DAOS: A New Storage Paradigm

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Notices

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Agenda

• Storage Challenges and DAOS overview
• Next Gen HPC Storage Vision
• Next Gen Storage Stack
• Middleware I/O & Applications
• DAOS/Lustre Integration
Today’s HPC Storage System Pain Points

- HPC storage systems perform poorly with random, unaligned or small I/Os
  - Require larger & larger well-aligned sequential I/Os
- Scientific data models limited by POSIX
  - One-size-fits-all POSIX data model
  - **Worst-case** concurrency control mechanism
- Hitting scalability limits of traditional PFS
Challenge: I/O Latency & IOPS

- HDD
- Software stack
Challenge: I/O Latency & IOPS
Challenge: I/O Latency & IOPS

Traditional storage stack entirely masks low latency of 3D XPoint™!
Challenge: Access Granularity

Traditional storage stack entirely masks low latency & capabilities of 3D XPoint™!
**Distributed Asynchronous Object Storage**

- **Scale-out object store** designed from the ground up for nextgen storage & fabric technologies
  - High **throughput/IOPS**
  - Byte addressable
  - **OS bypass** with lightweight client/server

- **Advanced storage API**
  - New scalable **storage model** suitable for both **structured** & **unstructured** data
  - **Non-blocking** data & metadata operations

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* I/O middleware not ported to DAOS
** I/O middleware prototyped over DAOS
Distributed Asynchronous Object Storage

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  - New data & storage model suitable for both structured & unstructured data
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Open source

[APACHE 2.0 License](https://github.com/daos-stack)

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DAOS

Open Source Apache 2.0 License

- I/O middleware not ported to DAOS
- I/O middleware prototyped over DAOS

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** I/O middleware prototyped over DAOS
Next Gen HPC Storage Vision

• NVM storage storing datasets
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• NVM storage storing datasets
  • *Externally* accessible
Next Gen HPC Storage Vision

• NVM storage storing datasets
  • Externally accessible
Next Gen HPC Storage Vision

• NVM storage storing datasets
  • **Externally** accessible

• **System namespace**
  • **Global** POSIX namespace
  • **Links** to datasets
  • Binaries, libraries, user files, ...

Data streaming (e.g. from instrument(s))
Next Gen Storage Stack

New storage API (DAOS) provides extended capabilities and high bandwidth/IOPS to middleware
Next Gen Storage Stack

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

**New** storage API (DAOS) provides extended capabilities and high bandwidth/IOPS to middleware
Next Gen Storage Stack

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

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

New storage API (*DAOS*) provides extended capabilities and high bandwidth/IOPS to middleware.
Lightweight Storage Stack

• Mercury user space function shipping
• Applications link directly with DAOS lib
• Userspace DAOS server
  • Mmap non-volatile memory (NVML)
  • NVMe access through SPDK/BlobFS
Storage Model

DAOS Tier

Pool

Container

Object

DKey

Akey[i]

dakey

akey

0 1 2 3 ... 4k

Record size = 1 Byte
(Byte Array)

akey

0 1 2 3 ... 10

Record size = 1024 Bytes

Single any-size value
DAOS Ecosystem

HPC Apps
(HACC, ACME, CLAMR, …)

Big Data & AI Apps
(No)SQL*, Spark RDD*

Enterprise & Cloud Apps
NFS*, S3*

Legion
NetCDF

POSIX I/O*
MPI-IO*
SCR*, FTI*, VeloC*
Dataspaces*

HDF5**, Dataspaces*

DAOS
Open Source Apache 2.0 License

NVRAM
NVMe

Byte-granular data/metadata
Bulk data (e.g. checkpoints)

* I/O middleware not ported to DAOS
** I/O middleware prototyped over DAOS
HDF5

- Mapping HDF5 to DAOS:
  - HDF5 file -> DAOS Container
  - HDF5 Objects -> DAOS KV objects

- HDF5 DAOS VOL Plugin
  - Prototyped in ESSIO
  - All applications or middleware I/O libraries (e.g. NetCDF4, PIO, etc.) that use HDF5 would be able to utilize the DAOS tier with minimal changes.
  - Newly developed applications or I/O libraries can utilize new extensions to HDF5 that are not available to date without the DAOS VOL plugin (some might be added to the POSIX HDF5 plugin in the future):
    - Asynchronous I/O for both metadata and raw data operations
    - Query, Indexing, & Analysis shipping
    - Container Snapshots
    - User controlled transactions
    - End to End data integrity
POSIX I/O

- POSIX Encapsulation
  - Each DAOS container encapsulates a namespace.
  - Highly scalable I/O to single shared file or file per process with full OS bypass.
  - Relaxed POSIX compliance
    - OK for most applications
    - Strong compliance comes at the price of complexity and performance.

- POSIX Extensions
  - Asynchronous I/O operations.
  - POSIX namespace snapshots

- Not yet implemented
**MPI-I/O**

- **MPI-I/O Support**
  - Implement an ADIO driver in ROMIO (widely used as the de-facto MPI-I/O implementation in most MPI libraries).
  - Minimal application modification (set a hint to use the DAOS driver) + Supports middleware libraries that use MPI-I/O but have not implemented a DAOS driver as a backend.
  - Scalable mapping of an MPI file to a DAOS object with implicit stripping across multiple Distribution Keys.
  - Consistency and Recoverability features of DAOS epochs can be exposed through `MPI_File_sync()` that advances the container epoch.

- **Not yet implemented**

**Mapping MPI-I/O to DAOS:**
- 1 DAOS container to hold 1 MPI-I/O file.
- File striped across multiple object D-Keys
Application Evaluation

• **Legion**
  • Data Centric programming model
• **Hardware/Hybrid Accelerated Cosmology Code**
  • Improved fault tolerance by storing transactional checkpoints
• **Cell-Based Adaptive Mesh Refinement**
  • Use HDF5 instead of POSIX I/O
• **Accelerated Climate Modeling for Energy**
  • Ported NetCDF & PIO to HDF5 DAOS VOL plugin
DAOS/Lustre Integration

• DAOS Tier
  • **Checkpoint/defensive I/O**
  • Advanced data **analytics**
  • New data intensive **workflow**
  • New data-centric **programming models**
  • Storage media
    • 3D-XPoint **NVDIMMs**
      • byte-granular data & metadata
    • 3D-NAND or 3D-XPoint **SSDs**
      • bulk data, including checkpoint data

• Lustre Tier
  • **Robust** system namespace
    • Mature & scalable POSIX namespace
    • Rich feature sets
  • **Smooth** migration path
    • Lustre directly accessible through Mercury IOF
    • Slowly migrate applications to DAOS
    • APPs with strong POSIX requirements
  • Storage media
    • **Dual-ported JBOD**
    • **Dual-ported JBOF**
Single Namespace

Lustre directories & files
DAOS storage area
DAOS storage persistent reservation
HDF5 Container
DAOS POSIX Container
DAOS MPI-IO File

Legend:
- Lustre
- DAOS storage area
- DAOS storage persistent reservation
- HDF5 Container
- DAOS POSIX Container
- DAOS MPI-IO File

Diagram:
- Users
  - Buzz
    - .shrc
    - moon.mpg
  - mkl.so
  - hdf5.so
- Libraries
  - Apollo
    - EA: PUUID
    - Simul.h5
      - EA: CUUID
  - Mercury
    - EA: PUUID
    - Result.dn
      - EA: CUUID
    - Simul.out
      - EA: CUUID
- Projects

Data structures:
- Lustre directories & files
- DAOS storage area
- DAOS storage persistent reservation
- HDF5 Container
- DAOS POSIX Container
- DAOS MPI-IO File
Lustre/DAOS Data Mover

- DAOS container parking
  - Serialize/deserialize DAOS container to/from Lustre
    - DAOS specific format
  - Middleware agnostic
  - Retain history, snapshot and DAOS metadata

- Data transformation
  - Convert container from DAOS format to POSIX format and vice versa
  - Middleware dependent
    - MPI-IO & POSIX share same layout
    - hdf5dump
  - Specific snapshot or HCE
    - History lost in transformation
DAOS Development

• Extreme Scale Storage & I/O
  • DAOS prototype
    • N-way replication with online rebuild
    • Metadata replication with Raft
  • HDF5 VOL plugin + extensions
  • *End in Q2’17*

• Follow-on project
  • NVMe support
  • Automatic service discovery, configuration & monitoring

• Future Work
  • DAOS & HDF5 productization
  • MPI-IO support
  • Erasure code & Progressive layout
  • System integration
  • Management tools
  • Security model
  • Application evaluation in co-design
Questions?

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Resources:

• https://github.com/daos-stack/daos