HighFive

Yet another C++ wrapper for HDF5

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HDF5 User Group Meeting
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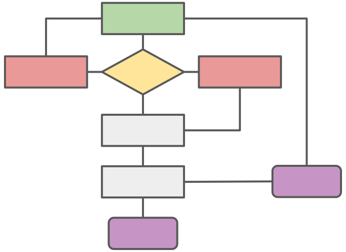
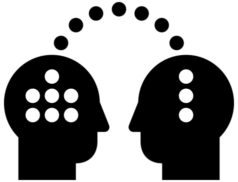
Portable scientific data formats are vital for scientific computing

A requirement for:

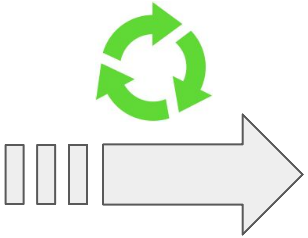


Complex Workflows

Reliable Data Storage



Knowledge transfer



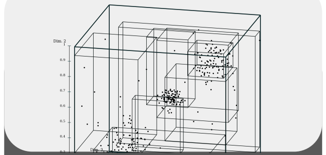
Long-term maintainability & reproducibility

HDF5

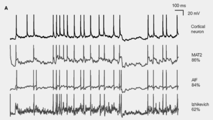
- The official HDF5 library is versatile and well supported, but it only provides a low-level C/C++ interface.
- Several C++ wrapper libraries exist, but are mostly domain-specific or incomplete.

I/O is an essential part of Neuroscience

HDF5 is critical to the Blue Brain Project. We require storing millions of neuron morphologies alongside their physiological properties, connections, and other data:



Circuit Building



Simulation Reports

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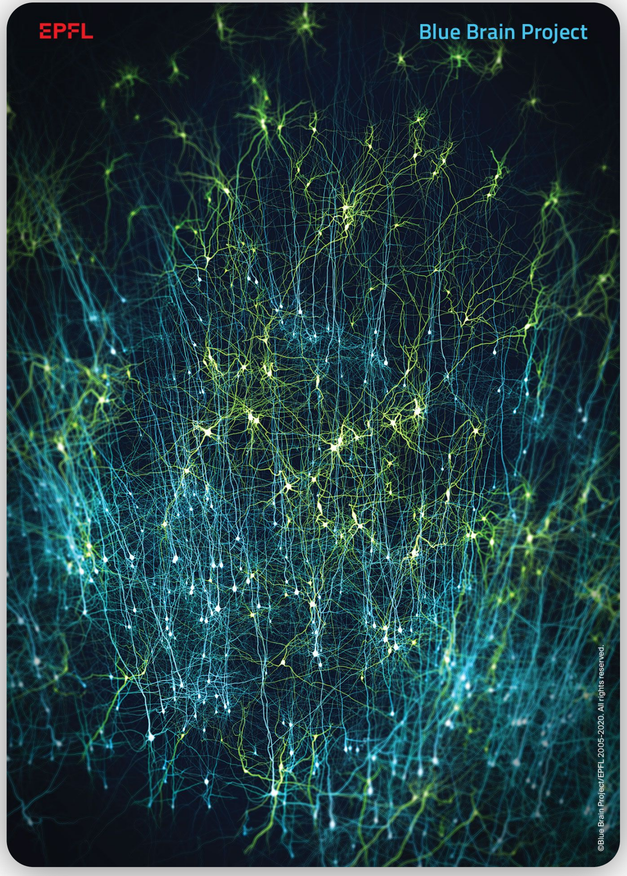
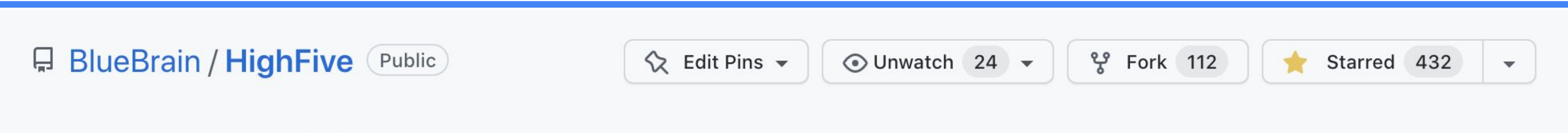
SONATA Format

As our codebase is mostly written in >=C++11, **we found the need for a suitable API for HDF5 in C++.**





A Modern C++11 Wrapper

Project started 7 years ago

Active community

16 Releases (9 official). Latest: v2.4.1

Programmer Friendly

Header-only library

API enables concise code
and provides sensible defaults

Wide Compatibility

Cross platform: Windows, Linux, Mac

Very few requirements: C++11, hdf5-1.8

Supports Eigen, Boost and more

Stability & Performance

Used in production at BBP

Good test coverage, multiple scenarios

Low overhead

HighFive: Looking under the hood

HighFive > RAII and resource management

HighFive utilizes RAII to handle object life-times and automatically manages reference counting on HDF5 objects from the C library.

The following example uses HighFive datatypes to create and open a dataset “`/a/b`” and fill it with four integers. The scope releases any associated resources:

```cpp
using namespace HighFive;
...

{
    File file("foo.h5", File::ReadWrite | File::Create);
    DataSet dataset = file.createDataSet("/a/b", std::vector<int>{1,2,3,4});
}
```

HighFive > RAII and resource management

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The following example uses HighFive datatypes to create and open a dataset “`/a/b`” and fill it with four integers. The scope releases any associated resources:

Internally, **HighFive __transparently__ manages the creation of the Group, DataSpace, Attributes, and more in HDF5**

```
using na

...

{
    DataSet dataset = file.createDataSet("/a/b", std::vector<int>{1,2,3,4});
}
```

HighFive > Type Conversion / Induction

The library uses C++ templating for automatic type mapping, even of non-contiguous types**.** This increases programmer productivity while reducing coding bugs:

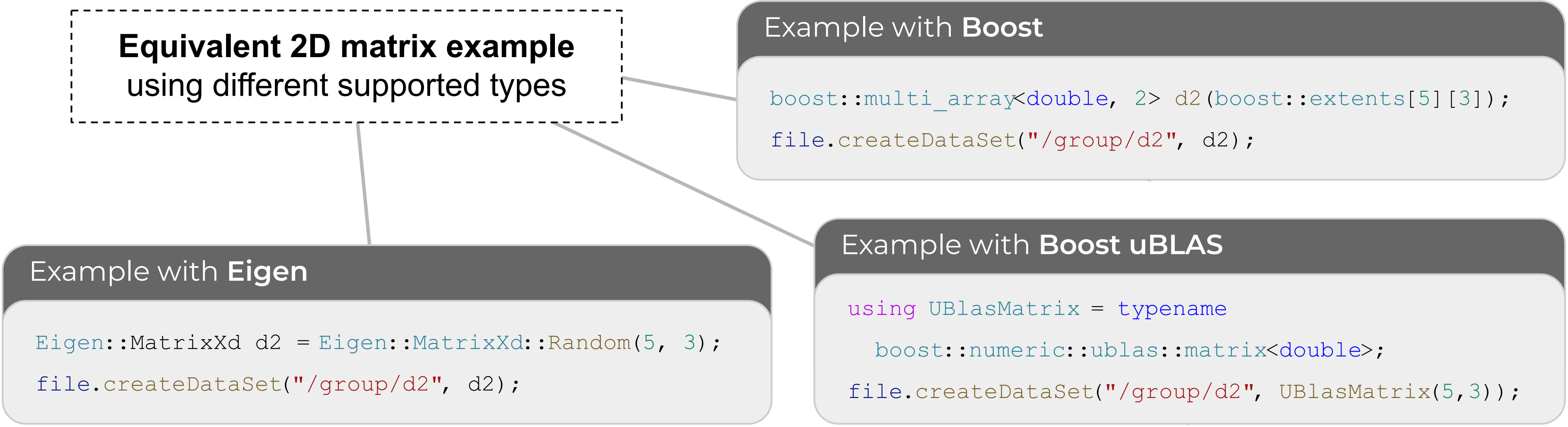
Example with **STL Container**

```
...
std::vector<std::vector<double>> d2 = make_matrix();
file.createDataSet("/group/d2", d2);
...
```

} **Non-contiguous type conversion**
for read / write, and primitive types

HighFive > Type Conversion / Induction (Continuation)

In addition to the support for standard types (e.g., `std::vector`, `std::map`, ...), **HighFive supports types from Boost, Eigen, XTensor, and others.** Here is another example:



Equivalent 2D matrix example
using different supported types

Example with **Boost**

```
boost::multi_array<double, 2> d2(boost::extents[5][3]);
file.createDataSet("/group/d2", d2);
```

Example with **Eigen**

```
Eigen::MatrixXd d2 = Eigen::MatrixXd::Random(5, 3);
file.createDataSet("/group/d2", d2);
```

Example with **Boost uBLAS**

```
using UBlasMatrix = typename
  boost::numeric::ublas::matrix<double>;
file.createDataSet("/group/d2", UBlasMatrix(5,3));
```

HighFive > Example

With HighFive, we can easily create a source code example that illustrates the creation of an HDF5 file with:

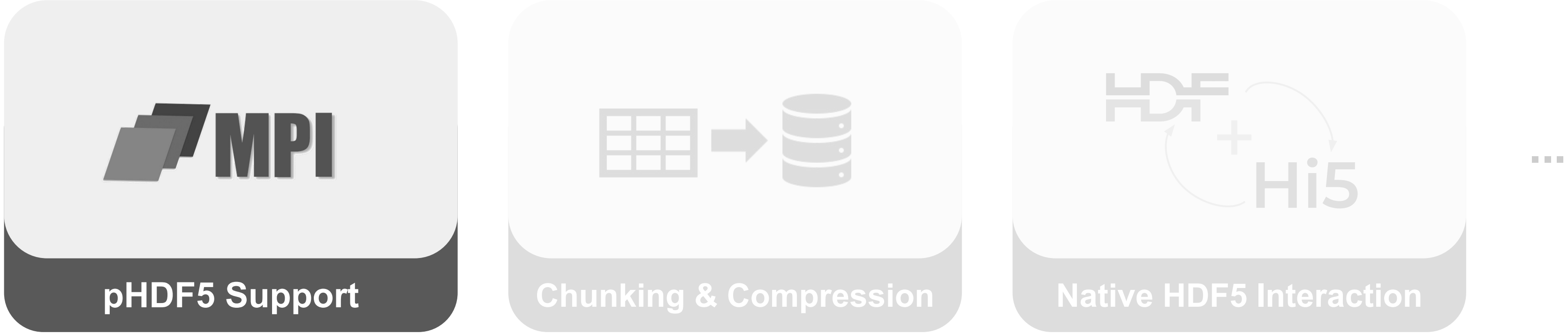
1. A **dataset** with a vector of integers that has an **attribute** for the units.
2. A **dataset** with 2D matrix based on a non-contiguous datatype.

The example on the right also shows how to **read** back one of the datasets.

```
using namespace HighFive;

...

File file("tmp.h5", File::ReadWrite | File::Create);

// Create DataSet and write data (short form)
file.createDataSet("/group/d1",
                   std::vector<int>{1,2,3,4,5});

// Attribute supported
file.createAttribute("/group/d1/units",
                     std::string("cm/s"));

// Nested STL containers
std::vector<std::vector<double>> d2 = make_matrix();
file.createDataSet("/group/d2", d2);

// Reading
std::vector<int> d1_read;
file.getDataSet("/group/d1").read(d1_read);

...
```

HighFive > Advanced Features

HighFive is built with scientific applications in mind. The library supports advanced features that eases the development of complex C++ applications, while maintaining the source code readability. **These are some of the most relevant:**



pHDF5 Support

Chunking & Compression

Native HDF5 Interaction

...

HighFive > Advanced Features

The only requirement is to use the `MPIOFileDriver` in the `File` opening. No other special API calls are required.

HighFive is dvanced features that ning the source code readability. **These are some of the most relevant:**

pHDF5 Support

```
...
File file("parallel_highfive.h5",
          File::ReadWrite | File::Create | File::Truncate,
          MPIOFileDriver(MPI_COMM_WORLD, MPI_INFO_NULL));
...
```

HighFive > Advanced Features (Continuation)

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Native HDF5 Interaction

...

d Feat

Group properties can be set for compression, chunking and much more

```
...
DataSetCreateProps props;
props.add(Chunking(std::vector<hsize_t>{2, 2}));
props.add(Deflate(9));
file.createDataSet("/group/d2", d2, props);
...
```

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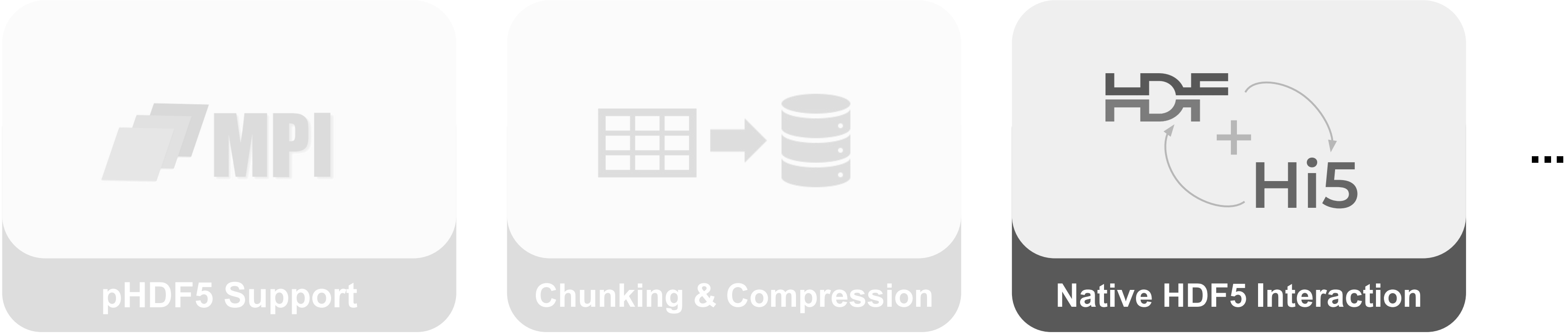

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HighFive > Advanced Features (Continuation)

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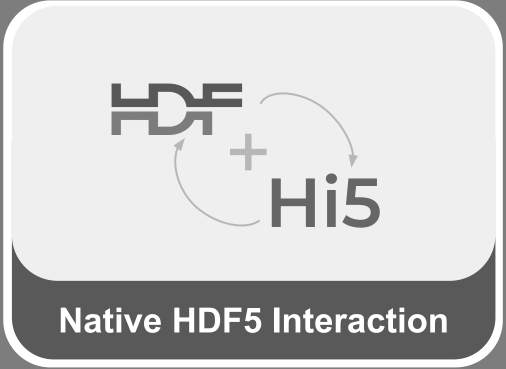
HighFive gives access to the native types of HDF5

and allows the user to call non-supported functionality

```
...
File file("myfile.h5");
std::cout << H5Fget_freespace(file.getId()) << std::endl;
...
```

pHDF5 Support

Chunking & Compression



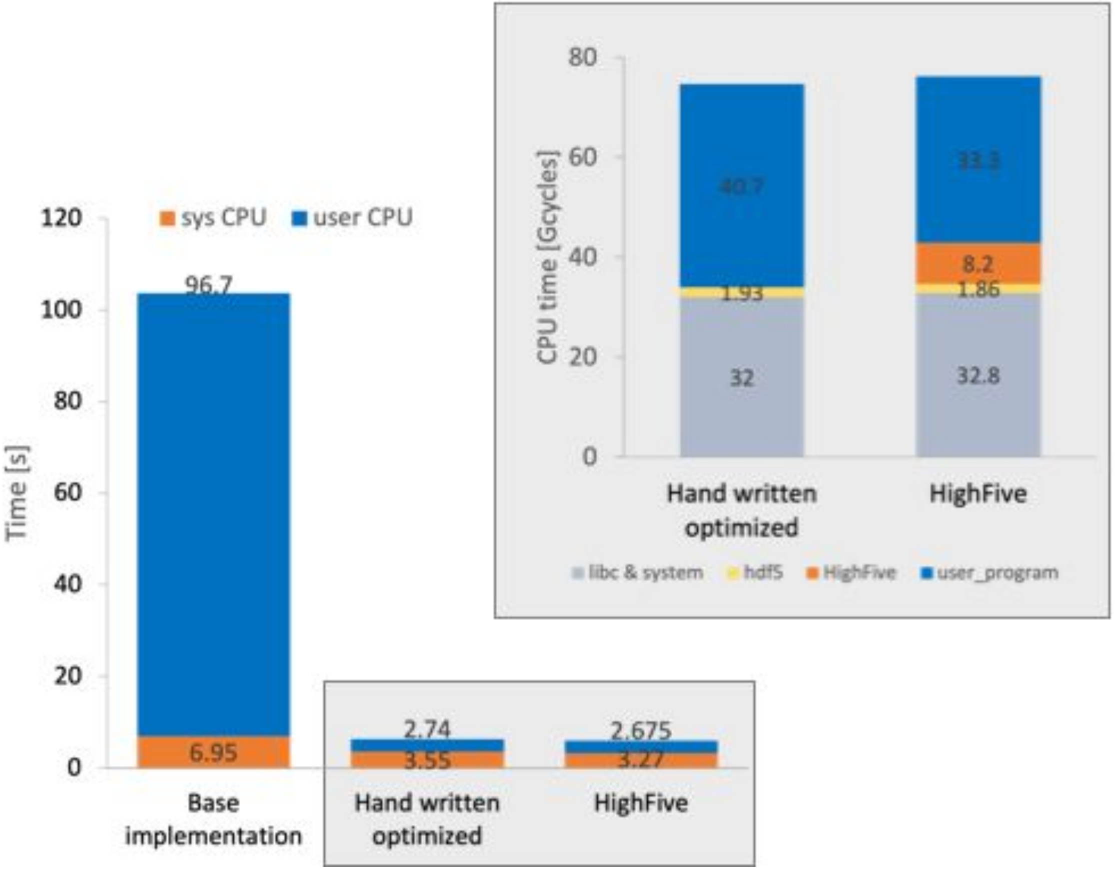
Native HDF5 Interaction

...

HighFive’s performance overhead compared to HDF5 code in C

- Naively writing row-by-row performs ~15 times slower.

- Fastest hand-written code took profiling and careful optimization and is substantially longer than the HighFive code (28 lines vs. 2 lines).



CPU time to write a 2D dataset [1M x 10 ints] 200 times (8 GB total)

Challenges

Despite the longevity of the project, we are still working on several challenges:

- **Multi-threading within HDF5**
  - Multi-threaded I/O is funneled either by the library or MPI user. Fully parallel read-access would be a *really* useful feature to have.

- **# of datasets or groups scalings**
  - Inserting O(1e6) of groups into a single HDF5 container on spinning disks gives notable latency of group retrieval, slow to construct such large files.

- **Support for mapping user defined, *deeply nested*, compound data types easily**

Thanks

Public repo: https://github.com/BlueBrain/HighFive
More information: https://go.epfl.ch/hi5

Thank you for listening

Questions?

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HighFive: one more C++ wrapper