Guiding Parallel I/O – The Semantical Gap

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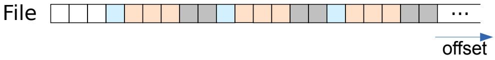
Gliederung

Semantical Gap of File Access (1)

Applications work with (semi)structured data

- Vectors, matrices, n-Dimensional data

A file is just a sequence of bytes!



Applications/Programmers must serialize data into a flat namespace

- Uneasy handling of complex data types
- Mapping is performance-critical (on HDDs)
- Vertical data access unpractical
  (e.g. to to pick a slice of multiple files)

Semantical Gap of File Access (2)

Information hidden from file systems

- Data types
- Data semantics
- Value of data
- Type: Checkpoint, computed, original, logfile
- Data lifecycle: production, usage, deletion

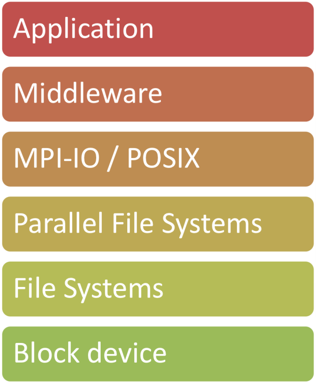
Characteristics can even vary within a file, e.g. for metadata

Storage systems could use this information for

- Improving performance: Automatic tiering, caching, replication
- Simplifying management: ILM, offering alternative data views
- Correctness: Ensuring data consistency

Peeking at the Current I/O Stack – System Perspective

- Coexistence of access paradigms
  - File (POSIX, ADIOS, HDF5), SQL, NoSQL
- Semantical information is lost through layers
  - Suboptimal performance
- Reimplementation of features across stack
  - Unpredictable interactions
  - Wasted ressources
- Restricted (performance) portability
  - Optimizing each layer for each system?



Example I/O stack

User Perspective: Accessing Data

Multitude of data models

- POSIX File: Array of bytes
- HDF5: Container like a file system
  - Dataset: N-D array of a (derived) datatype
  - Rich metadata, different APIs (tables)
- Database: structured (+arrays)
- NoSQL: document, key-value, graph, tuple

Choosing the right interface is difficult.
A workflow could involve different data models.

Properties / qualities

- Namespace: Hierarchical, flat, relational
- Access: Imperative, declarative, implicit (`mmap()`)
- Concurrency: Blocking vs. non-blocking
- Consistency semantics: Visibility and durability of modifications

Consistency Semantics

Example: Two processes accessing one file ("data", offset, size)

P1: write("1", 0, 1024) write("1", 1024, 1024) read(0, 2048)

P2: write("2", 0, 1024) write("2", 1024, 1024) read(0, 2048)

Which data is stored and read depends on the execution sequence AND the consistency semantics.

Aspects of consistency

- Visibility to the modifying processes vs. other processes
  - Distributed system makes consistency expensive
  - Delay before modifications become visible – Inconsistency window
- Granularity in which modifications are atomic
  - No guarantee, single operation, batch or transactions

Consistency Models (Selection)

- Strict (linear) consistency (POSIX)
  - Modifications made to NFS if accessed by only one node
- Sequential consistency
  - Any possible sequential execution possible
  - Processes have the same view always
  - Atomic-Mode for MPI-IO (applicable for collective file access)
- Weak consistency
  - Inconsistency “window”
- Eventual consistency (DNS, Amazon S3)
  - Inconsistency window can be estimated
  - Especially for replicated services
- Read-after-write consistency (does not include data updates)
  - Amazon S3 rolling upgrade in US between 2009 and 2012: Now all clients see new data
- Release consistency (like the session model of NFS)

Performance Tweaks

- There are many options to tune the I/O-stack
  - API: `posix_fadvise()`, HDF5 properties, open flags, cache size
  - Via command line: `lfs setstripe`
  - Setup/initialization of a storage system
- Many options are of technical nature
  - Performance gain/loss depend on hardware, software
  - Specific to file system, API (MPI, POSIX, HDF5)
  - Many types of hints/tweaks are not portable
- Performance loss forces us to use these optimization

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Usually we are losing system performance!

Critical Discussion

Questions from the users' perspective

- Why do I have to organize the file format?
  - It's like taking care of the memory layout of C-structs
- Why do I have to convert data between storage paradigms?
- Why must I provide system specific performance hints?
  - It's like telling the compiler to unroll a loop exactly 4 times
- Why can't I rely on a correct implementation of the (POSIX) consistency model?
  - Parallel file systems have their issues with most models
- Why is a file system not offering the consistency model I need?
  - My application knows the required level of synchronization

Would you rather like to code your actual application?

Guided Interfaces

Guiding vs. automatism vs. technical hints

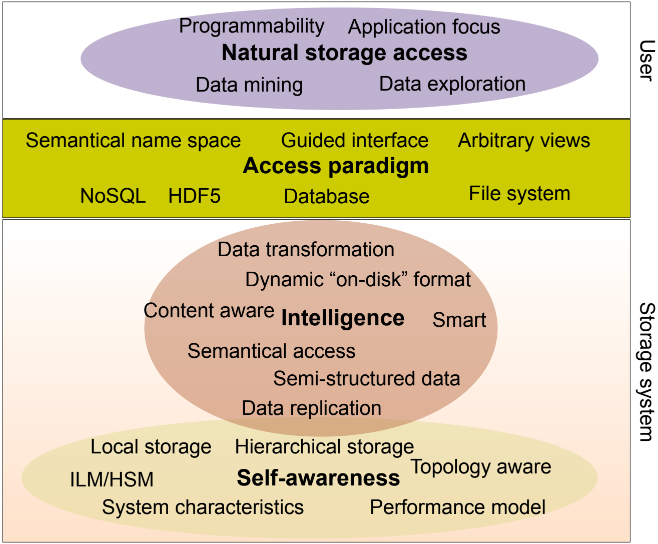
Users provide additional information to guide an intelligent system.
The I/O stack exploits this information.

Information which could be provided by users

- Data types
- Semantics
- Relations between data
- Lifecycle (especially usage)

Several issues have been addressed in different access paradigms.
Also some behavioral hints exist: open() flags, fadvise(), ...

Personal Vision of Future Storage Systems



Ongoing Projects

Newer, current and future projects aim to

- Converge / unify the I/O stack
- Abstract from existing solutions, e.g. by a middleware
- Offer new ways of exploiting user information / semantics

Let's peek at

- ADIOS
- Fast Forward Storage & IO
- Exascale10

ADIOS

Adaptable IO System

- Alternative high-level I/O interface
  - Annotations of variables similar to HDF5
- Offers various back-ends: POSIX, MPI-IO, NULL or in-situ vis.
- Own file format (BP)
  - Throughput oriented, avoids synchronization
  - An ADIOS file may be represented by one or multiple objects
  - Easy conversion of BP files into NetCDF or HDF5
- XML specification of variables and run-time parameters
  - Adapt programs to the site's file system without code adjustment
  - Translate XML into C or Fortran code to read/write data

Example code using ADIOS

```
    int NX = 10, NY = 10, NZ = 100;  double matrix[NX][NY][NZ];
    MPI_Comm comm = MPI_COMM_WORLD; int64_t adios_handle;
    int adios_err; uint64_t adios_groupsize, adios_totalsize;

    MPI_Init(&argc, &argv); MPI_Comm_rank(comm, &rank);
    adios_init("example.xml");

    for (t = 0; t < 10 ; t++) {
      adios_start_calculation();
      /* computation */
      adios_stop_calculation();
      /* MPI communication */
      adios_open(&adios_handle, "fullData", "testfile.bp", t == 0
          ? "w": "a", &comm);
#include "gwrite_fullData.ch"
      adios_close(adios_handle);
      /* indicate progress for write-behind */
      adios_end_iteration();
    }

    adios_finalize(rank); MPI_Finalize(); return 0;
```

Code automatically created from XML

gwrite_fullData.ch

```
adios_groupsize = 4 \
                + 4 \
                + 4 \
                + 8 * (NX) * (NY) * (NZ);
adios_group_size (adios_handle, adios_groupsize, &adios_totalsize);
adios_write (adios_handle, "NX", &NX);
adios_write (adios_handle, "NY", &NY);
adios_write (adios_handle, "NZ", &NZ);
adios_write (adios_handle, "matrix_data", matrix);
```

Efficient I/O

Caching

- ADIOS aggressively caches data
- Write-behind during compute phases
- Iterative programs can indicate pace by calling a function

User controls runtime behavior via XML

- Choose the back-end for a supercomputer and task
- Set optimal parameters such as the cache size
- Instruct to create derived data (histograms)

ADIOS XML code

```
<adios-config host-language="C">
  <adios-group name="fullData" coordination-communicator="comm"
    time-index="iteration">
    <attribute name="description" path="/fullData"
      value="Global array of memory data" type="string"/>
    <var name="NX" type="integer"/>
    <var name="NY" type="integer"/>
    <var name="NZ" type="integer"/>
    <var name="matrix_data" gwrite="matrix"  type="double"
      dimensions="iteration,NX,NY,NZ"/>
  </adios-group>

  <analysis adios-group="fullData" var="matrix_data"
    min="0" max="3000000" count="30"/>
  <method group="fullData"    method="MPI"/>
  <buffer size-MB="80" allocate-time="now"/>
</adios-config>
```

Fast Forward Program: Storage & IO

US Department of Energy; 2-year funding
Collaboration: Whamcloud/Intel, HDF5 group, Cray, EMC

Goals

- The Exascale I/O Workgroup (EIOW/Exascale10)
- Exascale storage for scientists
- Support complex analysis, increase scalability
- Fault-tolerance, data consistency and integrity

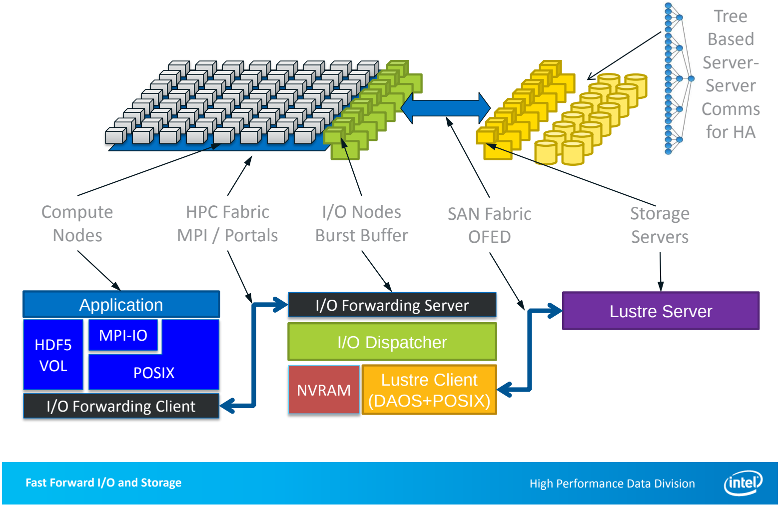
A completely redesigned IO stack for Exascale

- Objects instead of files
  - Array objects for semantic storage of multi-dimensional data
  - Blob objects for traditional sequences of bytes
  - Key-value stores for smaller get/put operations
- Containers instead of directories
  - Snapshots for efficient COW across sets of objects
  - Transactions for atomic operations across sets of objects
- List IO all the way through the stack
  - Reduce trips across network
- Everything fully asynchronous
  - Reads, writes, commits, unlink, etc
- Explicit Burst Buffer management exposed to app
  - Migrate, purge, pre-stage, multi-format replicas, semantic resharding
- End-to-end data integrity
  - Checksums stored with data, app can detect silent data corruption

Fast Forward I/O and Storage | High Performance Data Division | intel

Source: Presentation DOE Storage Fast Forward Quick Overview and Programming API's/Vignettes by Gary Grider

Fast Forward I/O Architecture

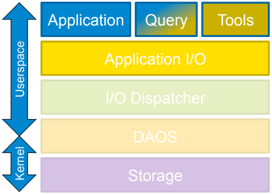


Source: Presentation DOE Storage Fast Forward Quick Overview and Programming API's/Vignettes by Gary Grider

I/O stack

Applications and tools

- Query, search and analysis
  - Index maintenance
- Data browsers, visualizers, editors
- Analysis shipping
  - Move I/O intensive operations to data



Application I/O

- Non-blocking APIs
- Function shipping CN/ION
- End-to-end application data/metadata integrity
- Domain-specific API styles
  - HDFS, Posix, …
  - OODB, HDF5, …
    - Complex data models

Fast Forward I/O and Storage High Performance Data Division intel

Source: Presentation Fast Forward I/O & Storage by Eric Barton

New HDF5 Capabilities

- Asynchronous Operations
  - All HDF5 routines that touch the file add event to an “event queue” object
  - Event queues have test/wait routines that operate on all events in queue, etc.
- Transactions
  - New “transaction” API in HDF5: open, commit, abort, etc.
  - Explicitly bundle HDF5 operations into a transaction
  - Explicitly push/pull data between flash and disk storage
- End-to-End Integrity
  - Checksums applied to all data on CN, stored all the way to disk, verified on reads

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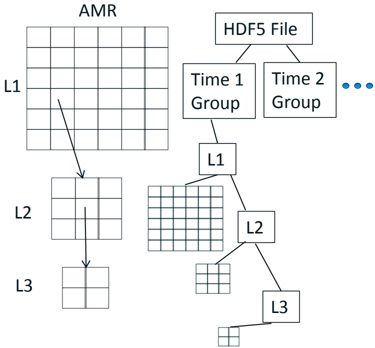
HDF5 (the current example of a high level API to this new IO stack)



H5TRbegin(trans1, eq1)
H5Fcreate(“FileA.h5”, … trans1, eq1)
H5Gcreate(…, trans1, eq1)
…
H5TRcommit(trans1, eq1)
<go do other work>
H5AOtest/wait(eq1)
H5TRbegin(trans2, eq2)
H5Dwrite(…, trans2,eq2)
…
H5TRcommit(trans2, eq2)
<go do other work>
H5AOtest/wait(eq2)

- You can even start a new transaction to do metadata or data ops with trans3++ and overlap as much IO and computation, including abort.
- You can't be sure anything made it to storage until H5AOtest/wait says that transaction is secure.
- You can control structure, async behavior, rollback, etc.

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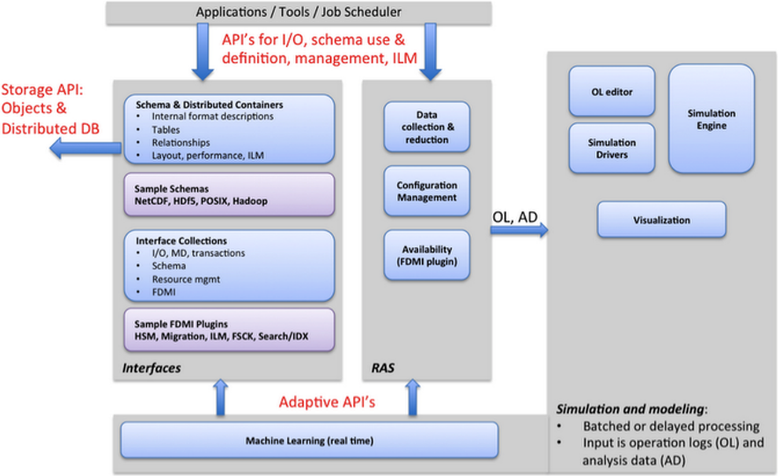
Source: Presentation DOE Storage Fast Forward Quick Overview and Programming API's/Vignettes by Gary Grider

Exascale10 / EIOW

- The Exascale I/O Workgroup (EIOW/Exascale10)
- Goal: Development of a Middleware with advanced features
  - Complete redesign of the I/O system
  - Different back-ends (hardware, file systems)
  - Arbitrary schemas (POSIX, HDF5, Flatland, ...)
  - Guided interfaces / Behavior indicators
  - Embedded monitoring & performance optimization
- International and open initiative
  - Collaboration: Xyratex, BSC, JGU Mainz, UHH, ...
  - Driven by the needs of the community (e.g. in requirement workshops)
  - Work-in-progress

Current architecture



Component decomposition (source: `http://eiow.org`)

Behind the Scenes

- Low-level interface: Key/Value store + data block objects
- A schema builds its operations on top of the low-level interface
- A domain bundles objects, indices, transactions into a container
- User-assigned IDs for objects
- Full asynchronous access
- Objects support attributes on block-level

For more details see "clovis: 1.0e18" by Nikita Danilov.

Consistency

A domain offers methods for consistent access

- At most one application may access a domain at a given time
- User-defined transactions encapsulate access to one domain
- No (low) inter-container consistency

```
clovis_tx_init(tx, callback);
clovis_tx_add(tx, op0);
clovis_tx_add(tx, op1);
clovis_tx_close(tx);
...
callback(tx)
{
  ...
  clovis_tx_done(tx);
}
```

Code snippet from the presentation “clovis: 1.0e18” by Nikita Danilov.

Summary & Conclusions

- File access paradigm will change
  - Transactions
  - Different namespace
  - Away from explicit technical hints
  - Applications have to realize their consistency model
- Guided interfaces provide insight into intended behavior
- Let the storage system and infrastructure take care of
  - Data conversion
  - Data arrangement & “file“ format
  - Performance optimization
  - HSM / ILM
- Take the chance to influence upcoming “standards”
  - Make sure your requirements are heard/handled
  - Consider joining the Exascale10 BoF and meeting at SC’13!

References

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