
H5Z-ZFP Documentation

Release 0.6.0

H5Z-ZFP

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H5Z-ZFP is a compression filter for **HDF5** using the **ZFP compression library**, supporting *lossy* and *lossless* compression of floating point and integer data to meet bitrate, accuracy, and/or precision targets. The filter uses the **registered HDF5** filter ID, 32013. It supports single and double precision floating point and integer data *chunked* in 1, 2 or 3 dimensions. The filter will function on datasets of more than 3 dimensions (or 4 dimensions for ZFP versions 0.5.4 and newer), albeit at the possible expense of compression performance, as long as no more than 3 (or 4) dimensions of the HDF5 dataset chunking are of size greater than 1.

Contents:

1.1 Installing via Spack

The [HDF5](#) and [ZFP](#) libraries and the [H5Z-ZFP](#) plugin are all now part of the [Spack](#) package manager. If you already have [Spack](#) installed, the easiest way to install [H5Z-ZFP](#) is to simply use the [Spack](#) command `spack install h5z-zfp`. If you do not have [Spack](#) installed, it is very easy to install.

```
git clone https://github.com/llnl/spack.git
. spack/share/spack/setup-env.sh
spack install h5z-zfp
```

By default, [H5Z-ZFP](#) will attempt to build with Fortran support which requires a Fortran compiler. If you wish to exclude support for Fortran, use the command

```
spack install h5z-zfp~fortran
```

Note that these commands will build [H5Z-ZFP](#) **and** all of its dependencies including the [HDF5](#) library (as well as a number of other dependencies you may not initially expect. Be patient and let the build complete). In addition, by default, [Spack](#) installs packages to directory *hashes* within the cloned [Spack](#) repository's directory tree, `$spack/opt/spack`. You can find the resulting installed [HDF5](#) library with the command `spack find -vp hdf5` and your resulting [H5Z-ZFP](#) plugin installation with the command `spack find -vp h5z-zfp`. If you wish to exercise more control over where [Spack](#) installs things, have a look at [configuring Spack](#)

1.2 Manual Installation

If [Spack](#) is not an option for you, information on *manually* installing is provided here.

1.2.1 Prerequisites

- [ZFP Library](#) (or from [Github](#))

- [HDF5 Library](#)
- [H5Z-ZFP filter plugin](#)

1.2.2 Compiling ZFP

- There is a `Config` file in top-level directory of the [ZFP](#) distribution that holds `make` variables the [ZFP](#) Makefiles use. By default, this file is setup for a vanilla GNU compiler. If this is not the appropriate compiler, edit `Config` as necessary to adjust the compiler and compilation flags.
- An important flag you **will** need to adjust in order to use the [ZFP](#) library with this [HDF5](#) filter is the `BIT_STREAM_WORD_TYPE` CPP flag. To use [ZFP](#) with [H5Z-ZFP](#), the [ZFP](#) library **must** be compiled with `BIT_STREAM_WORD_TYPE` of `uint8`. Typically, this is achieved by including a line in `Config` of the form `DEFS += -DBIT_STREAM_WORD_TYPE=uint8`. If you attempt to use this filter with a [ZFP](#) library compiled differently from this, the filter's `can_apply` method will always return false. This will result in silently ignoring an [HDF5](#) client's request to compress data with [ZFP](#). Also, be sure to see [Endian Issues](#).
- After you have setup `Config`, simply run `make` and it will build the [ZFP](#) library placing the library in a `lib` sub-directory and the necessary include files in `inc[ude]` sub-directory.
- For more information and details, please see the [ZFP README](#).

1.2.3 Compiling HDF5

- If you want to be able to run the fortran tests for this filter, [HDF5](#) must be configured with *both* the `--enable-fortran` and `--enable-fortran2003` configuration switches. Otherwise, any vanilla installation of [HDF5](#) is acceptable.
- The Fortran interface to this filter *requires* a Fortran 2003 compiler because it uses `ISO_C_BINDING` to define the Fortran interface.
- If you are using [HDF5](#)-1.12 and wish to use the filter as a *library* (see [Plugin vs. Library Operation](#)), you may need configure [HDF5](#) with `--disable-memory-alloc-sanity-check` to work around a memory management issue in [HDF5](#).

1.3 Compiling H5Z-ZFP

[H5Z-ZFP](#) is designed to be compiled both as a standalone [HDF5](#) *plugin* and as a separate *library* an application can explicitly link. See [Plugin vs. Library Operation](#).

Once you have installed the prerequisites, you can compile [H5Z-ZFP](#) using a command-line...

```
make [FC=<Fortran-compiler>] CC=<C-compiler> \  
    ZFP_HOME=<path-to-zfp> HDF5_HOME=<path-to-hdf5> \  
    PREFIX=<path-to-install>
```

where `<path-to-zfp>` is a directory containing [ZFP](#) `inc[ude]` and `lib` dirs and `<path-to-hdf5>` is a directory containing [HDF5](#) `include` and `lib` dirs. If you don't specify a C compiler, it will try to guess one from your path. Fortran compilation is optional. If you do not specify a Fortran compiler, it will not attempt to build the Fortran interface. However, if the variable `FC` is already defined in your environment (as in [Spack](#) for example), then [H5Z-ZFP](#) will attempt to build Fortran. If this is not desired, the solution is to pass an *empty* `FC` on the `make` command line as in...


```
make FC= CC=<C-compiler> \
    ZFP_HOME=<path-to-zfp> HDF5_HOME=<path-to-hdf5> \
    PREFIX=<path-to-install>
```

The Makefile uses GNU Make syntax and is designed to work on OSX and Linux. The filter has been tested on gcc, clang, xlc, icc and pgcc compilers and checked with valgrind.

The command `make help` will print useful information about various make targets and variables. `make check` will compile everything and run a handful of tests.

If you don't specify a `PREFIX`, it will install to `./install`. The installed package will look like...

```
$(PREFIX)/include/{H5Zzfp.h,H5Zzfp_plugin.h,H5Zzfp_props.h,H5Zzfp_lib.h}
$(PREFIX)/plugin/libh5zfp.{so,dylib}
$(PREFIX)/lib/libh5zfp.a
```

where `$(PREFIX)` resolves to whatever the full path of the installation is.

To use the installed filter as an [HDF5 plugin](#), you would specify, for example, `setenv HDF5_PLUGIN_PATH $(PREFIX)/plugin`

1.4 H5Z-ZFP Source Code Organization

The source code is in two separate directories

- `src` includes the [ZFP](#) filter and a few header files
 - `H5Zzfp_plugin.h` is an optional header file applications *may* wish to include because it contains several convenient macros for easily controlling various compression modes of the [ZFP](#) library (*rate, precision, accuracy, expert*) via the [Generic Interface](#).
 - `H5Zzfp_props.h` is a header file that contains functions to control the filter using *temporary Properties Interface*. Fortran callers are *required* to use this interface.
 - `H5Zzfp_lib.h` is a header file for applications that wish to use the filter explicitly as a library rather than a plugin.
 - `H5Zzfp.h` is an *all-of-the-above* header file for applications that don't care too much about separating out the above functionalities.
- `test` includes various tests. In particular `test_write.c` includes examples of using both the [Generic Interface](#) and [Properties Interface](#). In addition, there is an example of how to use the filter from Fortran in `test_rw_fortran.F90`.

1.5 Silo Integration

This filter (`H5Zzfp.c`) is also built-in to the [Silo library](#). In particular, the [ZFP](#) library itself is also embedded in Silo but is protected from appearing in Silo's global namespace through a struct of function pointers (see [Namespaces in C](#)). If you happen to examine the source code here for [H5Z-ZFP](#), you will see some logic here that is specific to using this plugin within Silo and dealing with [ZFP](#) as an embedded library using this struct of function pointers wrapper. In the source code for [H5Z-ZFP](#) this manifests as something like what is shown in the code snippet below...

```
1  switch (ndims_used)
2  {
3  case 1: dummy_field = Z zfp_field_ld(0, zt, dims_used[0]); break;
```

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```
4      case 2: dummy_field = Z zfp_field_2d(0, zt, dims_used[1], dims_used[0]);  
↪break;  
5      case 3: dummy_field = Z zfp_field_3d(0, zt, dims_used[2], dims_used[1], dims_  
↪used[0]); break;  
6  #if ZFP_VERSION_NO >= 0x0540  
7      case 4: dummy_field = Z zfp_field_4d(0, zt, dims_used[3], dims_used[2], dims_  
↪used[1], dims_used[0]); break;  
8  #endif  
9      default: H5Z_ZFP_PUSH_AND_GOTO(H5E_PLINE, H5E_BADVALUE, 0,  
10 #if ZFP_VERSION_NO < 0x0530  
11         "chunks may have only 1...3 non-unity dims");  
12 #else  
13         "chunks may have only 1...4 non-unity dims");  
14 #endif  
15 }
```

In the code snippet above, note the funny `Z` in front of calls to various methods in the `ZFP` library. When compiling `H5Z-ZFP` normally, that `Z` normally resolves to the empty string. But, when the code is compiled with `-DAS_SILO_BUILTIN` (which is supported and should be done *only* when `H5Zzfp.c` is being compiled *within* the Silo library and *next to* a version of `ZFP` that is embedded in Silo) that `Z` resolves to the name of a struct and struct-member dereferncing operator as in `zfp..` There is a similar `B` used for a similar purpose ahead of calls to `ZFP`'s bitstream library. This is something to be aware of and to adhere to if you plan to contribute any code changes here.

There are two interfaces to control the filter. One uses HDF5's *generic* interface via an array of unsigned int `cd_values` as is used in `H5Pset_filter()`. The other uses HDF5 *properties* added to the *dataset creation property list* used when the dataset to be compressed is being created. You can find examples of writing HDF5 data using both the *generic* and *properties* interfaces in `test_write.c`.

The filter itself supports either interface. The filter also supports all of the standard ZFP controls for affecting compression including *rate*, *precision*, *accuracy*, *expert* and *reversible* modes. For more information and details about these modes of controlling ZFP compression, please see the [ZFP README](#).

Finally, you should *not* attempt to combine the ZFP filter with any other *byte order altering* filter such as, for example, HDF5's shuffle filter. Space-performance will be ruined. This is in contrast to HDF5's *deflate* filter which often performs *better* when used in conjunction with the *shuffle* filter.

2.1 Generic Interface

The generic interface is the only means of controlling the H5Z-ZFP filter when it is used as a *dynamically loaded* HDF5 plugin.

For the generic interface, the following CPP macros are defined in the `H5Zzfp_plugin.h` header file:

```
H5Pset_zfp_rate_cdata(double rate, size_t cd_nelmts, unsigned int *cd_vals);
H5Pset_zfp_precision_cdata(unsigned int prec, size_t cd_nelmts, unsigned int *cd_
↪vals);
H5Pset_zfp_accuracy_cdata(double acc, size_t cd_nelmts, unsigned int *cd_vals);
H5Pset_zfp_expert_cdata(unsigned int minbits, unsigned int maxbits,
                        unsigned int maxprec, int minexp,
                        size_t cd_nelmts, unsigned int *cd_vals);
H5Pset_zfp_reversible_cdata(size_t cd_nelmts, unsigned int *cd_vals);
```

These macros utilize *type punning* to store the relevant ZFP parameters into a sufficiently large array (≥ 6) of unsigned int `cd_values`. It is up to the caller to then call `H5Pset_filter()` with the array of `cd_values` constructed by one of these macros.

Here is example code from `test_write.c...`

```

1  if (zfpmode == H5Z_ZFP_MODE_RATE)
2      H5Pset_zfp_rate_cdata(rate, cd_nelmts, cd_values);
3  else if (zfpmode == H5Z_ZFP_MODE_PRECISION)
4      H5Pset_zfp_precision_cdata(prec, cd_nelmts, cd_values);
5  else if (zfpmode == H5Z_ZFP_MODE_ACCURACY)
6      H5Pset_zfp_accuracy_cdata(acc, cd_nelmts, cd_values);
7  else if (zfpmode == H5Z_ZFP_MODE_EXPERT)
8      H5Pset_zfp_expert_cdata(minbits, maxbits, maxprec, minexp, cd_nelmts, cd_
↪ values);
9  else if (zfpmode == H5Z_ZFP_MODE_REVERSIBLE)
10     H5Pset_zfp_reversible_cdata(cd_nelmts, cd_values);
11  else
12     cd_nelmts = 0; /* causes default behavior of ZFP library */
13
14  /* print cd-values array used for filter */
15  printf("%d cd_values= ", (int) cd_nelmts);
16  for (i = 0; i < (int) cd_nelmts; i++)
17     printf("%u,", cd_values[i]);
18  printf("\n");
19
20  /* Add filter to the pipeline via generic interface */
21  if (0 > H5Pset_filter(cpid, H5Z_FILTER_ZFP, H5Z_FLAG_MANDATORY, cd_nelmts, cd_
↪ values)) ERROR(H5Pset_filter);
22

```

However, these macros are only a convenience. You do not **need** the `H5Zzfp_plugin.h` header file if you want to avoid using it. But, you are then responsible for setting up the `cd_values` array correctly for the filter. For reference, the `cd_values` array for this **ZFP** filter is defined like so...

	cd_values index					
ZFP mode	0	1	2	3	4	5
rate	1	unused	rateA	rateB	unused	unused
precision	2	unused	prec	unused	unused	unused
accuracy	3	unused	accA	accB	unused	unused
expert	4	unused	minbits	maxbits	maxprec	minexp
reversible	5	unused	unused	unused	unused	unsued

A/B are high/low 32-bit words of a double.

Note that the `cd_values` used in the generic interface to `H5Pset_filter()` are **not the same** `cd_values` ultimately stored to the **HDF5** dataset header for a compressed dataset. The values are transformed in the `set_local` method to use **ZFP**'s internal routines for 'meta' and 'mode' data. So, don't make the mistake of examining the values you find in a file and think you can use those same values, for example, in an invocation of `h5repack`.

2.2 Properties Interface

For the properties interface, the following functions are defined in the `H5Zzfp_props.h` header file:

```

herr_t H5Pset_zfp_rate(hid_t dcpl_id, double rate);
herr_t H5Pset_zfp_precision(hid_t dcpl_id, unsigned int prec);
herr_t H5Pset_zfp_accuracy(hid_t dcpl_id, double acc);
herr_t H5Pset_zfp_expert(hid_t dcpl_id,

```

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```

    unsigned int minbits, unsigned int maxbits,
    unsigned int maxprec, int minexp);
herr_t H5Pset_zfp_reversible(hid_t dcpl_id);

```

These functions take a dataset creation property list, `hid_t dcpl_id` and create temporary [HDF5](#) property list entries to control the [ZFP](#) filter. Calling any of these functions removes the effects of any previous call to any one of these functions. In addition, calling any one of these functions also has the effect of adding the filter to the pipeline.

Here is example code from `test_write.c`...

```

1  H5Z_zfp_initialize();
2
3  /* Setup the filter using properties interface. These calls also add
4     the filter to the pipeline */
5  if (zfpmode == H5Z_ZFP_MODE_RATE)
6      H5Pset_zfp_rate(cpid, rate);
7  else if (zfpmode == H5Z_ZFP_MODE_PRECISION)
8      H5Pset_zfp_precision(cpid, prec);
9  else if (zfpmode == H5Z_ZFP_MODE_ACCURACY)
10     H5Pset_zfp_accuracy(cpid, acc);
11  else if (zfpmode == H5Z_ZFP_MODE_EXPERT)
12     H5Pset_zfp_expert(cpid, minbits, maxbits, maxprec, minexp);
13  else if (zfpmode == H5Z_ZFP_MODE_REVERSIBLE)
14     H5Pset_zfp_reversible(cpid);
15

```

The properties interface is more type-safe than the generic interface. However, there is no way for the implementation of the properties interface to reside within the filter plugin itself. The properties interface requires that the caller link with the filter as a *library*, `libh5zfp.a`. The generic interface does not require this.

Note that either interface can be used whether the filter is used as a plugin or as a library. The difference is whether the application calls `H5Z_zfp_initialize()` or not.

2.3 Fortran Interface

Fortran equivalents for both the properties and generic interfaces, described above, has been added by Scot Breitenfeld of the [HDF5](#) group. The code that implements the Fortran interfaces is in the file `H5Zzfp_props_f.F90`. An example of its use is in `test/test_rw_fortran.F90`.

2.4 Plugin vs. Library Operation

The filter is designed to be compiled for use as both a standalone [HDF5](#) dynamically loaded [HDF5](#) plugin and as an explicitly linked *library*. When it is used as a plugin, it is a best practice to link the [ZFP](#) library into the plugin dynamic/shared object as a *static* library. Why? In so doing, we ensure that all [ZFP](#) public namespace symbols remain *confined* to the plugin so as not to interfere with any application that may be directly explicitly linking to the [ZFP](#) library for other reasons.

All [HDF5](#) applications are *required* to find the plugin dynamic library (named `lib*. {so, dylib}`) in a directory specified by the environment variable, `HDF5_PLUGIN_PATH`. Currently, the [HDF5](#) library offers no mechanism for applications themselves to have pre-programmed paths in which to search for a plugin. Applications are then always vulnerable to an incorrectly specified or unspecified `HDF5_PLUGIN_PATH` environment variable.

However, the plugin can also be used explicitly as a *library*. In this case, **do not** specify the `HDF5_PLUGIN_PATH` environment variable and instead have the application link to `libH5Zzfp.a` in the `lib` dir of the installation. Instead two initialization and finalization routines are defined:

```
int H5Z_zfp_initialize(void);  
int H5Z_zfp_finalize(void);
```

These functions are defined in the `H5Zzfp_lib.h` header file. Any applications that wish to use the filter as a *library* are required to call the initialization routine, `H5Z_zfp_initialize()` before the filter can be referenced. In addition, to free up resources used by the filter, applications may call `H5Z_zfp_finalize()` when they are done using the filter.

HDF5 Chunking

HDF5's dataset **chunking** feature is a way to optimize data layout on disk to support partial dataset reads by downstream consumers. This is all the more important when compression filters are applied to datasets as it frees a consumer from suffering the UNcompression of an entire dataset only to read a portion.

3.1 ZFP Chunklets

When using **HDF5 chunking** with **ZFP** compression, it is important to account for the fact that **ZFP** does its work in tiny 4^d chunklets of its own where d is the dataset dimension (*rank* in **HDF5** parlance). This means that that whenever possible **chunking** dimensions you select in **HDF5** should be multiples of 4. When a **chunk** dimension is not a multiple of 4, **ZFP** will wind up with partial chunklets which it will pad with useless data reducing overall time and space efficiency of the results.

The degree to which this may degrade performance depends on the percentage of a **chunk** that is padded. Suppose we have 2D chunk of dimensions 27 x 101. **ZFP** will have to treat it as 28 x 104 by padding out each dimension to the next closest multiple of 4. The fraction of space that will wind up being wasted due to **ZFP** chunklet padding will be $(28 \times 104 - 27 \times 101) / (28 \times 104)$ which is about 6.4%. On the other hand, consider a 3D chunk that is 1024 x 1024 x 2. **ZFP** will have to treat it as a 1024 x 1024 x 4 resulting in 50% waste.

The latter example is potentially very relevant when attempting to apply **ZFP** to compress data long the *time* dimension in a large, 3D, simulation. Ordinarily, a simulation advances one time step at a time and so needs to store in memory only the *current* timestep. In order to give **ZFP** enough *width* in the time dimension to satisfy the minimum chunklet dimension size of 4, the simulation needs to keep in memory 4 timesteps. This is demonstrated in the example below.

3.2 More Than 3 (or 4) Dimensions

Versions of **ZFP** 0.5.3 and older support compression in only 1,2 or 3 dimensions. Versions of **ZFP** 0.5.4 and newer also support 4 dimensions.

What if you have a dataset with more dimensions than **ZFP** can compress? You can still use the **H5Z-ZFP** filter. But,

in order to do so you are *required* to **chunk** the dataset¹. Furthermore, you must select a **chunk** size such that no more than 3 (or 4 for **ZFP** 0.5.4 and newer) dimensions are non-unitary (e.g. of size one).

For example, what if you are using **ZFP** 0.5.3 and have a 4D HDF5 dataset you want to compress? To do this, you will need to **chunk** the dataset and when you define the **chunk** size and shape, you will need to select which of the 4 dimensions of the chunk you do *not* intend to have **ZFP** perform compression along by setting the size of the **chunk** in that dimension to unity (1). When you do this, as HDF5 processes writes and reads, it will organize the data so that all the **H5Z-ZFP** filter *sees* are chunks which have *extent* only in the non-unity dimensions of the **chunk**.

In the example below, we have a 4D array of shape `int dims[] = {256,128,32,16}`; that we have intentionally constructed to be *smooth* in only 2 of its 4 dimensions (e.g. correlation is high in those dimensions). Because of that, we expect **ZFP** compression to do well along those dimensions and we do not want **ZFP** to compress along the other 2 dimensions. The *uncorrelated* dimensions here are dimensions with indices 1 (128 in `dims[]`) and 3 (16 in `dims[]`). Thus, our **chunk** size and shape is chosen to set the size for those dimension indices to 1, `hsize_t hchunk[] = {256,1,32,1}`;

```

1  if (highd)
2  {
3      /* dimension indices 0  1  2  3 */
4      int fd, dims[] = {256,128,32,16};
5      int ucdims[]={1,3}; /* UNcorrlated dimensions indices */
6      hsize_t hdims[] = {256,128,32,16};
7      hsize_t hchunk[] = {256,1,32,1};
8
9      buf = gen_random_correlated_array(TYPDBL, 4, dims, 2, ucdims);
10
11      cpid = setup_filter(4, hchunk, zfpmode, rate, acc, prec, minbits, maxbits,
12      ↪maxprec, minexp);
13
14      if (0 > (sid = H5Screate_simple(4, hdims, 0))) ERROR(H5Screate_simple);
15
16      /* write the data WITHOUT compression */
17      if (0 > (dsid = H5Dcreate(fid, "highD_original", H5T_NATIVE_DOUBLE, sid, H5P_
18      ↪DEFAULT, H5P_DEFAULT, H5P_DEFAULT))) ERROR(H5Dcreate);
19      if (0 > H5Dwrite(dsid, H5T_NATIVE_DOUBLE, H5S_ALL, H5S_ALL, H5P_DEFAULT,
20      ↪buf)) ERROR(H5Dwrite);
21      if (0 > H5Dclose(dsid)) ERROR(H5Dclose);
22
23      /* write the data with compression */
24      if (0 > (dsid = H5Dcreate(fid, "highD_compressed", H5T_NATIVE_DOUBLE, sid,
25      ↪H5P_DEFAULT, cpid, H5P_DEFAULT))) ERROR(H5Dcreate);
26      if (0 > H5Dwrite(dsid, H5T_NATIVE_DOUBLE, H5S_ALL, H5S_ALL, H5P_DEFAULT,
27      ↪buf)) ERROR(H5Dwrite);
28      if (0 > H5Dclose(dsid)) ERROR(H5Dclose);
29
30      /* clean up from high dimensional test */
31      if (0 > H5Sclose(sid)) ERROR(H5Sclose);
32      if (0 > H5Pclose(cpid)) ERROR(H5Pclose);
33      free(buf);
34  }

```

What analysis process should you use to select the **chunk** shape? Depending on what you expect in the way of access patterns in downstream consumers, this can be a challenging question to answer. There are potentially two competing interests. One is optimizing the **chunk** size and shape for access patterns anticipated by downstream consumers. The other is optimizing the **chunk** size and shape for compression. These two interests may not be compatible and you may have to compromise between them. We illustrate the issues and tradeoffs using an example.

¹ The **HDF5** library currently requires dataset chunking anyways for any dataset that has any kind of filter applied.

3.3 Compression Along the State Iteration Dimension

By *state iteration* dimension, we are referring to the main iteration loop(s) of the data producer. For many PDE-based simulations, the main iteration dimension is *time*. But, for some *outer loop* methods, the main iteration dimension(s) might be some kind of parameter study including multiple parameters.

The challenge here is to manage the data in a way that meets ZFP's chunklet size and shape *minimum* requirements. In any H5Dwrite at least 4 *samples* along a ZFP compression dimension are needed or there will be wasted space due to padding. This means that data must be *buffered* along those dimensions *before* H5Dwrite's can be issued.

For example, suppose you have a tensor valued field (e.g. a 3x3 matrix at every *point*) over a 4D (3 spatial dimensions and 1 time dimension), regularly sampled domain? Conceptually, this is a 6 dimensional dataset in HDF5 with one of the dimensions (the *time* dimension) *extendible*. You are free to define this as a 6 dimensional dataset in HDF5. But, you will also have to *chunk* the dataset. You can select any *chunk* shape you want except that no more than 3 (or 4 for ZFP versions 0.5.4 and newer) dimensions of the *chunk* can be non-unity.

In the code snippet below, we demonstrate this case. A key issue to deal with is that because we will use ZFP to compress along the time dimension, this forces us to keep in memory a sufficient number of timesteps to match ZFP's chunklet size of 4.

The code below iterates over 9 timesteps. Each of the first two groups of 4 timesteps are buffered in memory in tbuf. Once 4 timesteps have been buffered, we can issue an H5Dwrite call doing hyperslab can issue an H5Dwrite call doing hyperslab partial I/O on the 6D, *extendible* dataset. But, notice that the *chunk* dimensions (line 10) are such that only 4 of the 6 dimensions are non-unity. This means ZFP will only ever see something to compress that is essentially 4D.

On the last iteration, we have only one *new* timestep. So, when we write this to ZFP 75% of that write will be *wasted* due to ZFP chunklet padding. However, if the application were to *restart* from this time and continue forward, this *waste* will ultimately get overwritten with new timesteps.

```

1  /* Test six dimensional, time varying array...
2     ...a 3x3 tensor valued variable
3     ...over a 3D+time domain.
4     Dimension sizes are chosen to miss perfect ZFP block alignment.
5
6  */
7  if (sixd)
8  {
9      void *tbuf;
10     int t, fd, dims[] = {31,31,31,3,3}; /* a single time instance */
11     int ucdims[]={3,4}; /* indices of UNcorrelated dimensions in dims (tensor_
12     ↪components) */
13     hsize_t hdims[] = {31,31,31,3,3,H5S_UNLIMITED};
14     hsize_t hchunk[] = {31,31,31,1,1,4}; /* 4 non-unity, requires >= ZFP 0.5.4 */
15     hsize_t hwrite[] = {31,31,31,3,3,4}; /* size/shape of any given H5Dwrite */
16
17     /* Setup the filter properties and create the dataset */
18     cpid = setup_filter(6, hchunk, zfpmode, rate, acc, prec, minbits, maxbits,
19     ↪maxprec, minexp);
20
21     /* Create the time-varying, 6D dataset */
22     if (0 > (sid = H5Screate_simple(6, hwrite, hdims))) ERROR(H5Screate_simple);
23     if (0 > (dsid = H5Dcreate(fid, "6D_extendible", H5T_NATIVE_DOUBLE, sid, H5P_
24     ↪DEFAULT, cpid, H5P_DEFAULT))) ERROR(H5Dcreate);
25     if (0 > H5Sclose(sid)) ERROR(H5Sclose);
26     if (0 > H5Pclose(cpid)) ERROR(H5Pclose);
27
28     /* Generate a single buffer which we'll modulate by a time-varying function
29     to represent each timestep */
30     buf = gen_random_correlated_array(TYPDBL, 5, dims, 2, ucdims);

```

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```

27
28     /* Allocate the "time" buffer where we will buffer up each time step
29        until we have enough to span a width of 4 */
30     tbuf = malloc(31*31*31*3*3*4*sizeof(double));
31
32     /* Iterate, writing 9 timesteps by buffering in time 4x. The last
33        write will contain just one timestep causing ZFP to wind up
34        padding all those blocks by 3x along the time dimension. */
35     for (t = 1; t < 10; t++)
36     {
37         hid_t msid, fsid;
38         hsize_t hstart[] = {0,0,0,0,0,t-4}; /* size/shape of any given H5Dwrite */
39         hsize_t hcount[] = {31,31,31,3,3,4}; /* size/shape of any given H5Dwrite
↳ */
40         hsize_t hextend[] = {31,31,31,3,3,t}; /* size/shape of */
41
42         /* Update (e.g. modulate) the buf data for the current time step */
43         modulate_by_time(buf, TYPDBL, 5, dims, t);
44
45         /* Buffer this timestep in memory. Since chunk size in time dimension is
↳ 4,
46            we need to buffer up 4 time steps before we can issue any writes */
47         buffer_time_step(tbuf, buf, TYPDBL, 5, dims, t);
48
49         /* If the buffer isn't full, just continue updating it */
50         if (t%4 && t!=9) continue;
51
52         /* For last step, adjust time dim of this write down from 4 to just 1 */
53         if (t == 9)
54         {
55             /* last timestep, write a partial buffer */
56             hwrite[5] = 1;
57             hcount[5] = 1;
58         }
59
60         /* extend the dataset in time */
61         if (t > 4)
62             H5Dextend(dsid, hextend);
63
64         /* Create the memory dataspace */
65         if (0 > (msid = H5Screate_simple(6, hwrite, 0))) ERROR(H5Screate_simple);
66
67         /* Get the file dataspace to use for this H5Dwrite call */
68         if (0 > (fsid = H5Dget_space(dsid))) ERROR(H5Dget_space);
69
70         /* Do a hyperslab selection on the file dataspace for this write*/
71         if (0 > H5Sselect_hyperslab(fsid, H5S_SELECT_SET, hstart, 0, hcount, 0))
↳ ERROR(H5Sselect_hyperslab);
72
73         /* Write this iteration to the dataset */
74         if (0 > H5Dwrite(dsid, H5T_NATIVE_DOUBLE, msid, fsid, H5P_DEFAULT, tbuf))
↳ ERROR(H5Dwrite);
75         if (0 > H5Sclose(msid)) ERROR(H5Sclose);
76         if (0 > H5Sclose(fsid)) ERROR(H5Sclose);
77     }
78     if (0 > H5Dclose(dsid)) ERROR(H5Dclose);
79     free(buf);

```

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```
80     free(tbuf);  
81 }
```

Direct Writes (and Reads)

The purpose of `direct` writes is to enable an application to write data that is already compressed in memory *directly* to an HDF5 file without first uncompressing it so the filter can then turn around and compress it during write. However, once data is written to the file with a *direct* write, consumers must still be able to read it without concern for how the producer wrote it.

Doing this requires the use of an advanced HDF5 function for `direct` writes.

At present, we demonstrate only minimal functionality here using *single chunking*, where the chunk size is chosen to match the size of the entire dataset. To see an example of code that does this, have a look at...

```

1  if (zfparr>0 && zfpmode==1 && rate>0)
2  {
3      int          dims[] = {38, 128};
4      /*int        chunk_dims[] = {19, 34};*/
5      int          chunk_dims[] = {38, 128};
6      hsize_t      hdims[] = {38, 128};
7      /*hsize_t    hchunk_dims[] = {19, 34};*/
8      hsize_t      hchunk_dims[] = {38, 128};
9      hsize_t      hchunk_off[] = {0, 0};
10     #if defined(ZFP_LIB_VERSION) && ZFP_LIB_VERSION<=0x055
11         cfp_array2d *origarr;
12     #else
13         cfp_array2d origarr;
14     #endif
15
16     /* Create the array data */
17     buf = gen_random_correlated_array(TYPDBL, 2, dims, 0, 0);
18
19     /* Instantiate a cfp array */
20     origarr = cfp.array2d.ctor(dims[1], dims[0], rate, buf, 0);
21     cfp.array2d.flush_cache(origarr);
22
23     cpid = setup_filter(2, hchunk_dims, 1, rate, acc, prec, minbits, maxbits,
24     ↪maxprec, minexp);

```

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```

25     if (0 > (sid = H5Screate_simple(2, hdims, 0))) ERROR(H5Screate_simple);
26
27     /* write the data WITHOUT compression */
28     if (0 > (dsid = H5Dcreate(fid, "zfparr_original", H5T_NATIVE_DOUBLE, sid, H5P_
↪DEFAULT, H5P_DEFAULT, H5P_DEFAULT))) ERROR(H5Dcreate);
29     if (0 > H5Dwrite(dsid, H5T_NATIVE_DOUBLE, H5S_ALL, H5S_ALL, H5P_DEFAULT, ↪
↪buf)) ERROR(H5Dwrite);
30     if (0 > H5Dclose(dsid)) ERROR(H5Dclose);
31
32     /* write the data with compression via the filter */
33     if (0 > (dsid = H5Dcreate(fid, "zfparr_compressed", H5T_NATIVE_DOUBLE, sid, ↪
↪H5P_DEFAULT, cpid, H5P_DEFAULT))) ERROR(H5Dcreate);
34     if (0 > H5Dwrite(dsid, H5T_NATIVE_DOUBLE, H5S_ALL, H5S_ALL, H5P_DEFAULT, ↪
↪buf)) ERROR(H5Dwrite);
35     if (0 > H5Dclose(dsid)) ERROR(H5Dclose);
36
37     /* write the data direct from compressed array using H5Dwrite_chunk calls */
38     if (0 > (dsid = H5Dcreate(fid, "zfparr_direct", H5T_NATIVE_DOUBLE, sid, H5P_
↪DEFAULT, cpid, H5P_DEFAULT))) ERROR(H5Dcreate);
39     if (0 > H5Dwrite_chunk(dsid, H5P_DEFAULT, 0, hchunk_off, cfp.array2d.
↪compressed_size(origarr), cfp.array2d.compressed_data(origarr))) ERROR(H5Dwrite_
↪chunk);
40
41     if (0 > H5Dclose(dsid)) ERROR(H5Dclose);
42
43     free(buf);
44     cfp.array2d.dtor(origarr);
45 }

```

In particular, look for the line using `H5Dchunk_write` in place of `H5Dwrite`. In all other respects, the code looks the same.

The test case for this code writes uncompressed data as a dataset named `zfparr_original`, the compressed dataset named `zfparr_compressed` using the filter and then the compressed data a second time named `zfparr_direct` using a direct write. Then, the `h5diff` tool is used to compare the data in the original and direct datasets.

Note that in order for consumers to work as normal, the producer must set dataset *creation* properties as it ordinarily would using the `H5Z-ZFP` filter. In the call to `H5Dchunk_write`, the caller indicates to the HDF5 library not to invoke the filter via the `filters` mask argument.

Using H5Z-ZFP Plugin with H5Repack

A convenient way to use and play with the [ZFP](#) filter is a *plugin* with the [HDF5](#) `h5repack` utility using the `-f` filter argument to apply ZFP to existing data in a file.

5.1 Patching h5repack

Some versions of [HDF5](#)'s `h5repack` utility contain a bug that prevents proper parsing of the `-f` argument's option. In order to use `h5repack` with `-f` argument as described here, you need to apply the patch from [h5repack_parse.patch](#). To do so, after you've downloaded and untar'd [HDF5](#) but before you've built it, do something like the following using [HDF5-1.8.14](#) as an example:

```
gunzip < hdf5-1.8.14.tar.gz | tar xvf -
cd hdf5-1.8.14
patch ./tools/h5repack/h5repack_parse.c <path-to-H5Z-ZFP-test-dir>/h5repack_parse.
↪patch
```

5.2 Constructing an HDF5 `cd_values` array

[HDF5](#)'s `h5repack` utility uses only the *generic* interface to [HDF5](#) filters. Another challenge in using `h5repack` as described here is constructing the set `unsigned int cd_values` as is used in `H5Pset_filter()` required by the *generic* [HDF5](#) filter interface, especially because of the type-punning (doubles as unsigned int) involved.

Note: Querying an existing dataset using `h5dump` or `h5ls` to obtain the `cd_values` stored with a [ZFP](#) compressed dataset **will not provide the correct `cd_values`**. This is because the `cd_values` stored in the file are different from those used in the *generic* interface to invoke the [ZFP](#) filter.

To facilitate constructing a valid `-f` argument to `h5repack`, we have created a utility program, `print_h5repack_farg`, which is presently in the `test` directory and is built when tests are built.

You can use the `print_h5repack_farg` utility to read a command-line consisting of [ZFP](#) filter parameters you wish to use and it will output part of the command-line needed for the `-f` argument to `h5repack`.

5.3 Examples

In the examples below, we use `h5repack` with the example data file, `mesh.h5` in the `tests` directory.

To use **ZFP** filter in *rate* mode with a rate of 4.5 bits per value, first, use the `print_h5repack_farg`:

```
% ./print_h5repack_farg zfpmode=1 rate=4.5

Print cdvals for set of ZFP compression paramaters...
zfpmode=1      set zfp mode (1=rate,2=prec,3=acc,4=expert)
rate=4.5        set rate for rate mode of filter
acc=0           set accuracy for accuracy mode of filter
prec=11        set precision for precision mode of zfp filter
minbits=0      set minbits for expert mode of zfp filter
maxbits=4171   set maxbits for expert mode of zfp filter
maxprec=64     set maxprec for expert mode of zfp filter
minexp=-1074   set minexp for expert mode of zfp filter
help=0         this help message

h5repack -f argument...
-f UD=32013,0,4,1,0,0,1074921472
```

Next, cut-n-paste the `-f UD=32013,0,4,1,0,0,1074921472` in a command to `h5repack` like so:

```
env LD_LIBRARY_PATH=<path-to-dir-with-libhdf5.so>:${LD_LIBRARY_PATH} \
HDF5_PLUGIN_PATH=<path-to-dir-with-libh5zzfp.so> \
$(HDF5_BIN)/h5repack -f UD=32013,0,4,1,0,0,1074921472 \
-l Pressure,Pressure2,Pressure3:CHUNK=10x20x5 \
-l Velocity,Velocity2,Velocity3,VelocityZ,VelocityZ2,
→VelocityZ3:CHUNK=11x21x1x1 \
-l VelocityX_2D:CHUNK=21x31 \
mesh.h5 mesh_repack.h5
```

where the `-l` arguments indicate the dataset(s) to be re-packed as well as their (new) chunking.

To use **ZFP** filter in *accuracy* mode with an accuracy of 0.075, first, use the `print_h5repack_farg`:

```
% ./print_h5repack_farg zfpmode=3 acc=0.075

Print cdvals for set of ZFP compression paramaters...
zfpmode=3      set zfp mode (1=rate,2=prec,3=acc,4=expert)
rate=4          set rate for rate mode of filter
acc=0.075      set accuracy for accuracy mode of filter
prec=11        set precision for precision mode of zfp filter
minbits=0      set minbits for expert mode of zfp filter
maxbits=4171   set maxbits for expert mode of zfp filter
maxprec=64     set maxprec for expert mode of zfp filter
minexp=-1074   set minexp for expert mode of zfp filter
help=0         this help message

h5repack -f argument...
-f UD=32013,0,4,3,0,858993459,1068708659
```

Next, cut-n-paste the `-f UD=32013,0,4,3,0,858993459,1068708659` in a command to `h5repack` like so:

```
env LD_LIBRARY_PATH=<path-to-dir-with-libhdf5.so>:${LD_LIBRARY_PATH} \
HDF5_PLUGIN_PATH=<path-to-dir-with-libh5zzfp.so> \
```

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```
$ (HDF5_BIN)/h5repack -f UD=32013,0,4,3,0,858993459,1068708659 \  
-l Pressure,Pressure2,Pressure3:CHUNK=10x20x5 \  
-l Velocity,Velocity2,Velocity3,VelocityZ,VelocityZ2,  
↪VelocityZ3:CHUNK=11x21x1x1 \  
-l VelocityX_2D:CHUNK=21x31 \  
mesh.h5 mesh_repack.h5
```


The **ZFP** library writes an endian-independent stream.

When reading **ZFP** compressed data on a machine with a different endian-ness than the writer, there is an unavoidable inefficiency. Upon reading data from disk and decompressing the read stream with **ZFP**, the correct endian-ness is returned in the result from **ZFP** before the buffer is handed back to **HDF5** from the decompression filter. This happens regardless of reader and writer endian-ness incompatibility. However, the **HDF5** library is expecting to get from the decompression filter the endian-ness of the data as it was stored to file (typically that of the writer machine) and expects to have to byte-swap that buffer before returning to any endian-incompatible caller. So, in the **H5Z-ZFP** plugin, we wind up having to un-byte-swap an already correct result read in a cross-endian context. That way, when **HDF5** gets the data and byte-swaps it, it will produce the correct result. There is an endian-ness test in the Makefile and two **ZFP** compressed example datasets for big-endian and little-endian machines to test that cross-endian reads/writes work correctly.

Finally, *endian-targetting*, that is setting the file datatype for an endian-ness that is possibly different than the native endian-ness of the writer (to, for example, alleviate down-stream consumers from having to byte-swap due to endian incompatibility between writer and reader) is explicitly dis-allowed because it is not an operation that is currently supported by the **HDF5** library.

Tests and Examples

The tests directory contains a few simple tests of the [H5Z-ZFP](#) filter some of which also serve as decent examples.

The test client, `test_write.c` is compiled a couple of different ways. One target is `test_write_plugin` which demonstrates the use of this filter as a standalone plugin. The other target, `test_write_lib`, demonstrates the use of the filter as an explicitly linked library. By default, these test a simple 1D array with and without [ZFP](#) compression using either the [Generic Interface](#) (for plugin) or the [Properties Interface](#) (for library). You can use the code there as an example of using the [ZFP](#) filter either as a plugin or as a library. However, these also include some advanced usages for 4D and 6D, time-varying (e.g. *extendible*) datasets. The command `test_write_lib help` or `test_write_plugin help` will print a list of the example's options and how to use them.

7.1 Write Test Options

```
./test/test_write_lib --help
  ifile=""                      set input filename
  ofile="test_zfp.h5"          set output filename

1D dataset generation arguments...
  npoints=1024                 set number of points for 1D dataset
  noise=0.001                  set amount of random noise in 1D dataset
  amp=17.7                     set amplitude of sinusoid in 1D dataset
  chunk=256                    set chunk size for 1D dataset
  doint=0                      also do integer 1D data

ZFP compression paramaters...
  zfpmode=3                    (1=rate,2=prec,3=acc,4=expert,5=reversible)
  rate=4                       set rate for rate mode of filter
  acc=0                        set accuracy for accuracy mode of filter
  prec=11                      set precision for precision mode of zfp filter
  minbits=0                    set minbits for expert mode of zfp filter
  maxbits=4171                 set maxbits for expert mode of zfp filter
  maxprec=64                   set maxprec for expert mode of zfp filter
  minexp=-1074                 set minexp for expert mode of zfp filter
```

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```
Advanced cases...
  highd=0                                run 4D case
  sixd=0          run 6D extendable case (requires ZFP>=0.5.4)
  help=0                                this help message
```

The test normally just tests compression of 1D array of integer and double precision data of a sinusoidal array with a small amount of additive random noise. The `highd` test runs a test on a 4D dataset where two of the 4 dimensions are not correlated. This tests the plugin's ability to properly set chunking for HDF5 such that chunks span **only** correlated dimensions and have non-unity sizes in 3 or fewer dimensions. The `sixd` test runs a test on a 6D, extendible dataset representing an example of using ZFP for compression along the *time* axis.

There is a companion, `test_read.c` which is compiled into `test_read_plugin` and `test_read_lib` which demonstrates use of the filter reading data as a plugin or library. Also, the commands `test_read_lib help` and `test_read_plugin help` will print a list of the command line options.

To use the plugin examples, you need to tell the HDF5 library where to find the H5Z-ZFP plugin with the `HDF5_PLUGIN_PATH` environment variable. The value you pass is the path to the directory containing the plugin shared library.

Finally, there is a Fortran test example, `test_rw_fortran.F90`. The Fortran test writes and reads a 2D dataset. However, the Fortran test is designed to use the filter **only** as a library and not as a plugin. The reason for this is that the filter controls involve passing combinations of integer and floating point data from Fortran callers and this can be done only through the *Properties Interface*, which by its nature requires any Fortran application to have to link with an implementation of that interface. Since we need to link extra code for Fortran, we may as well also link to the filter itself alleviating the need to use the filter as a plugin. Also, if you want to use Fortran support, the HDF5 library must have, of course, been configured and built with Fortran support as well.

In addition, a number tests are performed in the Makefile which test the plugin by using some of the HDF5 tools such as `h5dump` and `h5repack`. Again, to use these tools to read data compressed with the H5Z-ZFP filter, you will need to inform the HDF5 library where to find the filter plugin. For example..

```
env HDF5_PLUGIN_PATH=<dir> h5ls test_zfp.h5
```

Where `<dir>` is the relative or absolute path to a directory containing the filter plugin shared library.

It is possible to build the H5Z-ZFP filter using the CMake build system. If you decide to do so, please build ZFP also with its CMake build system. This is necessary to get the correct dependencies from ZFP. For example, it is possible to build ZFP with OpenMP support. The resulting CMake config files of ZFP build will make sure that this OpenMP dependency is correctly propagated to the build of H5Z-ZFP filter. However, for HDF5 it is not necessary to build it with its CMake build system but it is strongly recommended.

8.1 Compiling H5Z-ZFP

Similar as for the Makefile installation, the CMake build system is designed such it compiles both the standalone *HDF5 plugin* and a separate *library* an application can explicitly link. See *Plugin vs. Library Operation*

Once you have installed both HDF5 and ZFP, you can compile *H5Z-ZFP* using a command=line...

```
export HDF_DIR=<path-to_hdf5>
export ZFP_DIR=<path-to-zfp>
CC=<C-compiler> FC=<Fortran-compiler> cmake -DCMAKE_INSTALL_PREFIX=<path-to-install>
↪<src-dir>
```

where <path-to-zfp> is a directory containing *ZFP* `inc[lude]` and `lib` directories and <path-to-hdf5> is a directory containing *HDF5* `include` and `lib` directories. Furthermore, `src-dir` is the directory where the source is located and `path-to-install` is the directory in which the resulting *plugin* and *library* will be installed. Once `cmake` has finished successfully, you can build and install the filter using the command...

```
make install
```

This `cmake` and `make` combination builds both the C and Fortran interface. In the case you want to specify the <path-to-hdf5> and <path-to-zfp> via command-line to CMake, the command looks like this...

```
CC=<C-compiler> FC=<Fortran-compiler> cmake -DCMAKE_INSTALL_PREFIX=<path-to-install>
-DCMAKE_PREFIX_PATH="<path-to-hdf5>;<path-to-zfp>" <src-dir>
```

Please, notice the double quotes in the `CMAKE_PREFIX_PATH` expression. These are needed to make sure that semicolon is interpreted as a semicolon instead of a new command.

It is possible to build the filter without the Fortran interface. This is done as follows...

```
export HDF5_DIR=<path-to_hdf5>
export ZFP_DIR=<path-to-zfp>
CC=<C-compiler> cmake -DCMAKE_INSTALL_PREFIX=<path-to-install> -DFORTRAN_
↳INTERFACE:BOOL=OFF <src-dir>
```

followed by the same make command...

```
make install
```

8.2 Including H5Z-ZFP filter in a CMake project

Suppose you have built the H5Z-ZFP filter using the CMake build system and installed it in `<path-to-h5z_zfp>`. To include it in another CMake project is done using the following steps. First edit the `CMakeLists.txt` by adding the following two lines...

```
cmake_policy(SET CMP0028 NEW) # Double colon in target name means ALIAS or IMPORTED_
↳target.
...
set(H5Z_ZFP_USE_STATIC_LIBS OFF)
find_package(H5Z_ZFP 1.0.1 CONFIG)
...
target_link_libraries(<target> h5z_zfp::h5z_zfp)
...
```

where `<target>` in the target within the CMake project. This could be, for example, a executable or library. Furthermore, check if the cmake version is equal or greater than 3.9. Next, you need to make sure that the filter can be found by CMake, followed CMake itself and make...

```
export H5Z_ZFP_DIR=<path-to-h5z_zfp>
CC=<C-compiler> cmake -DCMAKE_INSTALL_PREFIX=<path-to-install> <src-dir>
make install
```

The `cmake` command itself could be different depending on the CMake project you have created. If you want to make use of the H5Z_ZFP *library* instead of the plugin, change cmake variable `H5Z_ZFP_USE_STATIC_LIBS` to ON and build the project.