h5bench: HDF5 I/O Kernel Suite for Exercising HPC I/O Patterns

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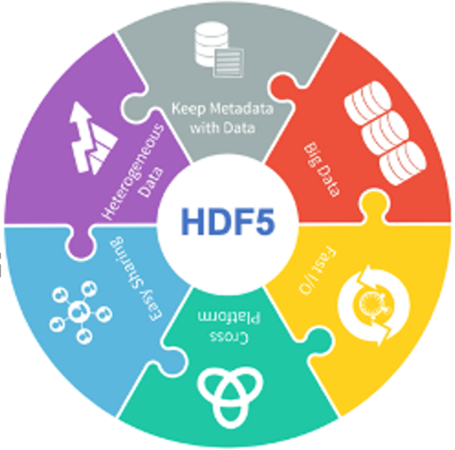
Agenda

- Brief intro to HDF5
- Existing HDF5 benchmarks
- Issues and requirements
- h5bench
- Evaluation on Cori
  - Write benchmark
  - Read benchmark

HDF5 - I/O API, self-describing file format

- Self-describing file format, API, and tools designed to store, access, analyze, share, and preserve diverse, complex data in continuously evolving heterogeneous computing and storage environments
    - Maintained and developed by The HDF Group in collaboration with the ECP ExaIO team
    - https://github.com/HDFGroup/hdf5
- Heavily used library on DOE supercomputing systems
- Many ECP AD & ST teams have critical dependency on HDF5



Existing HDF5 performance benchmarks

- h5perf
- Application specific benchmarks
  - Flash-IO benchmark
  - HACC-IO
  - …
- I/O patterns
  - IOR has a HDF5 output
  - MinIO
  - PIOK (Parallel I/O kernels)
    - VPIC-IO, BD-CATS-IO, VORPAL-IO, GCRM-IO
  - …

Issues with existing benchmarks

- Coverage of access patterns is sparse
- New HDF5 optimizations are not implemented
  - Asynchronous I/O
  - Caching
  - I/O between GPU and storage
- Other tuning parameters are not exercised
  - MPI-IO aggregation strategies (collective buffering settings)
  - File system-specific tuning parameters (alignment, striping, etc.)

Requirements

- Coverage of representative app I/O patterns (read / write, data / metadata, locality)
- Scalable
- Exercise new HDF5 features
- Tuning parametersI/O software layers
  - File system layer

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ECP EXASCALE COMPUTING PROJECT

h5bench - A suite of HDF5 benchmarks

- Captures various I/O patterns
  - Locality in memory and in files
    - Contiguous, strided, compound data types (structures)
  - Array dimensionality - 1D, 2D, and 3D
- I/O modes
  - Synchronous
  - Asynchronous - Implicit and explicit
    - to overlap I/O time between successive compute phases
- Processor type - CPUs and GPUs
- MPI-IO modes
  - Collective buffering on or off
- File system configuration
  - Alignment and striping

Other configurable options in h5bench

- Several configurable parameters
  - Scale -- number of MPI processes
  - Data size per MPI rank
  - Dimensionality
  - For read benchmark - read all data, partial data, random data
  - Emulated computation phase time
  - Memory limit for double-buffering in asynchronous I/O
  - MPI-IO collective buffering
- Metadata stress testing benchmarks

Code repository and usage instructions

- Available on GitHub for public access
  - https://github.com/hpc-io/h5bench
  - README.md has instructions to install, configure, and use
  - Contact: sbyna@lbl.gov / koziol@lbl.gov
- GPU benchmarks are in a separate branch
  - PR and code review in progress
- Open source to add new benchmarks or to fix current code
  - Communicate with us about any new benchmarks to add
  - Fork, add new HDF5 benchmarks / modify / bug fixes, and submit a PR

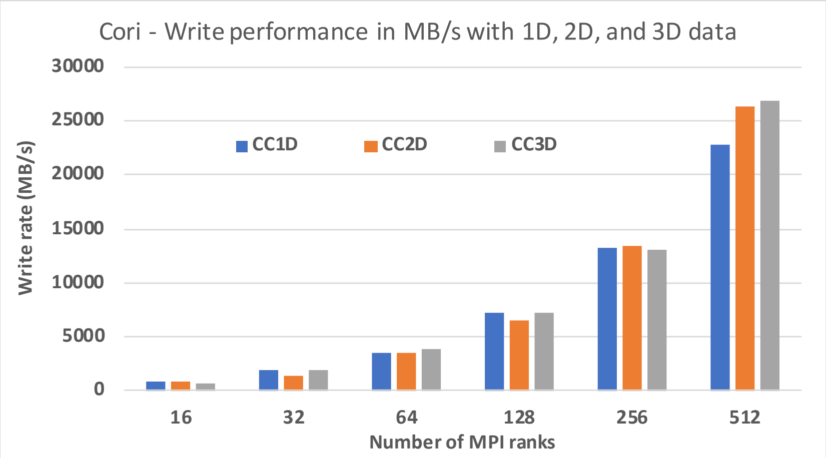
Early evaluation on Cori

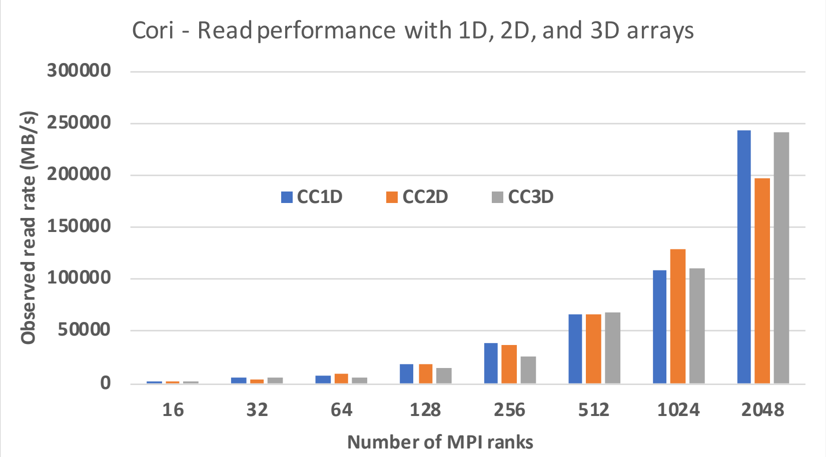
- Cori - Cray XC40 system at NERSC
- Configuration used in early evaluation
  - Haswell partition with 32 cores per node
  - Lustre parallel file system
- I/O Patterns
  - Write benchmarks at various scales
    - Dimensionality - 1D, 2D, and 3D
    - Locality - memory and file offsets
    - Synchronous and asynchronous I/O
  - Read benchmarks
    - Reading the entire data - synchronous and asynchronous
    - Reading a subset of data

Write benchmarks - 1D, 2D, 3D

- Contiguous in memory and in file
- 8 million particles per MPI rank (weak-scaling)
- 8 variables per particle
- Organized as 1D, 2D, and 3D

Initial results show similar performance for contiguous writes (in memory and in file) of 1D, 2D, and 3D arrays





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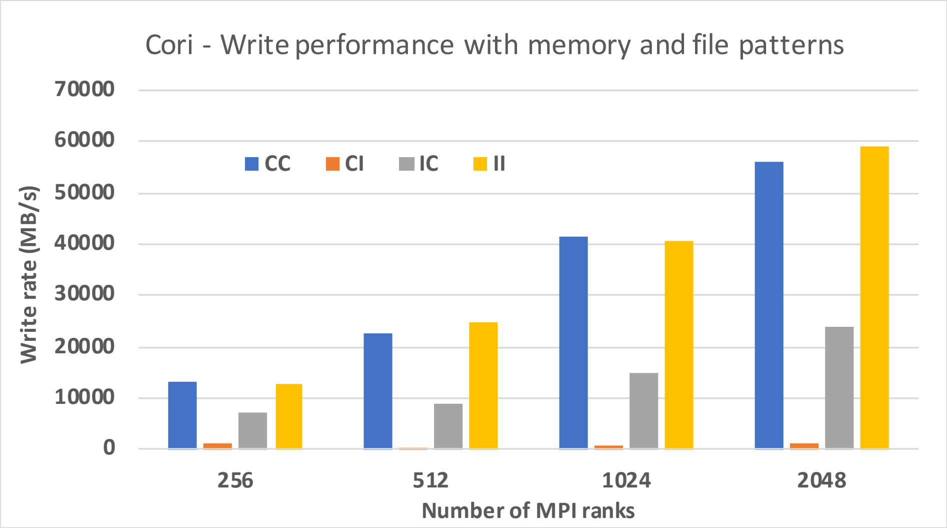
Write benchmarks - Memory and file patterns

- Memory and file contiguity
- Contiguous - Memory buffers map to HDF5 file datasets directly
- Noncontiguous
  - Memory buffer is a C struct
  - HDF5 dataset is a compound datatype (C struct-like)

Constructing a compound datatype achieves poor performance

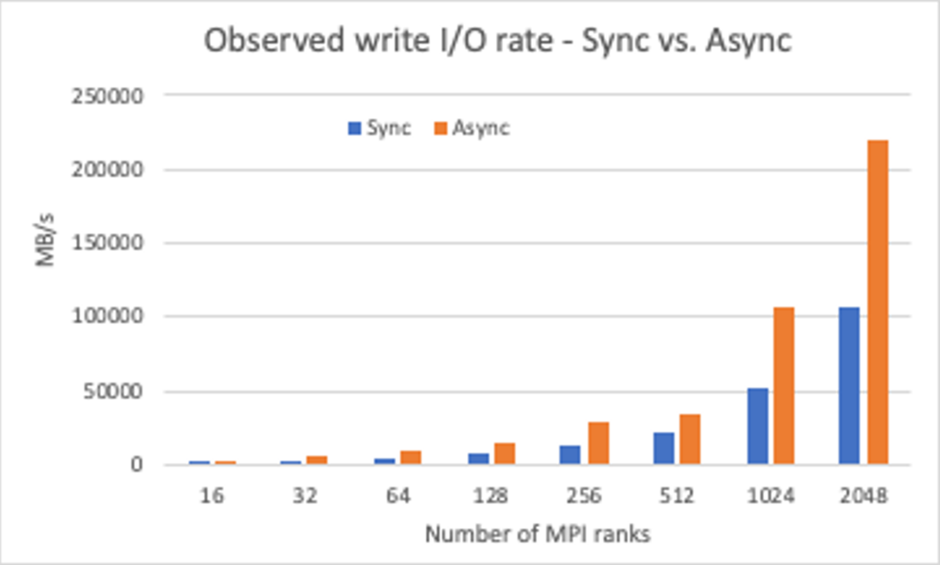
Direct mapping of memory and file data structures achieves good performance



Write benchmarks - Sync vs. Async I/O

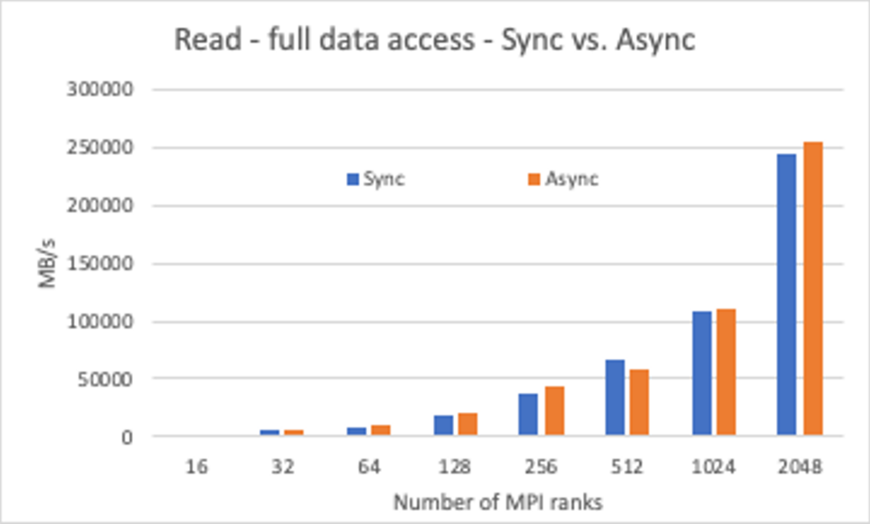
- Writing 5 time steps of data
- Computation phases between I/O phases
- Workloads similar to simulations that periodically checkpoint or write their memory state

I/O time is effectively overlapped by computation phases



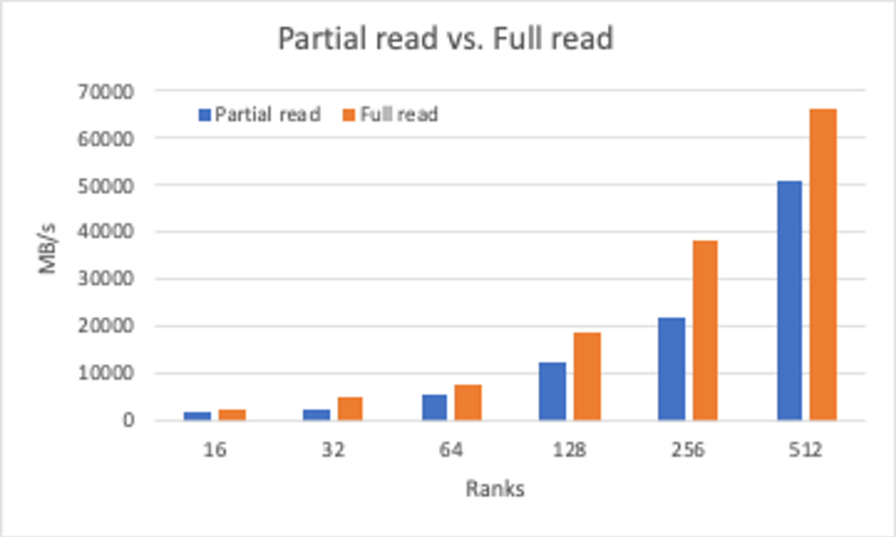
Read benchmarks - Full data access

- Reading all HDF5 datasets that write benchmark stored
- 8 variables, 8 million particles per rank
- Single time step
- Synchronous and asynchronous modes
  - Read right after writing
  - Caching effects have not been isolated
  - Further testing is in progress



Read benchmarks - Partial

- Read partial amount of data
  - First 10% particle data in each variable
- Reading full data achieves better I/O rate
  - Contiguous and large accesses
  - Further testing is in progress



Conclusions

- h5bench
  - Provides a wide variety of I/O patterns
  - Allows weak-scaling and strong scaling
  - Exercises new HDF5 features
  - Configurable options for tuning parameters
- Evaluation to understand I/O behavior is in progress (Full paper)
- Future work
  - Add more HDF5 features -- caching on node-local storage, metadata buffering, new file system features (Lustre progressive file layouts, etc.)
  - Add more I/O kernels or RW patterns from ECP and EOD applications -- variable length, streaming, ML / AI workloads

Thanks to ECP, and to the ExaIO HDF5 team (The HDF Group, ANL, LBL)