HDF5 Roadmap for 2019-2020 and Beyond

September 17, 2019

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Outline

- HDF5 Open Source Project
- HDF5 Challenges
- HDF5 Major Capabilities
- HDF5 Roadmap for 2019-2020
  - HDF5 releases schedule
- New Features in Design
- SWMR Demo
HDF5 Open Source Project
Challenges and solutions
HDF5 Open Source Project Challenges

- **OSS Project = Software + Community**
  - Project is not sustainable without community support and involvement
- **HDF5 project lacks community contributions**
  - Complex and undocumented software architecture
  - Obscure location of source code repository, issues database and documentation
  - Cumbersome process of submitting patches
  - Lack of coding and development process standards
  - Minimum time available to The HDF Group developers to work with the contributors
  - ”Conflict” between community interests and The HDF Group’s paid projects
  - ....
HDF5 Open Source Project Challenges (cont’d)

- How can we solve this problem?
  - Address the issues of HDF5 developers’ documentation
  - Publish our internal standards
  - Grow a team of external developers by working with individuals
  - Collaborate with developers of HDF5 ecosystem software (e.g., h5py, HDFql) and encourage them to contribute to HDF5
  - Outreach:
    ‣ Workshops
    ‣ Users’ groups
    ‣ Technical Webinars
    ‣ Blogs
Building HDF5 Contributors Community

- **HDF5 JIRA access**
  - HDF5 JIRA is open
    - Register at [https://hdfgroup.org](https://hdfgroup.org)
    - Login to [https://jira.hdfgroup.org](https://jira.hdfgroup.org) with your login and password
      - Browse issues
      - Vote for issues

- **HDF5 Help Desk**
  - Submit and watch your issues via Atlassian Service Desk

- **Access to HDF5 Bitbucket**
  - We opened access to HDF5 repository in Bitbucket
    - Register at [https://hdfgroup.org](https://hdfgroup.org)
    - Contact [help@hdfgroup.org](mailto:help@hdfgroup.org) for Bitbucket account

- **Contact us to present your project at our Webinar or write a blog**
  - [HDFql](https://www.hdfgroup.org) talk will be scheduled in November/December 2019
Strengthening Connections with HDF5 Ecosystem Community

- Community Portal  [https://www.hdfgroup.org/community/](https://www.hdfgroup.org/community/)

HDF5® and HDF4® both have rich ecosystems of applications created by our user community. The following are different collections of these software tools.

- HDF5®
  - Software using HDF5 sorted by name or application type.

- GitHub
  - HDF5 software projects on GitHub.

- PyPi
  - Python-related HDF5 software projects.

- HDF4®
  - Summary of software using HDF4.
Connecting to HDF5 Ecosystem Community

- Github has 1,533 HDF5 related projects
  - Language wrappers or High-Level APIs
  - Converters (PyROOT, Pandas-to-Postgress)
  - Visualization and browsing tools
  - Packages to work with specific types of data (e.g., times series)
  - Focus on ease of access to data stored in HDF5
  - Many are dormant or abandoned
  - Let use know about your software and we will add it to our Community Portal
  - Present at our Webinar and internal technical seminar

- Invite us to collaborate
  - Proposals
  - Papers
  - Conferences, etc.

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HDF5 Roadmap for 2019-2020 and beyond
h5py collaboration

- Current collaboration with h5py developers
  - Minimum interaction and contributions
  - The HDF Group members are working on code contribution for new chunk query functions
    ‣ Released in 1.10.5 and 1.12.0
    ‣ Provide locations, lengths and filters information
    ‣ Can be used for direct access to data stored in HDF5 without HDF5 library
  - Monitor and answer questions on h5py FORUM (Github)
  - Use h5py and Kita Lab in The HDF Group Tutorials

- Plans
  - Work with h5py community on CI with HDF5 under development
  - Engage h5py representative(s)
HDFqI – High Level Language to Manage HDF5 Data

**Simple**
Designed to be as simple as SQL. Hides complex operations and frees users from low-level details.

**Reliable**
Unfailing robustness and reliability. HDFqI is checked against hundreds of existing tests before new versions are released.

**Clean**
Offers a clean interface requiring just a few intuitive statements even for complex operations. Gone are the days where HDF5 required endless lines of code.

**Writes**
Unlike other tools, HDFqI not only reads HDF5 but also allows you to write HDF5 data.

**Fast**
Processes data using all nodes and cores available. This means much higher volumes of data are processed in the same amount of time.

**Portable**
Portable across C, C++, Java, Python, C#, Fortran and R using one uniform high-level language.

**Intuitive**
Based on models of human cognition and natural language. Fast learning curve.

**Platforms**
Supports Windows, Linux, macOS.
HDFqI collaboration

- Presented at ISC 19 in Frankfurt, Germany
- Scheduled to present at THG Technical Seminar later this Fall
- HDFqI Blog
  - New blog is coming!
HDF5 Challenges

Performance
Extending HDF5 capabilities
HDF5 Challenges

- Maintenance of core HDF5 library and tools
- Modularity for easy maintenance and external contributions
- Architectural and maintenance documentation
- Backward and forward compatibility
- Performance
  - Establish performance regression testing
  - Enhance sequential performance
    ‣ Hyperslab selection mechanism
    ‣ Support for many (>1K) objects in the file
HDF5 Performance

CGNS library: Testing times with different HDF5 versions

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HDF5 Roadmap for 2019-2020 and beyond

Writing 5K datasets with different versions of HDF5
CGNS Application Before and After Tuning

Courtesy Greg Sjaardema, Sandia National Labs
How you can help us

- Contact The HDF Group ASAP when you see performance degradation
- Submit application I/O kernel to our performance regression test suite
- Contact us
  - help@hdfgroup.org
  - prioritysupport@hdfgroup.org for Enterprise Support customers
HDF5 Development Directions

- Extending the current way of performing I/O
  - One process writing/reading to/from HDF5 file(s) (sequential)
  - Multiple processes writing/reading to/from shared file using MPI I/O (parallel)
- Extending HDF5 capabilities with
  - Virtual Object Layer (VOL)
  - Virtual File Drivers (VFD)
- Accessing HDF5 data on non-POSIX systems
  - Cloud
  - Object Store
  - Burst buffers
- More on the following slides
HDF5 Major Capabilities
HDF5 1.10 and 1.12. releases
Overview

- Parallel HDF5 enhancements
  - Scalability for file open/close
  - Collective metadata I/O
  - Writing compressed data in parallel
- Watch for a Webinar announcement later this Fall
Overview

- Sequential HDF5 enhancements
  - Driven and funded by Light Source Community
    ‣ Dynamically loaded compression filters
    ‣ Direct access to chunked data to speed up I/O (direct chunk write/read)
    ‣ Access to data stored in multiple files and datasets (Virtual Dataset or VDS)
    ‣ Access to HDF5 file under construction (Single Writer/Multiple Reader or SWMR)
  - File space management
    ‣ Reusing free space in the file
  - Paged allocation and page buffering for better I/O
  - Control over HDF5 “file version” (i.e., which version of the library can read this HDF5 file?)
  - ....
Where to find information about new releases?

HDF5 Application Developer’s Guide
Release Specific Information

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HDF5 Roadmap for 2019-2020 and beyond
Motivation for HDF5 Virtual Dataset

Data the application will see when reading VDS dataset from vds.h5
The last row is filled with the fill value.
Use Cases for Unlimited Datasets

Virtual Dataset VDS with "gaps"

Series of images

File names are generated by printf

Virtual Dataset VDS has images A, B, C and D interleaved
HDF5 Virtual Dataset

- New storage property introduced in HDF5 1.10.0
- Allows to “aggregate” data stored in multiple HDF5 datasets and files
- Works with SWMR
- Not a performant feature
  - Possible improvements
    ‣ Hyperslab selections performance
    ‣ Caching open files
    ‣ More mapping use cases
      ‣ Example: “snake” mapping

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**Single Writer/Multiple Reader (SWMR)**

- Introduced in HDF5 1.10.0
- Implementation has many limitations
  - Based on POSIX semantics
    - No support for NSF
  - Works for raw data only
    - File structure cannot change
  - New data may not be visible for some time
  - Not high-performing
  - Doesn’t work for parallel applications
  - Introduced file locking
  - Order of writer and reader is critical

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HDF5 Roadmap for 2019-2020 and beyond
Full Single Writer/Multiple Reader (SWMR)

- **Goals**
  - Drop POSIX semantics requirement
    - Support for NFS
  - Allow modification of a file structure
    - Adding groups, links, datasets and attributes
    - Adding support for VL types
  - Guarantee maximum time from write availability to availability for read
  - Minimize maintenance cost
    - SWMR VFD
Demo
New SWMR implementation
Page buffering/ Paged allocation

- Introduced in 1.10.0
- Aggregate and align metadata and small data, and perform I/O on aligned pages
- See File Space Management Documentation
  https://portal.hdfgroup.org/display/HDF5/File+Space+Management
  ‣ One can reuse free space in the file between file open/close
Data and Metadata Aggregators

The aggregators pack small raw data and metadata allocations into aligned blocks (pages) which work with the page buffer.
HDF5 Page Buffering

Page buffer contains MD and small data pages (L2 cache)

Pages are aligned

HDF5 File
HDF5 Page Buffering

HDF5 APIs

Internals, MDC cache, preparation for I/O

L2 cache

HDF5 Library

I/O is performed on pages

VFD

HDF5 File

HDF5 Roadmap for 2019-2020 and beyond
HDF5 Reference Datatype in 1.12.0

HDF5 dataset may store references to other objects or references to selected elements of a dataset.

References to objects in other files are coming in HDF5 1.12.0.
HDF5 1.12.0 will allow to reference an attribute of a dataset or a group.
Extending HDF5 Capabilities with VOL and VFD

**Motivation**

- Our user and customers including vendors invested in HDF5 and HDF5-based software, but now HDF5 file format shows its limitations
- Everyone likes HDF5 data model for its simplicity and versatility
- Questions we asked ourselves:
  - How current HDF5 applications can take advantage of new storage paradigms?
  - How HDF5 data can be used with Big Data Technologies like Spark and Hadoop?
  - How can we take advantage of new storage paradigms to improve I/O performance?
  - How can we provide access to HDF5 data on new storage like Object Store and Cloud?
  - *Can we extend current HDF5 to answer the above questions with minimum modifications to HDF5 applications?*
HDF5 1.12 Library Architecture

Colored shapes represent library components available in the current releases.
HDF5 Applications Capabilities
Minor or no changes to applications are required to store data in the Cloud or Object Store

HDF5 Roadmap for 2019-2020 and beyond
HDF5 VOL Connectors

- [https://bitbucket.hdfgroup.org/projects/HDF5VOL](https://bitbucket.hdfgroup.org/projects/HDF5VOL)
HDF5 VOL Connectors (cont’d)

- Watch for a Webex on how to create a VOL connector
S3 VFD

- HDF5 1.12.0 will have a VFD to access HDF5 file via Amazon Simple Storage Service (Amazon S3)
  - Requires minimum changes to the application code
- h5dump and h5ls tools have a flag to access HDF5 file on S3
  
  h5ls --vfd=ros3

  https://s3.us-east-2.amazonaws.com/file.h5

- Uses “range get” commands to get “bytes” from HDF5 file stored on S3
- New API to set up S3 VFD
  
  herr_t H5Pset_fapl_ros3(hid_t fapl_id, H5FD_ros3_fapl_t *fa)
  
  - Credentials are passed via parameter to the function
HDFS VFD

- HDF5 1.12.0 will have a VFD to access HDF5 file on Hadoop Distributed File System (HDFS)
- New API to access HDF5 file on HDFS
  
  herr_t H5Pset_fapl_hdfs(hid_t fapl_id);

- HDF5 command line tools with enabled HDFS VFD allows to extract metadata and raw data from HDF5 and netCDF4 files on HDFS, and use Hadoop streaming to collect data from multiple HDF5 files
HDF5 2019-2023
Roadmap

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HDF5 Roadmap for 2019-2020 and beyond
**HDF5 Roadmap 2019 - 2020**

### HDF5 1.8

- **2019**
  - Q1
  - Q2
  - Q3
  - Q4
  - Today

- **2020**
  - Q1
  - Q2
  - Q3
  - Q4

- **Fall 2019**
  - 1.8.22
- **Summer 2020**
  - 1.8.23

### HDF5 1.10

- **November 2019**
  - 1.10.6
- **May 2020**
  - 1.10.7
- **November 2020**
  - 1.10.8
- **May 2021**
  - 1.10.9

- **Address degradation of performance between major HDF5 releases 1.6 – 1.10**
- **VDS HDF5 performance**
- **Public performance benchmark test suit**
- **S3, HDFS, Spark VFD connectors**

### HDF5 1.12

- **September 2019**
  - 1.12.0-beta
- **December 2019**
  - 1.12.0
- **2020-2021**
  - 1.12.X

- **VOL architecture**
- **References**
- **Parallel compression (enhanced)**
- **VOL plugins (DAOS)**
- **VFD plugins**
- **Dynamically loaded VFDs**
- **S3, HDFS, SPARK VFD connectors**
- **Query and indexing**
- **Full SWMR**
- **Mirror VFD**
- **Provenance (Onion) VFD**

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HDF5 2.0 instead of 1.14.0? Storage beyond the current File Systems and HDF5 file format

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HDF5 Roadmap for 2019-2020 and beyond
New features for Experimental and Observational Sciences
Mirror VFD

Local

- HDF5 Library
  - VFD Layer
  - Splitter VFD
  - Sec2 VFD

Remote

- Scheduler
  -- port assign
- mirror_r VFD
  -- Sec2 VFD

Local Host File System

Remote Host File System

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HDF5 Roadmap for 2019-2020 and beyond
HDF5 Query and Indexing will be released in HDF5 in 2020.

Query: "link = Pressure"
AND
"attr='SensorID'"
AND
"attr_val=2"
AND
"17 < val < 22"
Sparse Storage

- HDF5 was designed for “dense” array storage, when most of the array elements are defined:

- How to store sparse array efficiently? How to find the array elements that are defined?

- Share with us your use cases!

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HDF5 Roadmap for 2019-2020 and beyond
HDF5 File Provenance

- HDF5 offers no support for version control and provenance management.
- Data provenance is a major concern in cases where:
  - Original data must be preserved.
  - Changes are tracked and attributed.
- General HDF5 “undo” capability is technically challenging.
- Tracking changes per file open/close cycle may be sufficient:
  - Divide HDF5 file linear byte space into pages.
  - Build index that maps offsets in the files to the pages.
  - Save modified pages in the new locations and have new index associated with the modified file.
- There are several approaches to where we store modified pages and indexes.
HDF5 File Provenance

HDF5 file paged allocation is used to track changed pages:
1. Tracking in the same file
2. Additional file with tracked pages
3. Additional files for each version

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HDF5 Roadmap for 2019-2020 and beyond
New features for HDF5 Parallel Library

Sub-filing
HDF5 Sub-filing

- Sub-filing
  - M processes write to N files to reduce lock and contention issues on PFS
  - Compromise between shared file and file/per process approach
- VDS was used for prototyping HDF5 sub-filing feature
  - Transparent to application
  - Promising performance
  - See “subfiling” branch in HDF5 repo
HDF5 Sub-filing (cont’d)

- Initial performance results are promising
Thank you!

Questions?