HDF5 DAOS VOL Plugin

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Outline

- Introduction to The HDF Group HDF5 DAOS project
- HDF5 VOL Architecture
- HDF5 DAOS VOL Plugin

Introduction to the HDF5 DAOS Project

The HDF Group has a long history collaborating with the Intel team

- During 2013-2016 we created prototypes for
  - HDF5 VOL architecture
  - HDF5 DAOS VOL plugin

Goal: Provide a seamless way for the HDF5 applications to access data stored in DAOS Object Store

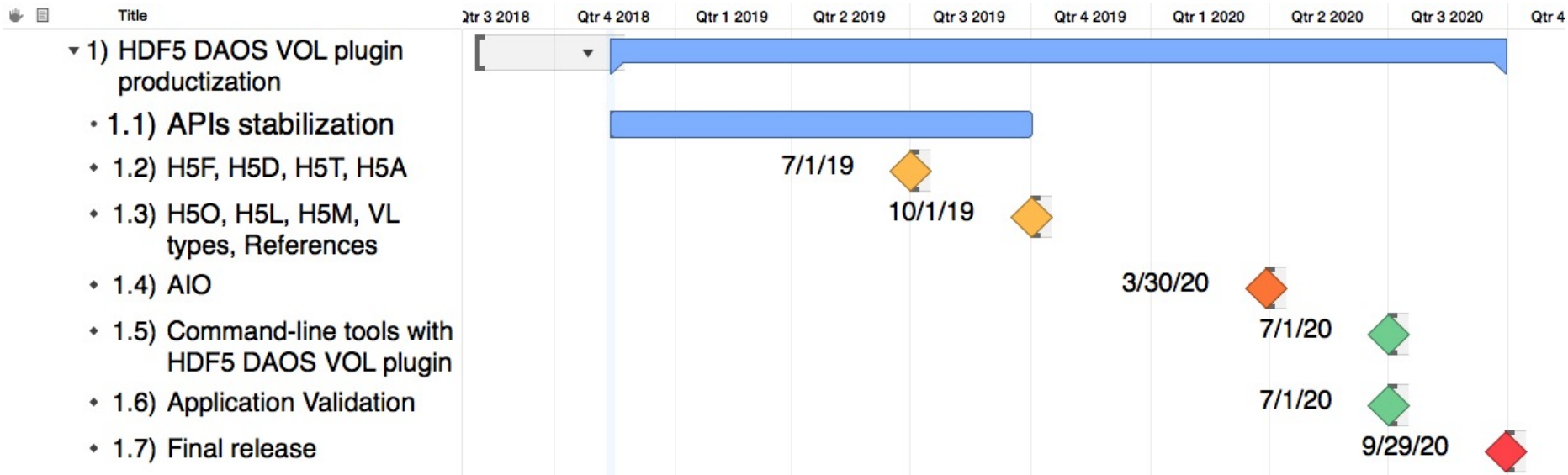
- Minimum changes to the source code
- Support both sequential and parallel I/O
- Get full advantage of the DAOS features
  - AIO
  - Transactions
  - Failure management
  - Map Objects

Introduction to the HDF5 DAOS Project

- **Objectives**
  - Stabilization of
    - HDF5 VOL architecture
    - HDF5 VOL plugin APIs
  - VOL plugin integration with HDF5 regression tests and command-line tools
  - Porting HDF5 applications to DAOS Object Store
  - Performance tuning

HDF5 DAOS Project Roadmap

The HDF Group



HDF5 VOL Architecture

Virtual Object Layer vs. Virtual File Driver

HDF5 VFD vs. HDF5 VOL

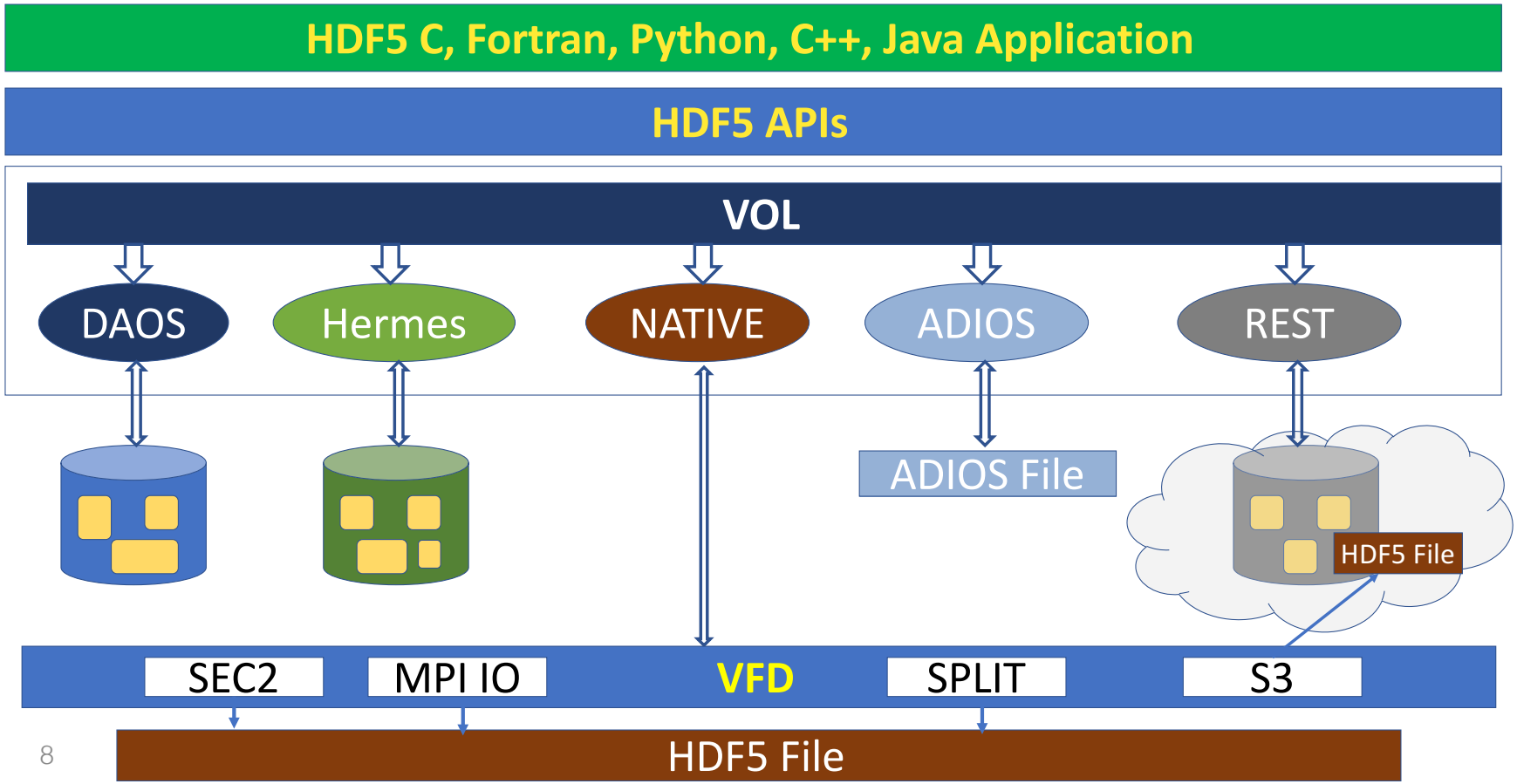
VFD

- HDF5 library I/O public interface
  - Writes/reads offsets and bytes
    - POSIX FS: SEC2, MPI I/O, Split, Family
    - Object Store-like: S3, HSDS
- Extendible and stackable
- *Cannot leverage Object Storage properties easily*

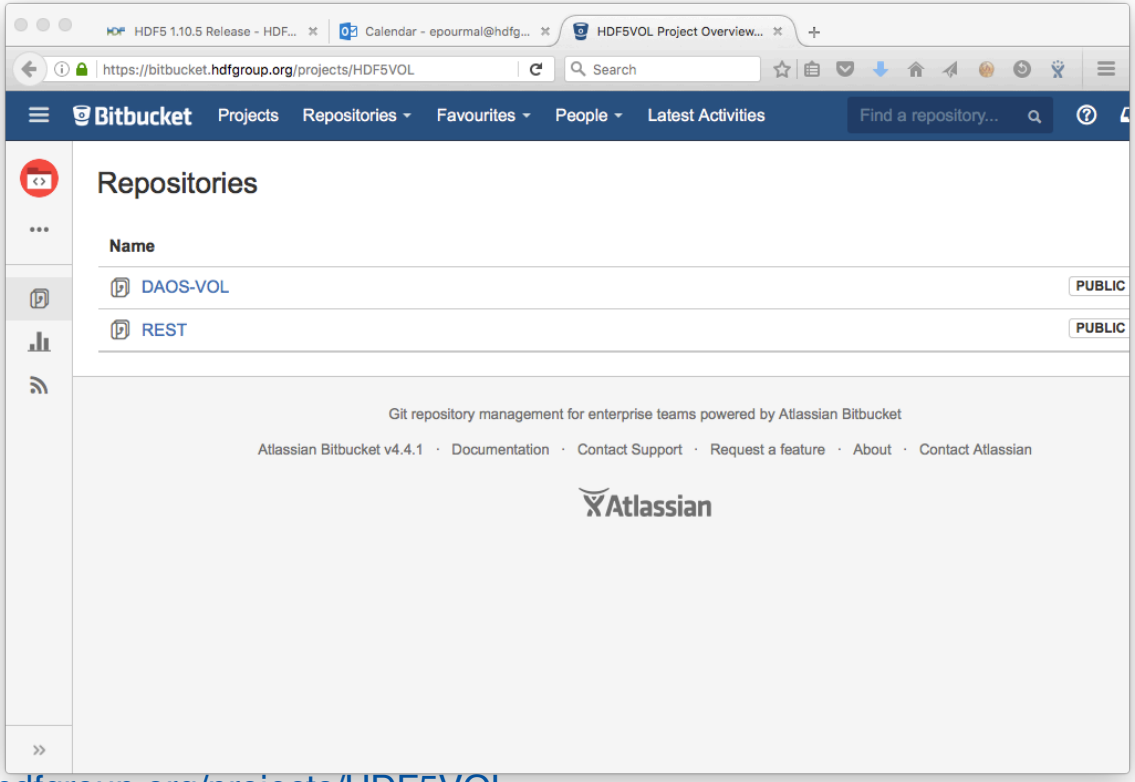
VOL

- HDF5 internal layer
  - Intercepts HDF5 calls and routes them to VOL plugin
    - NATIVE, DAOS, REST, netCDF, ADIOS
- Extendible and stackable
- *Cannot leverage easily HDF5 built-ins*
  - *Datatype conversion, compression, selections*

HDF5 VOL and VFD



HDF5 VOL Plugin and HDF5 VOL Source



https://bitbucket.hdfgroup.org/projects/HDF5VOL
https://bitbucket.hdfgroup.org/projects/HDFFV/repos/hdf5/browse

HDF5 DAOS VOL Plugin

Technical Considerations

HDF5 to DAOS Mapping

HDF5

- **HDF5 File**
- **HDF5 Group**
  - Link name
  - OID or PATH
- **HDF5 Dataset**
  - Chunk coordinates
  - Dataset values in the chunk
- **HDF5 Named Datatype**
- **HDF5 Map**

DAOS

- **DAOS Container**
- **DAOS Object**
  - dkey
  - value
- **DAOS Object**
  - dkey
  - value
- **DAOS Object**
- **DAOS Object**

HDF5 Programming Model for using VOL

- **Currently applications have to use hard-coded VOL specific APIs to initialize and use the plugin!**
  - Burden on application
  - Not portable between different VOL plugins
- **Programming Model with HDF5 DAOS VOL plugin:**
  - Initialize DAOS VOL plugin
    - **H5daos_init will be deprecated**
    - **H5VLregister**
    - **H5VLunregister ?**
  - Set HDF5 access property list to use DAOS VOL plugin
    - **H5Pset_fapl_daos will be deprecated**
    - **H5Pset_vol**
  - Use access property list to create or open DAOS container (HDF5 file)
  - Follow HDF5 programming model to manage objects in the container (in the file)

Unresolved Design Issues

- Finding, loading and initializing a VOL driver
- HDF5 VOL or VOL plugin specific issues
- HDF5 Tools
- HDF5 Testing

Finding, loading and initializing a VOL driver

- **How to tell HDF5 which VOL plugin to use and how to pass required information?**
- **Possible options**
  - Identifier
  - Filename as URI
  - Environment variables
  - Configuration file

Finding, loading and initializing a VOL driver

- **Filename as URI**
  - Similar to HTTP URL
  - Register URI scheme and VOL plugin with The HDF Group
    - URI scheme disctates which VOL plugin to use
  - VOL parameters can be passed as part of URI string using reserved character (TBD) to separate filename and parameters
  - hdf5:///home/user/file.h5**?**vol_param1=abc**?**vol_param2=xyz
- ***Will this approach work with stackable VOLs?***

Finding, loading and initializing a VOL driver

- **Environment variables**
  - Flexible
    - Easy to update, to overwrite the default VOL plugin settings, etc.
    - Used by HDF5 for other features
  - Requires a standard (as with URI) for passing information
    - All VOL plugins will need to follow the standard
    - May not work for some VOL plugins (e.g., username and password are required for accessing file)
- **Configuration file**
  - Flexible
  - Requires a standard that both HDF5 library and VOL plugins should follow

HDF5 VOL and VOL plugin specific issues

- **Non-exposed private routines and structure useful for a VOL plugin**
  - Copying dataspace selection
  - Functions to deal with “set operations” on the selections
  - Datatype conversion functions that need background conversion buffer
- **HDF5 References**
  - References to HDF5 objects and references to sub-regions in datasets
  - Use addresses of the objects in the file
  - Need to be unified into a single “token” that can be implemented by a VOL plugin

HDF5 command-line tools

- **Issues are similar to any other HDF5 application that uses VOL plugin**
  - Rely on HDF5 library to do “right” thing to find, load, and set up VOL plugin
- **Need a common way to specify a VOL plugin using command-line parameter**
- **Build issues**
  - VOL plugin cannot be built before HDF5 library, tools cannot be built before VOL plugin built, but tools are built at the same time when HDF5 library is built
  - Solution: HDF5 command-line tools has to be “VOL plugin” agnostic, i.e., we need “finding, loading, and initializing” process performed by the HDF5 library.

HDF5 Testing

- **How to test HDF5 library with different VOL plugins?**
  - Current HDF5 test suite consist of unit tests for testing library internals, APIs, and features
  - The test suite cannot be easily used with arbitrary settings like property lists, VFDs and VOL plugins
  - Work needs to be done to separate tests for HDF5 “native” specific VOL and general VOL plugins
    - Approach
      - Add test suite that was created for REST VOL and can be used by DAOS VOL
      - Refactor existing HDF5 test suite as we move forward

HDF5 Map Object

- **HDF5 map object (key-value store) is extension to "classical" HDF5 data model**
  - HDF5 uses key-value stores internally but doesn't expose a generic key-value store to the API.
- **Application uses HDF5 map object to index information stored in HDF5 file**
  - Use case (NASA JPSS data processing): find a dataset in a file with an attribute (or attributes) with a particular name and value(s), and run analytics on the dataset array.
  - Currently, one has to open all datasets in the file and read all attributes to find the one that is needed.
  - One can use map object to store ALL attributes (name, <value, object address or path>)
- **New HDF5 Map APIs**
  - Available only with DAOS plugin
  - H5M interface with the following operations
    - Create, open, iterate
    - Set/get key-value pair
    - Check if key exists
    - Get datatypes for keys ad values
    - Get number of key-value pairs store in the map object

Asynchronous I/O

Motivation

- **Time on HPC clusters is very valuable**
- **With traditional I/O, when waiting for write to complete, processors are idle**
  - Wasted time that could be used for computation
- **Asynchronous I/O: perform I/O in the background while processors continue computation**

Programming Model

- **Enable AIO on HDF5 file via file access property list (FAPL)**
  - `H5Pset_async(fapl_id)`
  - All operations are async that do not query file or hold buffer
    - Do not need to rework existing applications
- **Enable AIO on individual operation via dataset transfer property list (DXPL)**
  - `H5Pset_async_op(dxpl_id)`
  - Operations using this DXPL are always asynchronous
    - Application must ensure completion before reusing buffer (for write) or checking result (for read)

Implementation

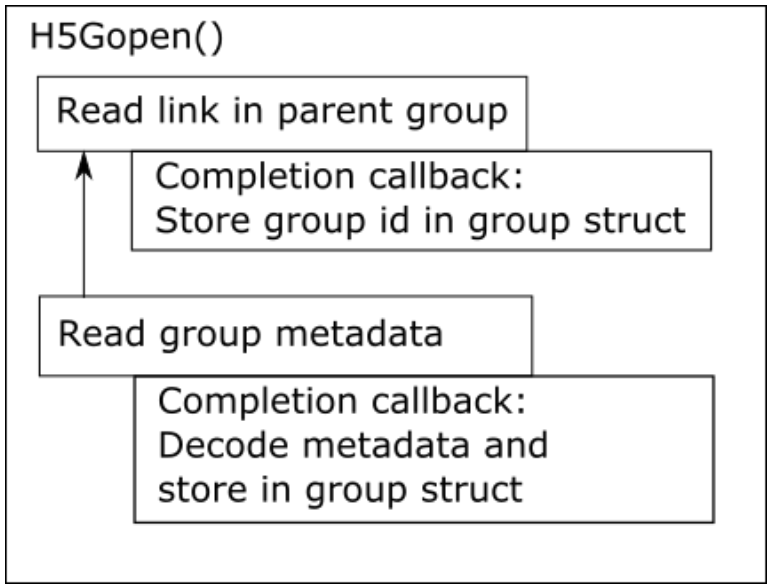
- **Threadless progress engine**
  - To make progress, check for AIO task completion, execute callbacks for completed tasks, and initiate execution of dependency children
  - Make progress whenever entering the HDF5/DAOS layer
- **Use DAOS task API to implement much of the progress engine**
  - Must integrate support for MPI asynchronous operations
- **App may spawn dedicated progress thread**
  - No need to call into HDF5/DAOS layer to make progress

Internal AIO

- **DAOS and MPI operations within an HDF5 operation can always be made asynchronously even if not requested through HDF5 API**
  - Wait at end of HDF5 operation if not asynchronous HDF5 op
- **Create dependencies between DAOS and MPI operations as needed**
- **On metadata write operations, place all operations in a DAOS transaction to make the HDF5 operation atomic**

Internal AIO Example: H5Gopen() (Independent)

- Must read link from parent group to retrieve target group's DAOS ID
- Using DAOS ID, read metadata from group's DAOS object
- Deserialize metadata and assemble in-memory group structure

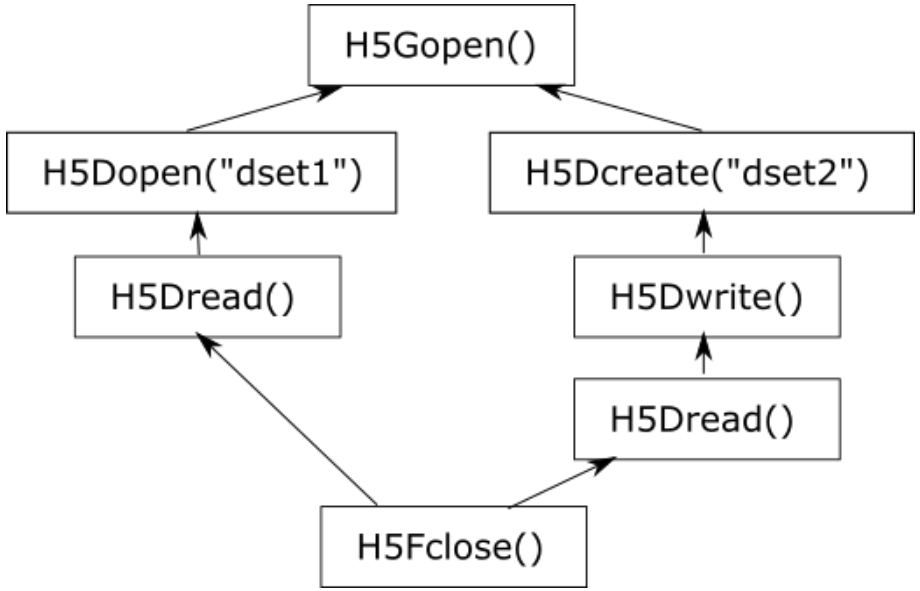


External AIO

- When HDF5 operations depend on each other, do not block on parent operation
- Create graph of DAOS/MPI operations that spans multiple HDF5 operations
- Use the same progress engine to manage the overall AIO graph
- Only applicable when AIO requested on the HDF5 file

External AIO Example

- Open a group
- Open two datasets in the group
- Read from one dataset, write to then read from the other
- Close the file



Possible Issues

- **Error reporting is more difficult – if an operation fails long after it started how do we inform the application which operation failed?**
  - Rollback entire file to state before failed operation?
- **Increased code complexity (both for internal implementation and applications)**
- **Application may not be able to progress if it can't modify the write buffer (general AIO issue)**

Implementation Roadmap

- **Build in AIO support at low level as operations are implemented**
  - Internal AIO
- **Add in support for external AIO**
- **Add support for HDF5 AIO API when available**
- **Add tests as features are implemented**

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