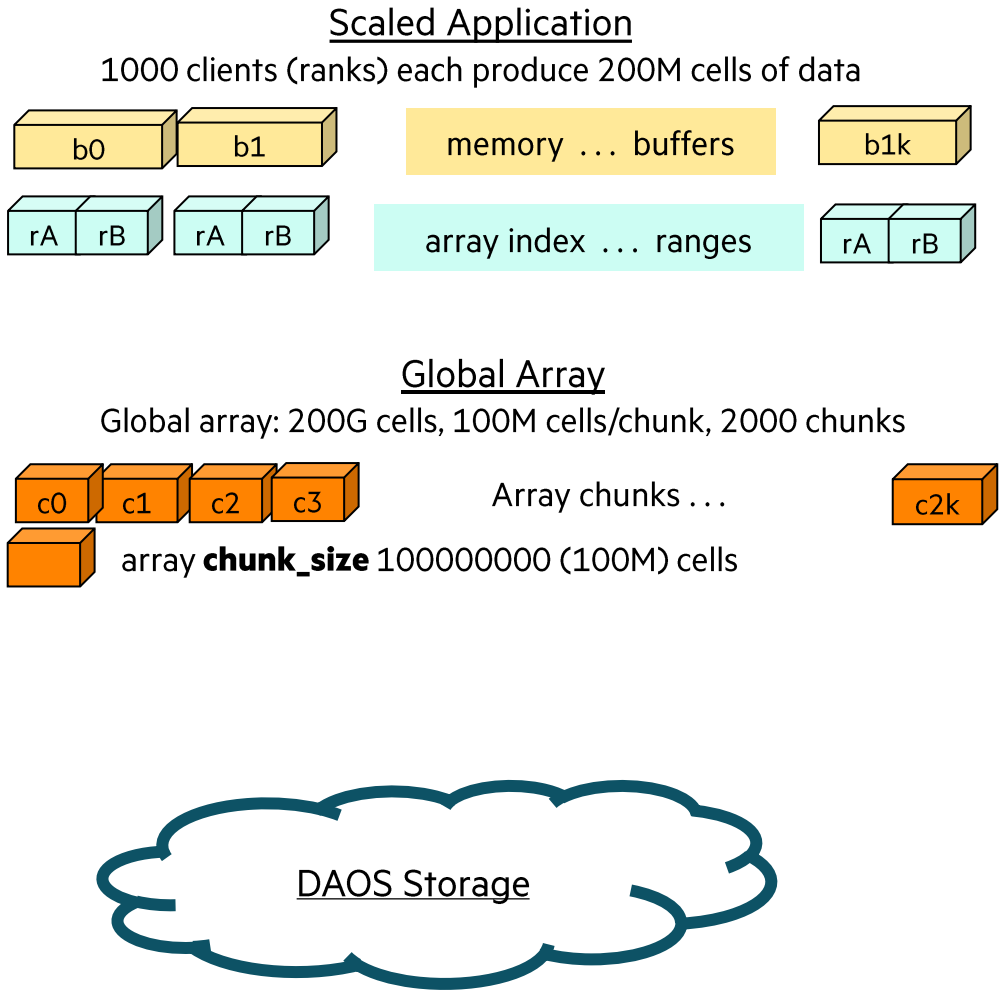
```
/** create array - 1 byte/cell, NCELLS=100 million cells per chunk */
daos_array_create(coh, oid, DAOS_TX_NONE, 1, 100000000, &array, NULL);

d_sg_list_t      sgl;    /* memory: scatter/gather list of iovecs */
d_iov_t          iov;    /* memory (iovec): 1 buffer (ptr, bytes) */
daos_array_iod_t iod;    /* array IO descriptor - array ranges */
daos_range_t     rgs[2]; /* array ranges(start index, num cells) */

/** set memory location, each rank writing BUFLEN */
sgl.sg_nr = 1;                  /** one memory buffer iovec */
d_iov_set(&iov, buf, BUFLEN); /** one buffer/ptr, BUFLEN=200M bytes */
sgl.sg_iovs = &iov;

/** specify this client's particular array (sub)ranges */
iod.arr_nr    = 2;                /** two array (sub)ranges */
iod.arr_rgs   = rgs;              /** the list of two ranges */
ra_start      = rank * NCELLS*2;  /** array ranges start indices */
rb_start      = ra_start + NCELLS;
rgs[0].rg_idx = ra_start;         /** (and rgs[1] from rb_start) */
rgs[0].rg_len = NCELLS;           /** length (and rgs[1] len=NCELLS) */
```

`



DAOS Array Object – Example

```
/** create array - 1 byte/cell, NCELLS=100,000,000 cells per chunk */
daos_array_create(coh, oid, DAOS_TX_NONE, 1, NCELLS, &array, NULL);

d_sg_list_t      sgl;    /* memory: scatter/gather list of iovecs */
d_iov_t          iov;    /* memory (iovec): 1 buffer (ptr, bytes) */
daos_array_iod_t iod;    /* array IO descriptor - array ranges */
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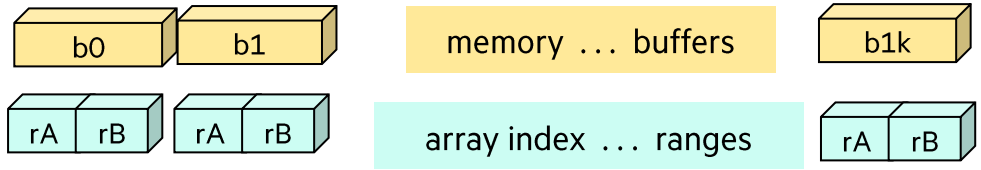
ra_start      = rank * NCELLS*2;  /** array ranges start indices */
rb_start      = ra_start + NCELLS;
rgs[0].rg_idx = ra_start;         /** (and rgs[1] from rb_start) */
rgs[0].rg_len = NCELLS;           /** length (and rgs[1] len=NCELLS) */

/** write array data to DAOS storage, and read back */
daos_array_write(array, DAOS_TX_NONE, &iod, &sgl, NULL);
daos_array_read(array, DAOS_TX_NONE, &iod, &sgl, NULL);
daos_array_close(array, NULL);
```

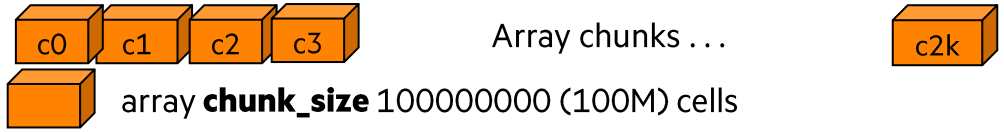
Scaled Application

1000 clients (ranks) each produce 200M cells of data



Global Array

Global array: 200G cells, 100M cells/chunk, 2000 chunks



DAOS Array Object – Example

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/** specify this client's particular array (sub)ranges */
iod.arr_nr    = 2;                /** two array (sub)ranges */
iod.arr_rgs   = rgs;              /** the list of two ranges */
ra_start      = rank * NCELLS*2;  /** array ranges start indices */
rb_start      = ra_start + NCELLS;
rgs[0].rg_idx = ra_start;         /** (and rgs[1] from rb_start) */
rgs[0].rg_len = NCELLS;           /** length (and rgs[1] len=NCELLS) */

/** write array data to DAOS storage, and read back */
daos_array_write(array, DAOS_TX_NONE, &iod, &sgl, NULL);
daos_array_read(array, DAOS_TX_NONE, &iod, &sgl, NULL);
daos_array_close(array, NULL);
```
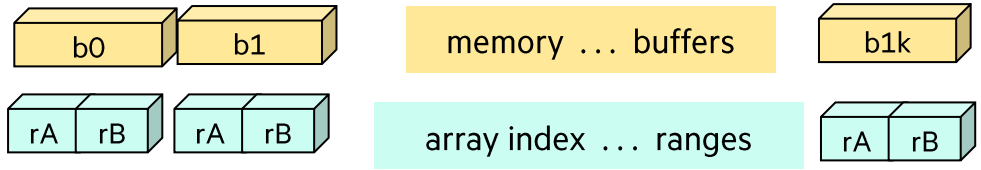

Scaled Application

1000 clients (ranks) each produce 200M cells of data



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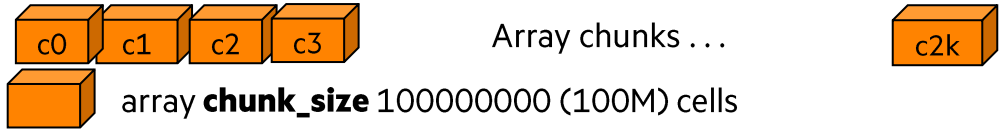
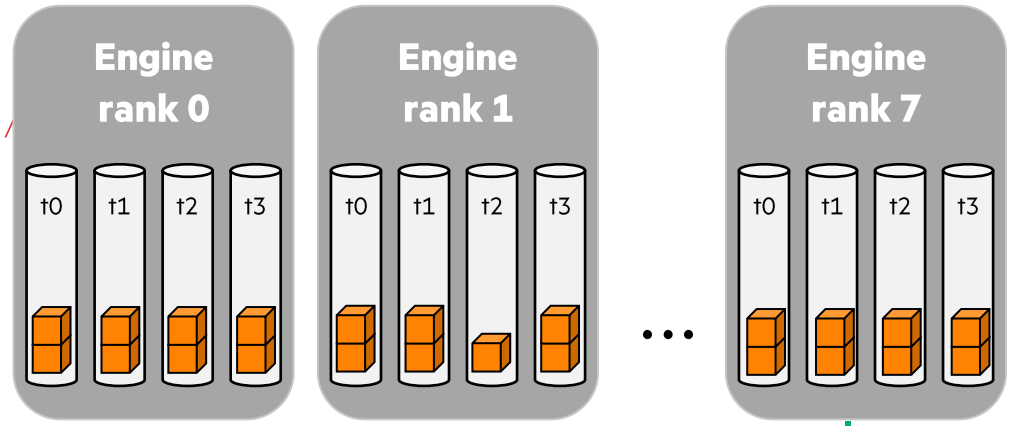


DAOS Storage

Stored in <num_daos_engines_in_pool> x tgts/daos_server

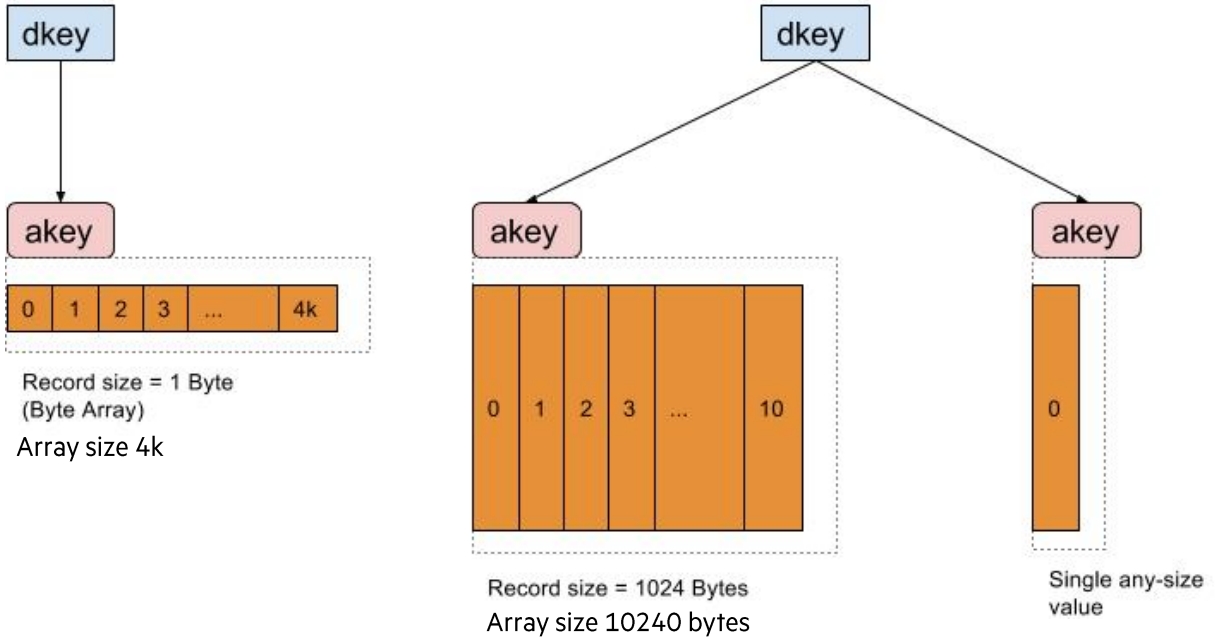
Ex: 8 servers x 4 tgts/server = 32 targets



Multi-Level KV Object

- Two-level key:
  - Distribution Key - Dkey (collocate all entries under it), holds multiple akeys
  - Attribute Key - Akey (lower level to address records)
  - Both are opaque (support any size / type)

- Value types (under a single akey):
  - Single value: one blob (traditional value in KV store)
  - Array value:
    - Array of fixed-size cells (records) that can be updated in a fine-grained manner via different range extents
    - This is different than a DAOS (global/distributed) array



- **Intentionally very flexible, rich API**
- **(at the expense of higher complexity for the typical user)**

Multi-Level KV Object – Management Operations

```
int daos_obj_open(daos_handle_t coh, daos_obj_id_t oid, unsigned int mode,
                  daos_handle_t *oh, daos_event_t *ev);
int daos_obj_close(daos_handle_t oh, daos_event_t *ev);

int daos_obj_punch(daos_handle_t oh, daos_handle_t th, uint64_t flags, /* ev */);
int daos_obj_punch_dkeys(daos_handle_t oh, daos_handle_t th, uint64_t flags,
                         unsigned int nr, daos_key_t *dkeys, daos_event_t *ev);
int daos_obj_punch_akeys(daos_handle_t oh, daos_handle_t th, uint64_t flags,
                         daos_key_t *dkey, unsigned int nr, daos_key_t *akeys, …);
```

API:

- input coh from daos_cont_open()
- Input oid from daos_obj_generate_oid()
- output object handle (oh)

Multi-Level KV Object – Access Operations (Update, Fetch)

```
int daos_obj_update(daos_handle_t oh, daos_handle_t th,
      uint64_t flags, daos_key_t *dkey, unsigned int nr,
      daos_iod_t *iods, d_sg_list_t *sgls, daos_event_t *ev);
```

```
daos_key_t iod_name;      /* akey */
daos_iod_type_t iod_type; /* value type (single value or array value) */
daos_size_t iod_size;     /* SV: value size, array: record size */
uint32_t iod_nr;          /* SV: 1, array: number of record extents */
daos_recx_t *iod_recxs;   /* SV: NULL, array: (offset, length) pairs */
      uint64_t rx_idx, rx_nr;
```

```
uint32_t sg_nr;
uint32_t sg_nr_out;
d_iov_t *sg_iovs;
```

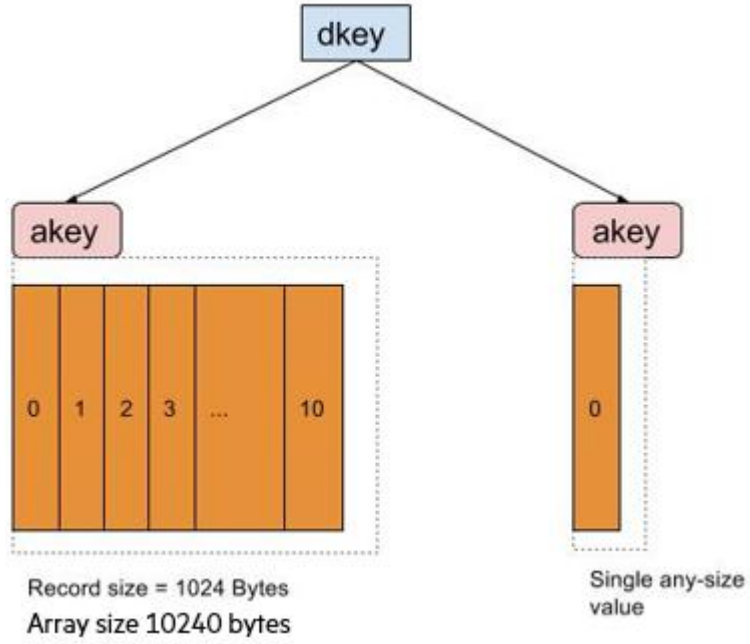
```
int daos_obj_fetch(daos_handle_t oh, daos_handle_t th, uint64_t flags,
      daos_key_t *dkey, unsigned int nr, daos_iod_t *iods,
      d_sg_list_t *sgls, daos_iom_t *ioms, daos_event_t *ev);
```

Multi-Level KV Object – Access Operations (List)

```
int daos_obj_list_dkey(daos_handle_t oh, daos_handle_t th, uint32_t *nr,
      daos_key_desc_t *kds, d_sg_list_t *sgl, daos_anchor_t *anchor,…);

int daos_obj_list_akey(daos_handle_t oh, daos_handle_t th,
      daos_key_t *dkey, uint32_t *nr, daos_key_desc_t *kds,
      d_sg_list_t *sgl, daos_anchor_t *anchor, daos_event_t *ev);
```

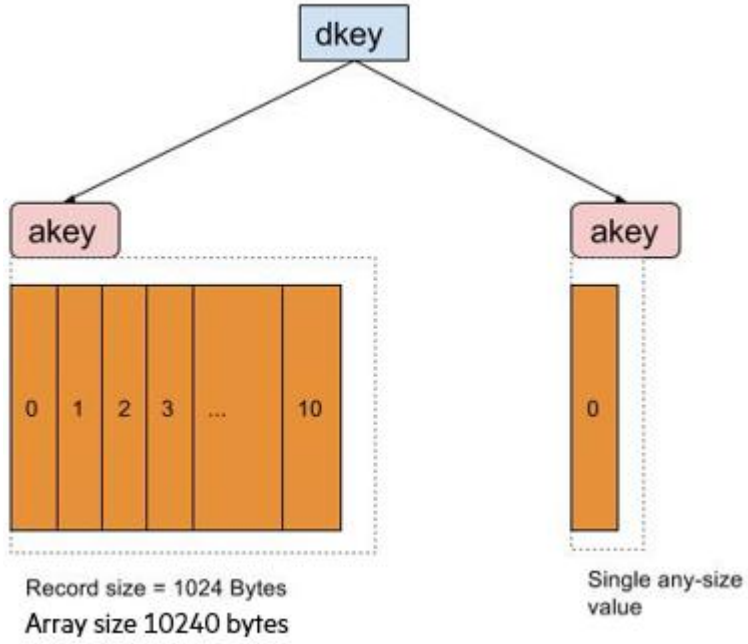
Multi-Level KV Object – Update Example

```
daos_obj_open(coh, oid, DAOS_OO_RW, &oh, NULL);

/* application buffers */
const char *buf2 = "single_value, my string";
d_iov_set(&sg_iovs[0], buf1, BUF1LEN);      /* 10240 byte array val: (dkey1,akey1) */
sgls[0].sg_nr = 1;
sgls[0].sg_iovs = &sg_iovs[0];
d_iov_set(&sg_iovs[1], buf2, strlen(buf2)); /* string val: (dkey1,akey2) */
sgls[1].sg_nr = 1;
sgls[1].sg_iovs = &sg_iovs[1];

/* keys */
d_iov_set(&dkey, "dkey1", strlen("dkey1"));
d_iov_set(&iods[0].iod_name, "akey1", strlen("akey1"));
d_iov_set(&iods[1].iod_name, "akey2", strlen("akey2"));

/* IODs for each akey */
iods[0].iod_type = DAOS_IOD_ARRAY;
iods[0].iod_size = 1;                   /* 1 byte/array cell */
recx.rx_idx = 0;                        /* array index range (0, BUF1LEN) */
recx.rx_nr = BUF1LEN;
iods[0].iod_nr = 1;
iods[0].iod_recxs = &recx;
iods[1].iod_type = DAOS_IOD_SINGLE;
iods[1].iod_size = strlen(buf2);
iods[1].iod_nr = 1;                     /* iod_recxs=NULL for SV */

daos_obj_update(oh, DAOS_TX_NONE, 0, &dkey, 2, &iods[0], &sgls[0], NULL);
```



Multi-Level KV Object – Fetch Example

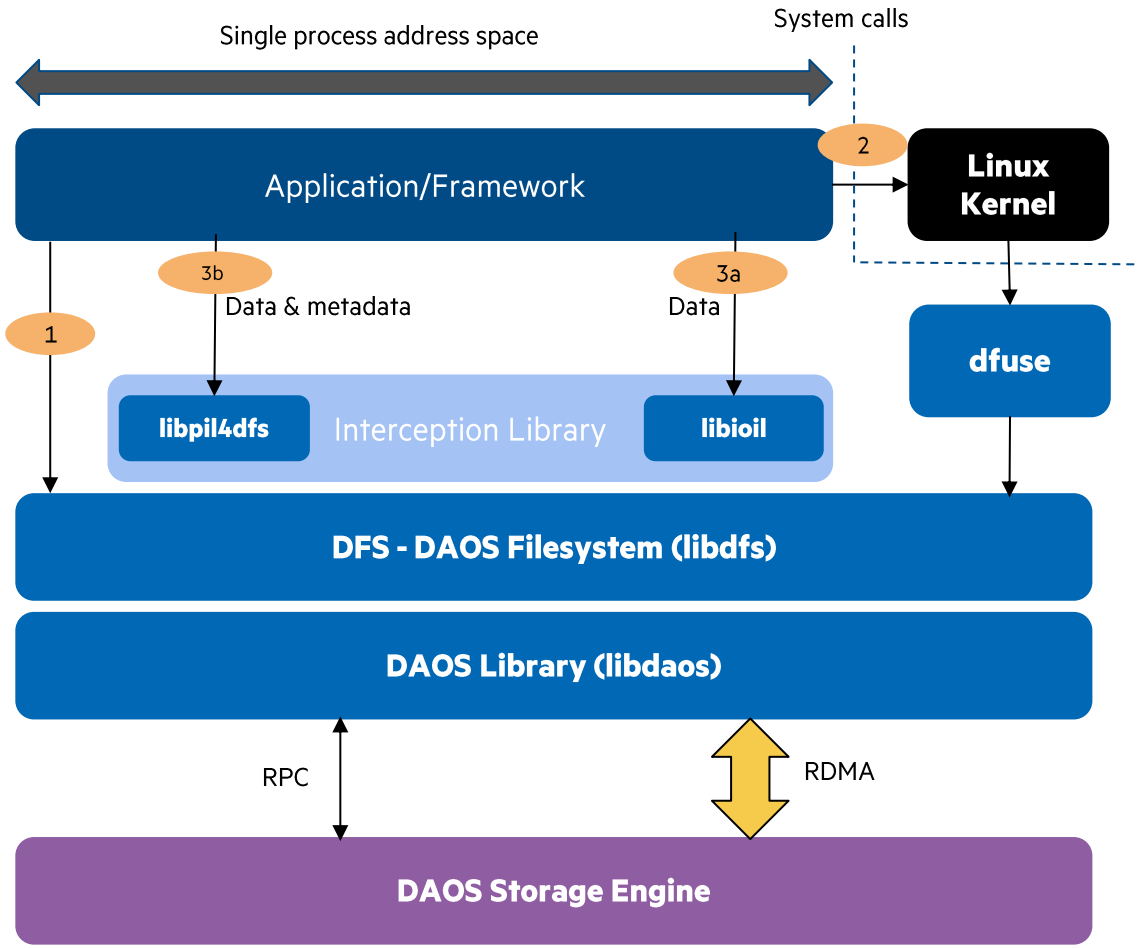
```
daos_obj_open(coh, oid, DAOS_OO_RW, &oh, NULL);

/* application buffers */
char rbuf2[128];
d_iov_set(&sg_iovs[0], rbuf1, BUF1LEN);     /* 10240 byte array val: (dkey1,akey1) */
sgls[0].sg_nr = 1;
sgls[0].sg_iovs = &sg_iovs[0];
d_iov_set(&sg_iovs[1], rbuf2, strlen(buf2)); /* string val: (dkey1,akey2) */
sgls[1].sg_nr = 1;
sgls[1].sg_iovs = &sg_iovs[1];

/* keys */
d_iov_set(&dkey, "dkey1", strlen("dkey1"));
d_iov_set(&iods[0].iod_name, "akey1", strlen("akey1"));
d_iov_set(&iods[1].iod_name, "akey2", strlen("akey2"));

/* IODs for each akey */
/** If iod_size is unknown: specify DAOS_REC_ANY, NULL sgl */
iods[0].iod_type = DAOS_IOD_ARRAY;
iods[0].iod_size = 1;                  /* 1 byte/array cell */
recx.rx_idx = 0;                       /* array index range (0, BUF1LEN) */
recx.rx_nr = BUF1LEN;
iods[0].iod_nr = 1;
iods[0].iod_recxs = &recx;
iods[1].iod_type = DAOS_IOD_SINGLE;
iods[1].iod_size = strlen(buf2);
iods[1].iod_nr = 1;                    /* iod_recxs=NULL for SV */

daos_obj_fetch(oh, DAOS_TX_NONE, 0, &dkey, 2, &iods[0], &sgls[0], NULL, NULL);
```



More Examples

- https://github.com/daos-stack/daos/blob/master/src/tests/simple_obj.c
- https://github.com/daos-stack/daos/blob/master/src/tests/simple_dfs.c

POSIX Support & Interception



1

Userspace DFS library with API like POSIX

- **Requires** application changes
- Low-latency and high-concurrency
- No caching

2

DFUSE daemon to support POSIX API

- **No changes** to application
- VFS mount point and high-latency
- Caching done by Linux kernel

3

DFUSE + Interception Library

- **No changes** to application
- 2 flavors, choose with LD_PRELOAD

3a

- Libioil
  - Intercept data only - (f)read/write
  - Metadata handled by dfuse / kernel

3b

- Libpil4dfs
  - Intercept data and metadata
  - Aim to deliver same performance as DFS (#1)
  - mmap() and binary execution via fuse

POSIX – How to Use DFS API (From a Modified Application)

- You should have access to a pool (identified by a string label).

- Create a POSIX container with the daos tool:
  - `daos cont create mypool mycont --type=POSIX`
  - Or: use API to create a container to use in your application (if using DFS and changing your app).

- Open the DFS mount:
  - `dfs_connect (mypool, mycont, O_RDWR, .. &dfs);`
  - `dfs_disconnect (dfs);`

POSIX – DFS API

POSIX	DFS
mkdir(), rmdir()	dfs_mkdir(), dfs_rmdir()
open(), close(), access()	dfs_open(), dfs_release(),dfs_lookup()
pwritev(), preadv()	dfs_read/write()
{set,get,list,remove}xattr()	dfs_{set,get,list,remove}xattr
stat(), fstat()	dfs_stat(),ostat()
readdir() …	dfs_readdir() …

- Mostly 1-1 mapping from POSIX API to DFS API.
- Instead of File & Directory descriptors, use DFS objects.
- All calls need the DFS mount which is usually done once (initialization time).

POSIX – DFUSE (With Unmodified Applications)

- To mount an existing POSIX container with dfuse, run the following command:
  - `dfuse mypool mycont -m /mnt/dfuse`
  - No one can access your container / mountpoint unless access is provided on the pool and container (via ACLs)

- Now you have a parallel file system under /mnt/dfuse on all nodes where that is mounted
  - "Easy path" for unmodified apps and daos – access files / directories as a namespace in the container

- dfuse + Interception Libraries:
  - Approach: intercept POSIX I/O calls, issue I/O directly from application through libdaos (kernel bypass)
  - To use: set LD_PRELOAD to point to the shared library in the DAOS install dir
    - (newer approach – metadata+data intercept) LD_PRELOAD=/path/to/daos/install/lib64/pil4dfs.so
    - (original approach – read/write only intercept) LD_PRELOAD=/path/to/daos/install/lib64/libioil.so

POSIX – Best Practices: Redundancy Factor (rd_fac) Container Property

- The number of (not yet rebuilt) concurrent failures container objects are protected against (without loss)
  - A number in the range 0-5

- Production systems recommendation: rd_fac:2 (which is a default value if not specified)
  - `daos cont create –type=POSIX –properties=rd_fac:2 <pool> <container>`

- Note: all objects must use a class with at least this degree of protection. Some legal examples:

	rd_fac:0	rd_fac:1	rd_fac:2
No Protection Classes	OC_S<*>	None	None
Replication Classes	Any	OC_RP_2G<*> OCP_RP_3G<*> …	OC_RP_3G<*> OC_RP_4G<*> …
Erasure Code Classes	Any	OC_EC_8P1G<*> OC_EC_16P1G<*>	OC_EC_8P2G<*> OC_EC_16P2G<*>

POSIX – Best Practices: Object Class Data Protection

- Recall: data protection is part of an object's "object class" – None, Replication, or Erasure Code

- Erasure Code:
  - Best for large IO access patterns.
  - Full stripe write: 12%-33% lower performance (vs. no data protection).
  - Partial stripe write: 66% lower performance (vs. no data protection).
  - Read performance should be the same.
  - Not supported for directory objects

- Replication:
  - Best for metadata objects (directories) and small files (<= 16k).
  - Write IOPS: slower (than no data protection) by the number of replicas created.
  - Read IOPS: equal or better (than no data protection) – more shards to serve concurrent requests.

POSIX – Best Practices: Object Class Striping (Wide or Narrow)

`daos cont create –type=POSIX –dir-oclass=<OC> --file-oclass=<OC>`

	rd_fac:0	rd_fac:1	rd_fac:2
Defaults - Widely-striped (“X”) objs for: - Large files (GBs), Lean dirs. (<10k ent) - Single-shared access, high BW required	File: SX Dir : S1	File: EC_16P1GX Dir : RP_2G1	File: EC_16P2GX Dir : RP_3G1
Small-stripe (1/2/4/16/32) objs for: - Something in-between huge and tiny files - File per process to large files.	File: S32 (S1/2/…/32) Dir : S1	File: EC_16P1_G32 (G1/2/…/32) Dir : RP_2G1	File: EC_16P2_G32 (G1/2/…/32) Dir : RP_3G1
One-stripe objs for: - tiny files, more IOPS required	File/Dir: S1	File/Dir: RP_2G1	File/Dir: RP_3G1

Recall: Sample Object Classes (`daos_oclass_id_t`)

```
/* Explicit layout, no data protection
 * Examples: OC_S1, OC_S2, …, OC_S32, OC_SX
 * S1 : shards=1, S2 shards=2, SX shards=all tgts
 */

/* Replicated object (OC_RP_), explicit layout:
 * <number of replicas> G<redundancy groups>
 * Ex OC_RP_2G1, 2G2..32 2GX, 3G1..32 3GX, …
 * 2G1 : 2 replicas group=1
 * 3G2 : 3 replicas groups=2, ...
 * 6GX : 6 replicas, spread across all targets
 */

/* Erasure coded (OC_EC_), explicit layout:
 * <data_cells>P<parity_cells>G<redun_groups>
 * Ex: EC_8P2G1, EC_8P2G<2..32>, EC_8P2GX,
 *     EC_16P2G1, EC_16P2G<2..32>, EC_16P2GX,
 * - 8P2G2:   8+2 EC object, groups=2
 * - 16P2GX: 16+2 EC object, all targets in pool
 * - 2P1G1:   2+1 EC object, group=1
 * - 4P2G8:   4+2 EC object, groups=2
 */
```

POSIX – Best Practices: Object Class Striping – Tradeoffs

```
daos cont create –type=POSIX –dir-oclass=<OC> --file-oclass=<OC>
```

	rd_fac:0	rd_fac:1	rd_fac:2
Defaults - Widely-striped ("X") objs for: - Large files (GBs), Lean dirs. (<10k ent) - Single-shared access, high BW required Tradeoffs: - If used with file-per-proc, non-scalable pool connect slows pool service. - Slow file stat(), remove, directory listing – RPC to all engines, query all targets.	File: SX Dir : S1	File: EC_16P1GX Dir : RP_2G1	File: EC_16P2GX Dir : RP_3G1
Small-stripe (1/2/4/16/32) objs for: - Something in-between huge / tiny files - File per process to large files. Tradeoffs: - Faster stat() and directory listing - Limited bandwidth to number of targets - Benchmarking file create/remove/stat could benefit from widely-striped dirs.	File: S32 (S1/2/…/32) Dir : S1	File: EC_16P1_G32 (G1/2/…/32) Dir : RP_2G1	File: EC_16P2_G32 (G1/2/…/32) Dir : RP_3G1
One-stripe objs for: - tiny files, more IOPS required	File/Dir: S1	File/Dir: RP_2G1	File/Dir: RP_3G1

Recall: Sample Object Classes (`daos_oclass_id_t`)

```
/* Explicit layout, no data protection
 * Examples: OC_S1, OC_S2, …, OC_S32, OC_SX
 * S1 : shards=1, S2 shards=2, SX shards=all tgts
 */

/* Replicated object (OC_RP_), explicit layout:
 * <number of replicas> G<redundancy groups>
 * Ex OC_RP_2G1, 2G2..32 2GX, 3G1..32 3GX, …
 * 2G1 : 2 replicas group=1
 * 3G2 : 3 replicas groups=2, ...
 * 6GX : 6 replicas, spread across all targets
 */

/* Erasure coded (OC_EC_), explicit layout:
 * <data_cells>P<parity_cells>G<redun_groups>
 * Ex: EC_8P2G1, EC_8P2G<2..32>, EC_8P2GX,
 *     EC_16P2G1, EC_16P2G<2..32>, EC_16P2GX,
 * - 8P2G2:   8+2 EC object, groups=2
 * - 16P2GX: 16+2 EC object, all targets in pool
 * - 2P1G1:   2+1 EC object, group=1
 * - 4P2G8:   4+2 EC object, groups=2
 */
```

POSIX – Best Practices: – EC Properties for Performance

- DFS Chunk Size, default 1MiB (`daos container create –chunk_size=`)
  - DAOS splits file data across dkeys in chunk size units

- `ec_cell_sz` container property
  - DAOS splits application buffer into `ec_cell_sz` byte parts (16 parts for EC_16P2, 8 parts for EC_8P2, etc.)

- Full (vs. Partial) Stripe Write – application buffer chunk is an even multiple of `ec_cell_sz` (or not).
  - Full stripe write is more efficient

EC Object Class	EC Cell Size	DFS Chunk size	Full or Partial Write?
16P2	128k	1m	Partial: 1m gets divided into 8 128k data parts which < 16 data shards of the object class used
8P2	128k	1m	Full
16P2	128k	2m, 4m, 8m, etc	Full
16P2	256k	2m	Partial
16P2	256k	4m, 8m, etc.	Full

Thank you

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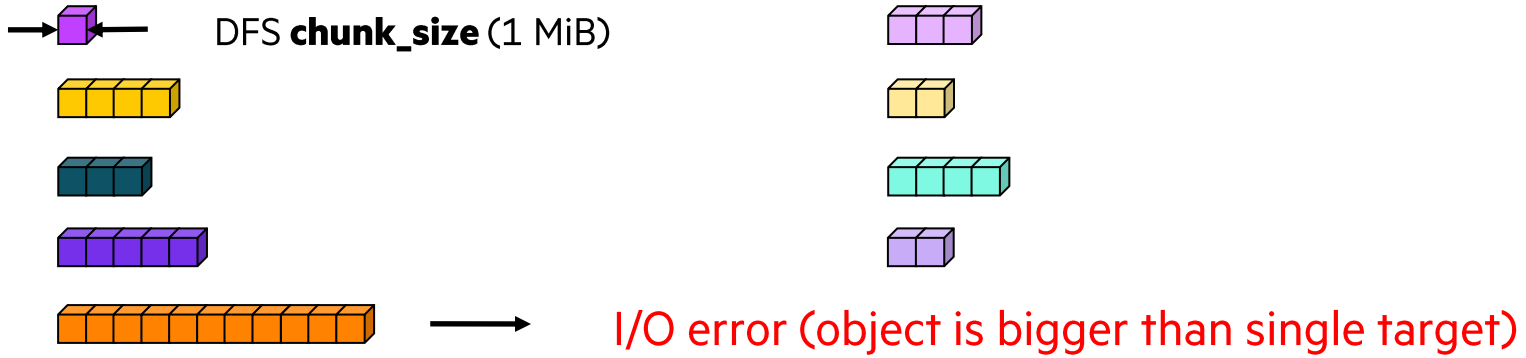
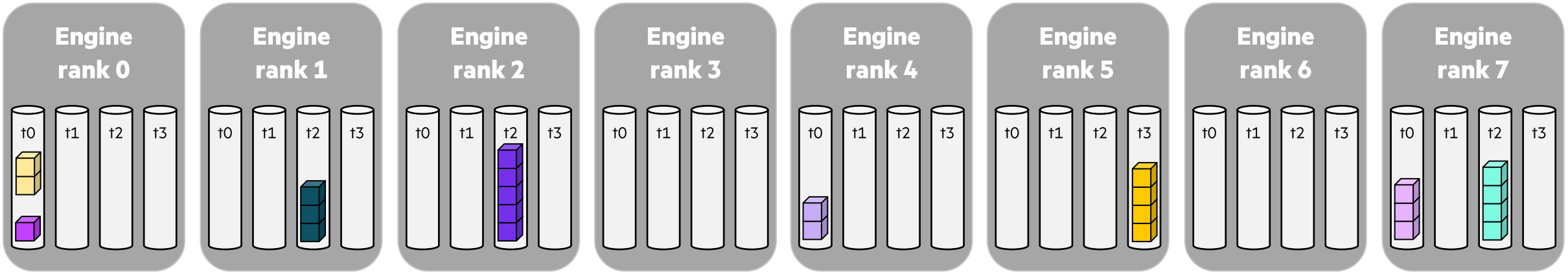
Data Distribution and Data Protection

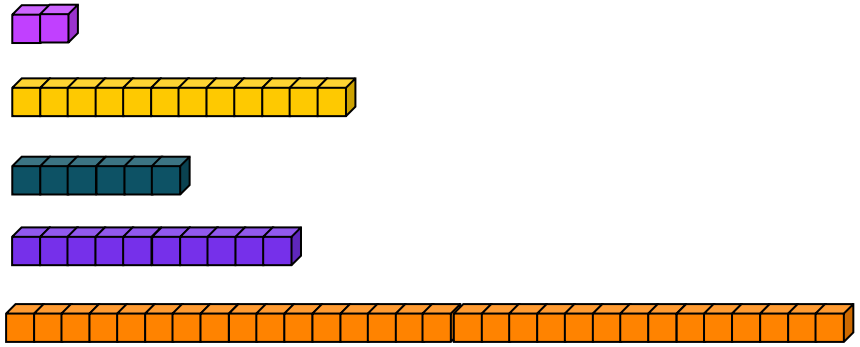
Sharding, object class S1

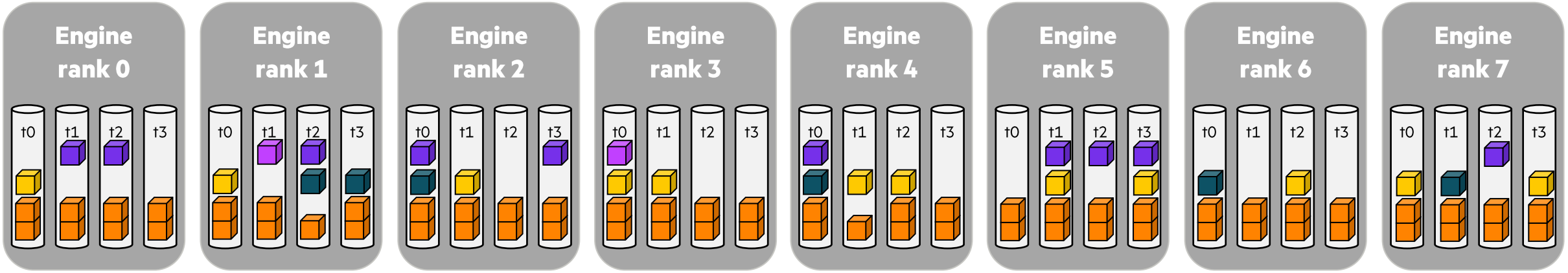




Data Distribution and Data Protection

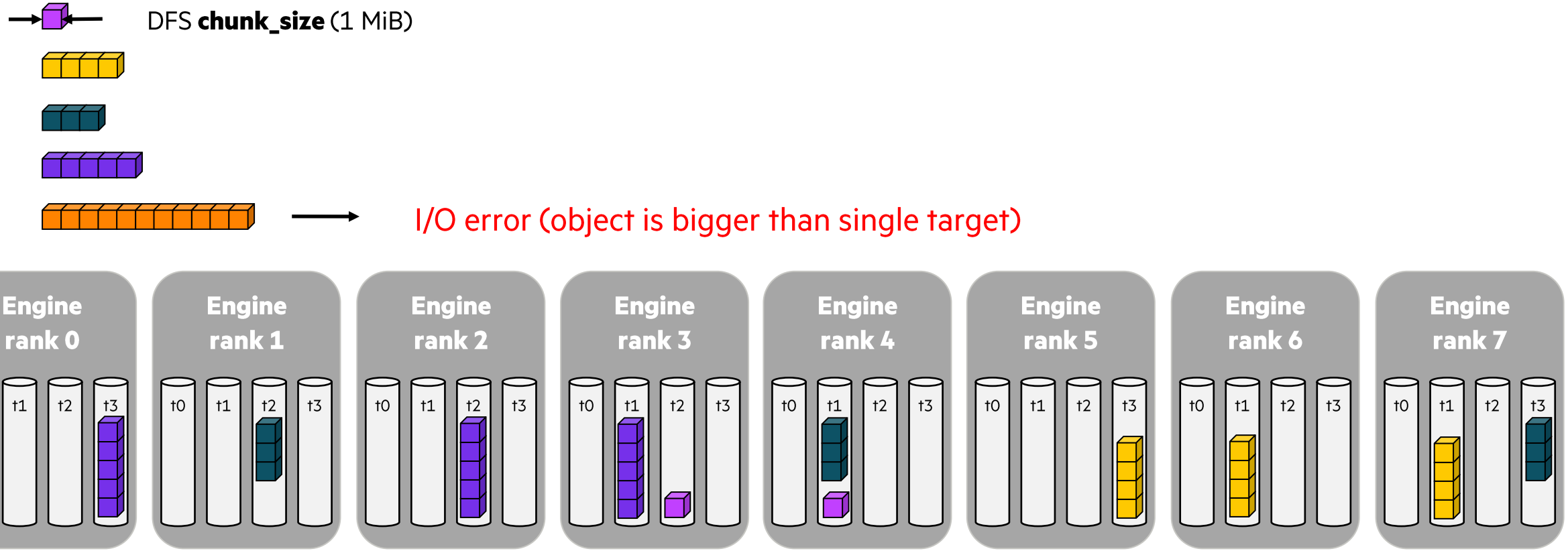
Sharding, object class SX





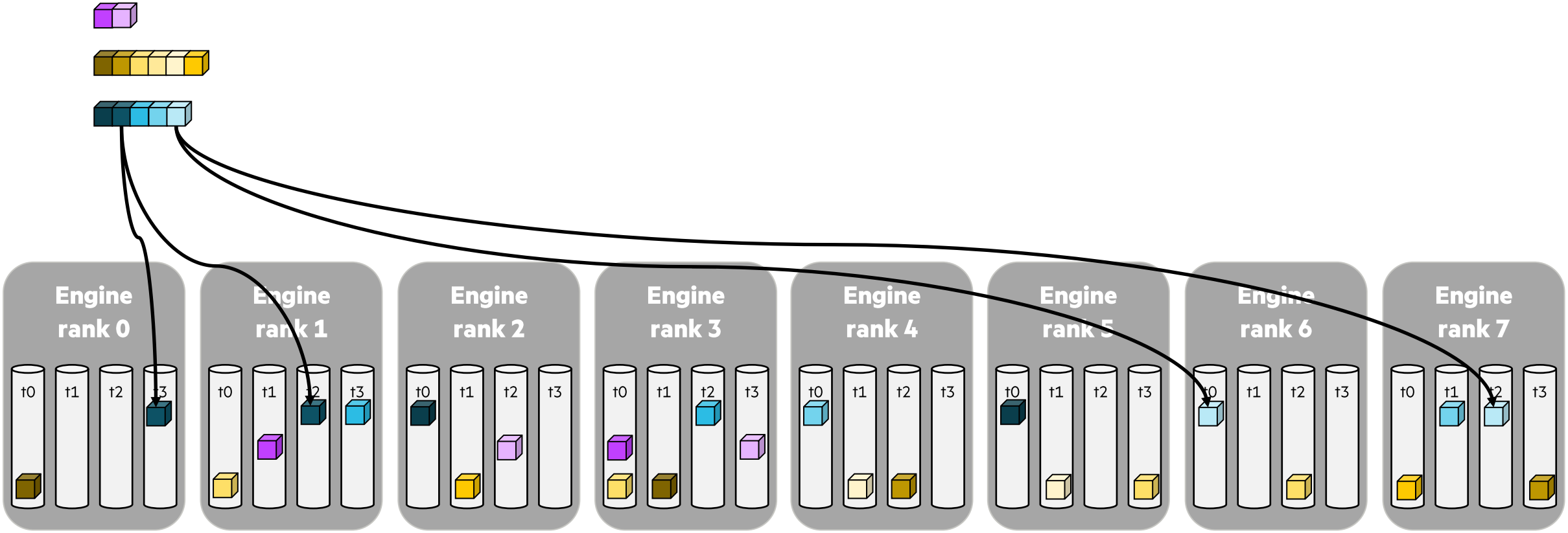
Data Distribution and Data Protection

Replication, object class RP_3G1 (rf_lvl=engine)



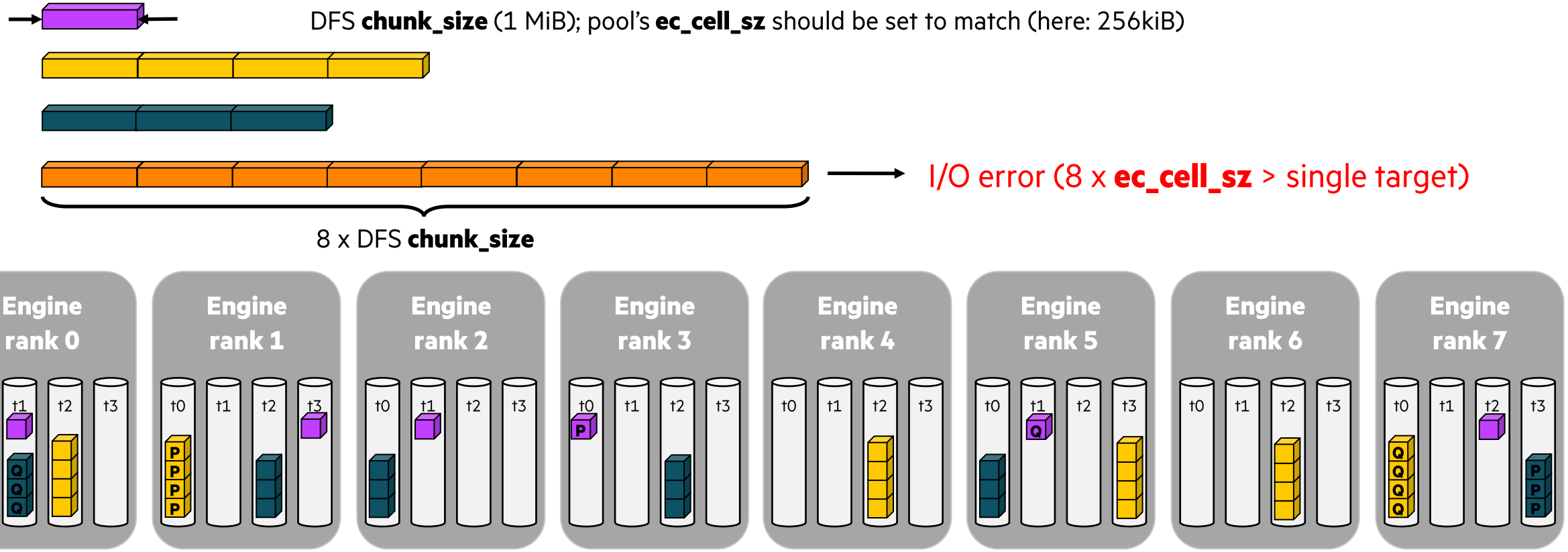
Data Distribution and Data Protection

Replication, object class RP_2GX (rf_lvl=engine)



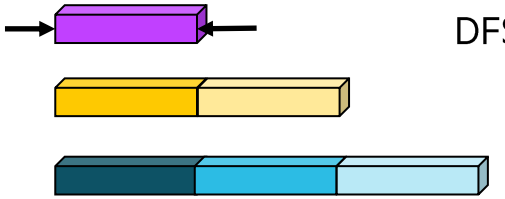
Data Distribution and Data Protection

Erasure Coding, object class EC_4P2G1 (rf_lvl=engine)

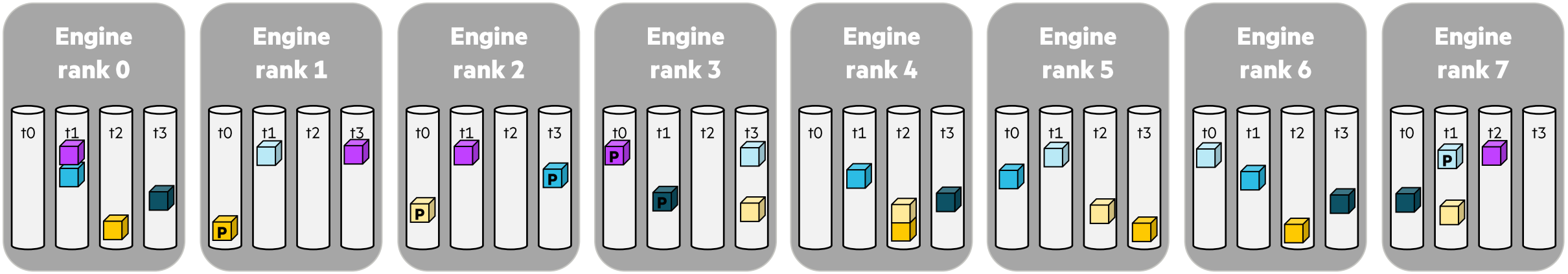


Data Distribution and Data Protection

Erasure Coding, object class EC_4P1GX (rf_lvl=engine)



DFS **chunk_size** (1 MiB); pool's **ec_cell_sz** should be set to match (here: 256kiB)



DAOS Object - Old Update Example

```
daos_obj_open(coh, oid, DAOS_OO_RW, &oh, NULL);
d_iov_set(&dkey, "dkey1", strlen("dkey1"));

d_iov_set(&sg_iov, buf, BUFLEN);
sgl[0].sg_nr = 1;
sgl[0].sg_iovs = &sg_iov;
sgl[1].sg_nr = 1;
sgl[1].sg_iovs = &sg_iov;

d_iov_set(&iod[0].iod_name, "akey1", strlen("akey1"));
d_iov_set(&iod[1].iod_name, "akey2", strlen("akey2"));

iod[0].iod_nr = 1;
iod[0].iod_size = BUFLEN;
iod[0].iod_recxs = NULL;
iod[0].iod_type = DAOS_IOD_SINGLE;

iod[1].iod_nr = 1;
iod[1].iod_size = 1;
recx.rx_nr = BUFLEN;
recx.rx_idx = 0;
iod[1].iod_recxs = &recx;
iod[1].iod_type = DAOS_IOD_ARRAY;

daos_obj_update(oh, DAOS_TX_NONE, 0, &dkey, 2, &iod, &sgl, NULL);
```

Multi-Level KV Object – Old Fetch Example

```
daos_obj_open(coh, oid, DAOS_OO_RW, &oh, NULL);
d_iov_set(&dkey, "dkey1", strlen("dkey1"));

d_iov_set(&sg_iov, buf, BUFLEN);
sgls[0].sg_nr = 1;
sgls[0].sg_iovs = &sg_iov;
sgls[1].sg_nr = 1;
sgls[1].sg_iovs = &sg_iov;

d_iov_set(&iod[0].iod_name, "akey1", strlen("akey1"));
d_iov_set(&iod[1].iod_name, "akey2", strlen("akey2"));

iod[0].iod_nr = 1;
iod[0].iod_size = BUFLEN; /** if size is not known, use DAOS_REC_ANY and NULL sgl */
iod[0].iod_recxs = NULL;
iod[0].iod_type = DAOS_IOD_SINGLE;

iod[1].iod_nr = 1;
iod[1].iod_size = 1; /** if size is not known, use DAOS_REC_ANY and NULL sgl */
recx.rx_nr = BUFLEN;
recx.rx_idx = 0;
iod[1].iod_recxs = &recx;
iod[1].iod_type = DAOS_IOD_ARRAY;

daos_obj_fetch(oh, DAOS_TX_NONE, 0, &dkey, 2, &iods[0], &sgls[0], NULL, NULL);
```

SUMMARY

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Aside: DAOS Fortran interfacing

```
type, public, bind(c) :: daos_array_stbuf_t
     integer (kind=daos_size_t) :: st_size
     integer (kind=daos_epoch_t) :: st_max_epoch
  end type daos_array_stbuf_t


interface


   integer(kind=c_int) function daos_array_create(coh, oid, th, cell_size, chunk_size,
oh, ev) bind(c,name="daos_array_create")
     import :: c_int
     import :: daos_handle_t
     import :: daos_obj_id_t
     import :: daos_size_t
     import :: daos_event_t
     type(daos_handle_t), value, intent(in) :: coh
     type(daos_obj_id_t), value, intent(in) :: oid
     type(daos_handle_t), value, intent(in) :: th
     integer(kind=daos_size_t), value, intent(in) ::cell_size
     integer(kind=daos_size_t), value, intent(in) ::chunk_size
     type(daos_handle_t), intent(inout) :: oh
     type(daos_event_t), intent(inout) :: ev
   end function daos_array_create
```

Hewlett Packard Enterprise

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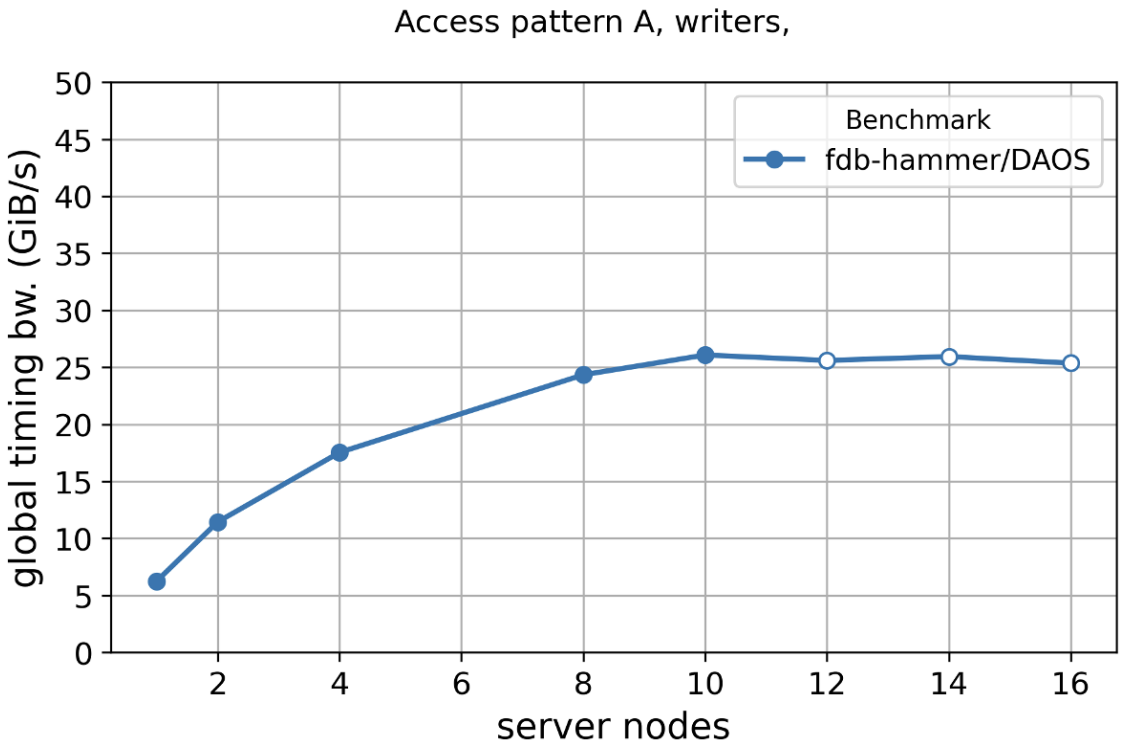
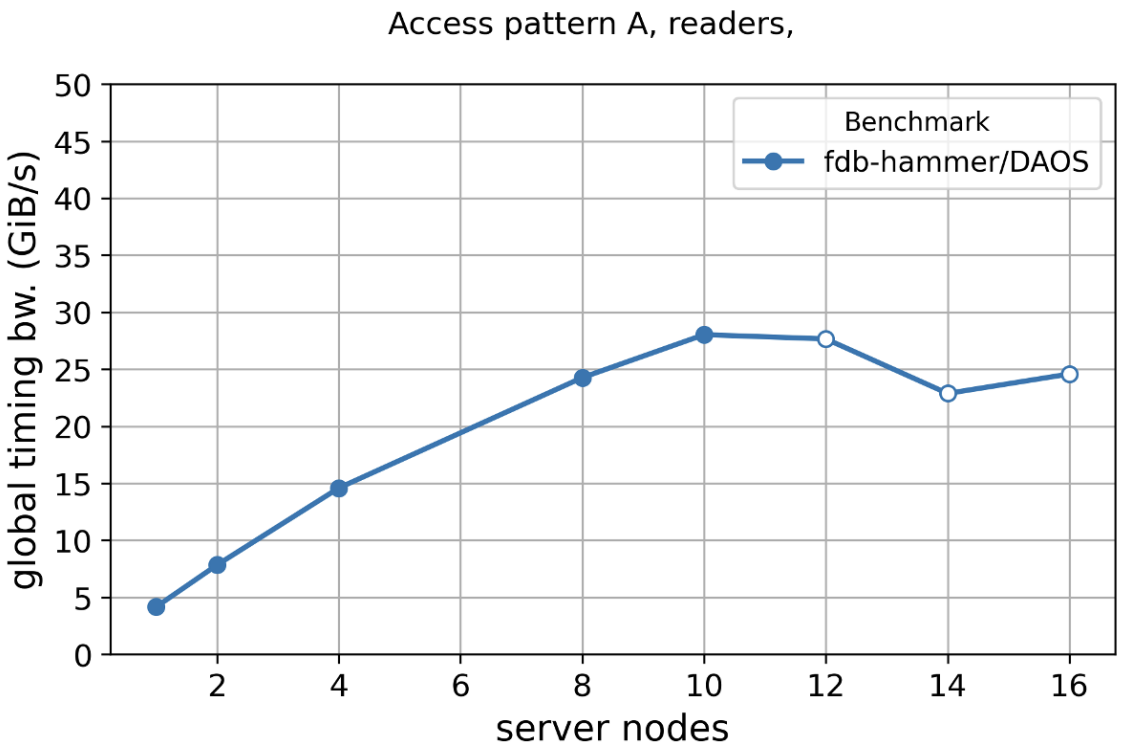
Evaluate performance/approach





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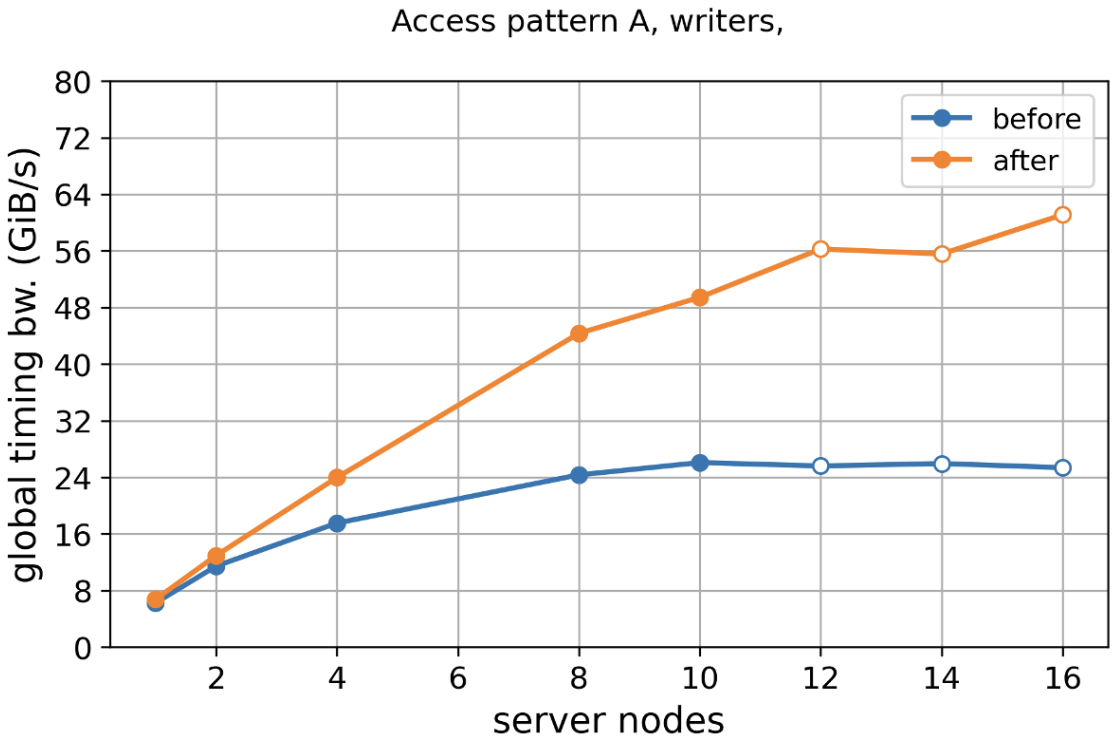
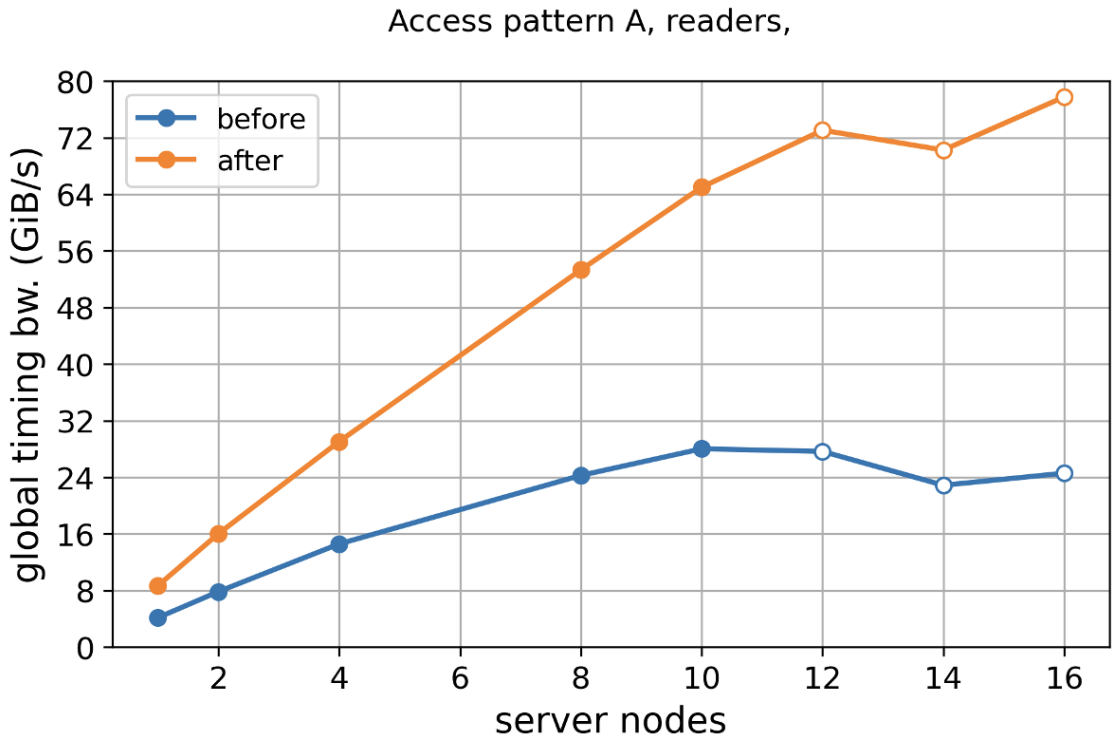
Optimised performance





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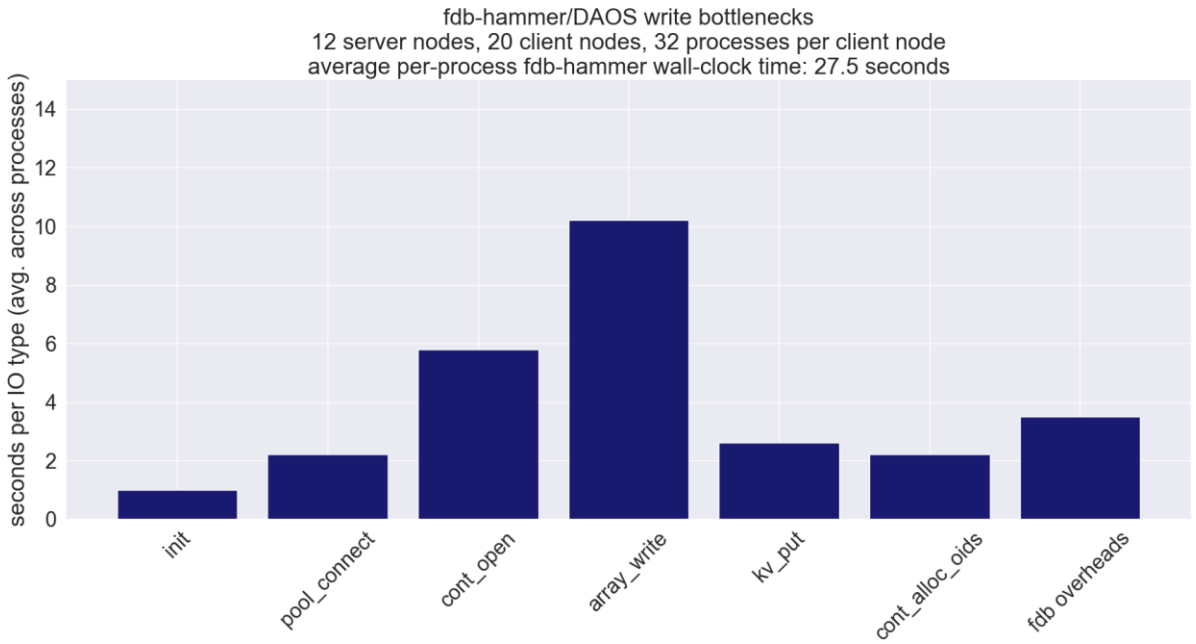
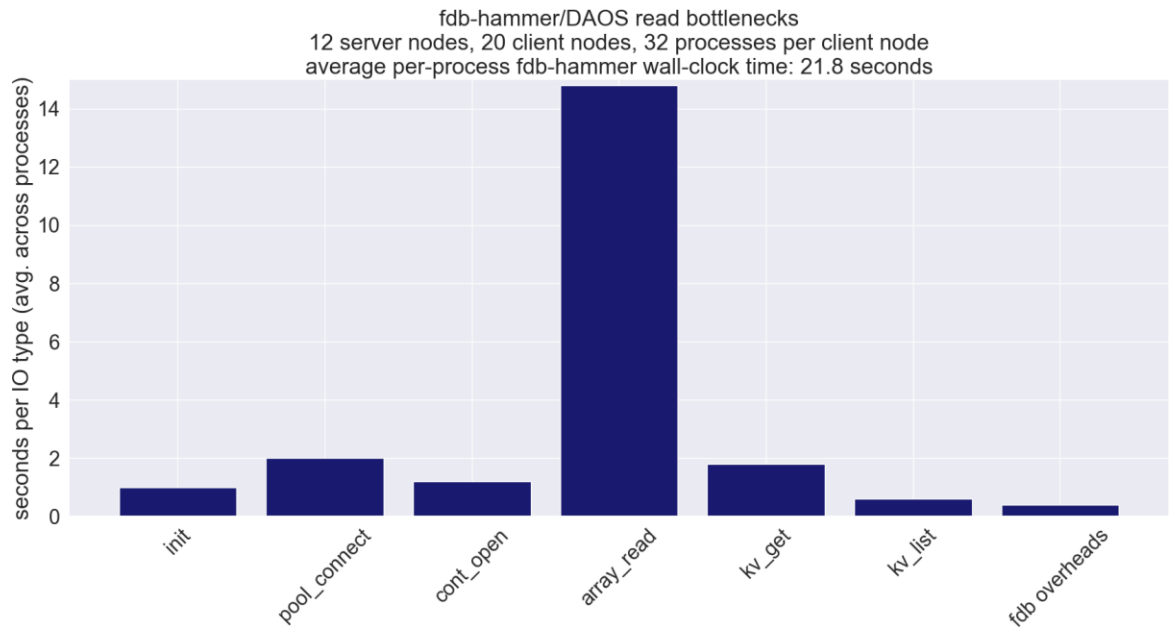
Profiling

- Example breakdown of where time is being spent
  - Manual profiling





Approach/recommendations

- Key-Value contention
- For a specific benchmark run configured with contention across processes on indexing Key-Values:
  - 20 GiB/s write
  - 13 GiB/s read
- Tweaking the benchmark configuration to have all processes operate on a separate Key-Values:
  - 35 GiB/s write
  - 68 GiB/s read
- This may not be trivial or possible for all applications, but if design can achieve it then this improves performance

Approach/recommendations

- Avoid communications on/with the server where possible
- Cache objects locally in DRAM if possible
- Use `daos_array_open_with_attr` to avoid `daos_array_create` calls
  - Only supported for `DAOS_OT_ARRAY_BYTE`, not for `DAOS_OT_ARRAY`
  - Warning: the cell size and chunk size attributes need to be provided consistently on any future `daos_array_open_with_attr` to avoid data corruption
- `daos_array_get_size` calls can be expensive
  - Can store array size in our indexing Key-Values
  - Can manually calculate
  - Also possible to infer the size by reading with overallocation:
    - use `DAOS_OT_ARRAY_BYTE`, over-allocate the read buffer, and read without querying the size. The actual read size (`short_read`) will be returned
- `daos_cont_alloc_oids` is expensive, call it just once per writer process
  - Required to generate object ideas to use in calls but can generate many at one

Approach/recommendation

- Creating several containers (starting at ~300) in a DAOS pool reduces performance
- Opening the same container from all processes is expensive
  - this happens even if only a few containers exist in the DAOS pool
  - e.g. out of 20 seconds taken by a process to write 2000 fields, 1.5 seconds were spent just to open one container
  - we observed this starting at ~200 parallel processes
  - Sharing handles using MPI is the way to fix this
- Opening more than one container per process is very expensive
  - e.g. out of 30 seconds taken by a process to read 2000 fields, 6 seconds were spent just to open two containers

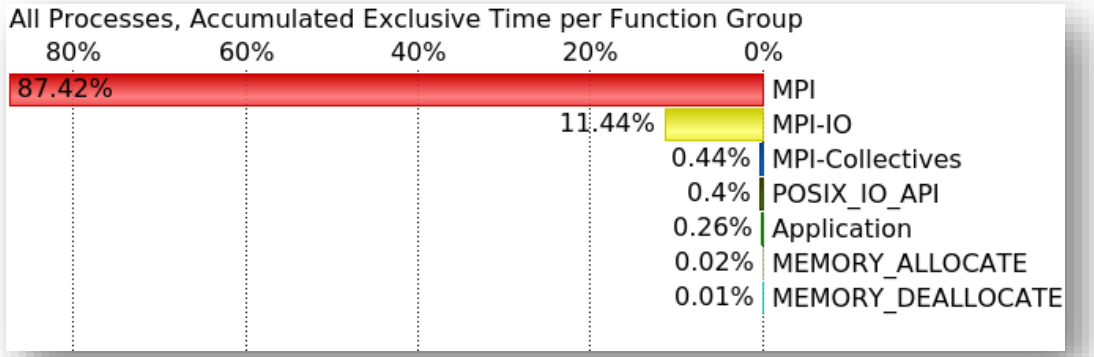
Approach/recommendations

- `daos_key_value_list` is expensive
- `daos_array_open_with_attrs`, `daos_kv_open` and `daos_array_generate_oid` are very cheap (no RPC)
- Normal `daos_array_open` is expensive
- `daos_cont_alloc_oids` is expensive
- `daos_kv_put` and `_get` are generally cheap
  - Value size impacts this
- `daos_obj_close`, `daos_cont_close` and `daos_pool_disconnect` are cheap
- Server configuration to use available networks/sockets/etc… important for performance
  - Just like any storage system or application

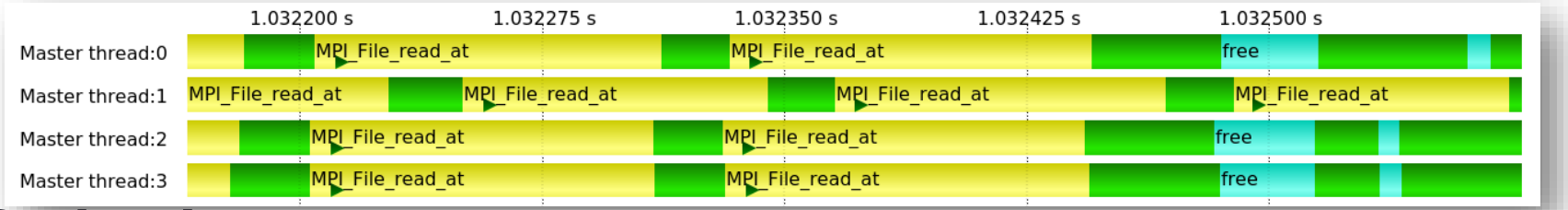
Object store usage design

- Mapping data structures to KV and Array objects is key to getting good performance functionality
- We suggest mapping contiguous chunks of arrays to be stored to single DAOS array object
  - Collect multiple arrays with associated KV to make the whole array
- Can be as extreme as having a single value per KV
  - Significant overheads in this
- Depends on your application data structures you may want to aggregate less data for I/O
  - Group based on meaningful/scientific dimensions
- HDF5 or similar hierarchies could map well to Keys with Arrays
- Adding keys to the array data/values can let data set structure to be created, enumerated, and extended
- See the Exercises/FullApplication in the GitHub repository for the tutorial

Summary



- Object storage can provide high performance
  - DAOS: 90+ GB/s per server is possible
  - Hardware and configuration dependent, just like all I/O
- Built in replication and redundancy under your/user control
- Different interfaces available
  - Filesystem for zero cost porting
  - Simple file like access for slightly improved performance at little effort
  - Programming APIs for full functionality
- Object store interface enables changing I/O granularity/patterns for bigger benefits



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Final Summary

- Thanks for attending!
- Happy to take further questions when/if they occur to you
  - Email or come and talk to us
- Tutorial system will stay active for the week
  - Time to complete the exercises/experiment with the technology
  - Any problems email me as well
- Want more help
  - Come and speak to us
  - Happy to collaborate/help with object store usage/porting/etc...

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