

HDF5.jl: Hierarchical Data Storage for Julia

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To Simon and Mustafa

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What is HDF5?

HDF5 stands for Hierarchical Data Format version 5 and is maintained by The HDF Group.

- HDF5 is a file format with an open specification
- HDF5 is a C Library and API
- HDF5 is a data model

When to use HDF5

- Store numeric array and attributes in nested groups
- Use it when you want to compactly store lot of binary data
- Do not use it when you have a lot of variable length strings
- Consider other formats when using tables

What is HDF5? - Related Formats

- NetCDF - Network Common Data Form (Unidata, UCAR)
- MAT - MATLAB data files v7.3+
- PyTables - Pandas

I. Introduction

- A. This Document
- B. Changes for HDF5 1.12
- C. Changes for HDF5 1.10

II. Disk Format: Level 0 - File Metadata

- A. Disk Format: Level 0A - Format Signature and Superblock
- B. Disk Format: Level 0B - File Driver Info
- C. Disk Format: Level 0C - Superblock Extension

III. Disk Format: Level 1 - File Infrastructure

- A. Disk Format: Level 1A - B-trees and B-tree Nodes
 - 1. Disk Format: Level 1A1 - Version 1 B-trees
 - 2. Disk Format: Level 1A2 - Version 2 B-trees
- B. Disk Format: Level 1B - Group Symbol Table Nodes
- C. Disk Format: Level 1C - Symbol Table Entry
- D. Disk Format: Level 1D - Local Heaps
- E. Disk Format: Level 1E - Global Heap
- F. Disk Format: Level 1F - Global Heap Block for Virtual Datasets
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- H. Disk Format: Level 1H - Free-space Manager
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IV. Disk Format: Level 2 - Data Objects

- A. Disk Format: Level 2A - Data Object Headers
 - 1. Disk Format: Level 2A1 - Data Object Header Prefix
 - a. Version 1 Data Object Header Prefix
 - b. Version 2 Data Object Header Prefix
 - 2. Disk Format: Level 2A2 - Data Object Header Messages
 - a. The NIL Message
 - b. The Dataspace Message
 - c. The Link Info Message
 - d. The Datatype Message
 - e. The Data Storage - Fill Value (Old) Message

IV. Disk Format: Level 2 - Data Objects *(Continued)*

A. Disk Format: Level 2A - Data Object Headers *(Continued)*

2. Disk Format: Level 2A2 - Data Object Header Messages *(Continued)*

- f. The Data Storage - Fill Value Message
- g. The Link Message
- h. The Data Storage - External Data Files Message
- i. The Data Layout Message
- j. The Bogus Message
- k. The Group Info Message
- l. The Data Storage - Filter Pipeline Message
- m. The Attribute Message
- n. The Object Comment Message
- o. The Object Modification Time (Old) Message
- p. The Shared Message Table Message
- q. The Object Header Continuation Message
- r. The Symbol Table Message
- s. The Object Modification Time Message
- t. The B-tree 'K' Values Message
- u. The Driver Info Message
- v. The Attribute Info Message
- w. The Object Reference Count Message
- x. The File Space Info Message

B. Disk Format: Level 2B - Data Object Data Storage

V. Appendix A: Definitions

VI. Appendix B: File Space Allocation Types

VII. Appendix C: Types of Indexes for Dataset Chunks

- A. The Single Chunk Index
- B. The Implicit Index
- C. The Fixed Array Index
- D. The Extensible Array Index
- E. The Version 2 B-trees Index

VIII. Appendix D: Encoding for Dataspace and Reference

- A. Dataspace Encoding
- B. Reference Encoding (Revised)
- C. Reference Encoding (Backward Compatibility)

HDF5 Specification: Superblock

Layout: Superblock (Versions 2 and 3)

byte	byte	byte	byte
Format Signature (8 bytes)			
Version # of Superblock	Size of Offsets	Size of Lengths	File Consistency Flags
Base Address ^O			
Superblock Extension Address ^O			
End of File Address ^O			
Root Group Object Header Address ^O			
Superblock Checksum			

(Items marked with an 'O' in the above table are of the size specified in the [Size of Offsets](#) field in the superblock.)

https://docs.hdfgroup.org/hdf5/v1_14/_f_m_t3.html#Superblock

A HDF5 Hex Dump

00000000	89	48	44	46	0d	0a	1a	0a	03	08	08	00	00	00	00	00	.HDF.....	
00000010	00	00	00	00	ff	ff	ff	ff	ff	ff	ff	ff	82	08	01	00	
00000020	00	00	00	00	30	00	00	00	00	00	00	00	92	3c	c0	2c0.....<.,	
00000030	4f	48	44	52	02	20	a3	5c	ae	64	a3	5c	ae	64	a3	5c	OHDR. .\.d.\.d.\	
00000040	ae	64	a3	5c	ae	64	78	02	12	00	00	00	00	ff	ff	ff	.d.\.dx.....	
00000050	ff	ff	ff	ff	ff	ff	ff	ff	ff	ff	ff	ff	ff	ff	0a	02	00
00000060	01	00	00	06	14	00	00	01	00	09	7a	61	72	72	73	68zarrsh	
00000070	61	72	64	c3	00	00	00	00	00	00	00	00	40	00	00	00	ard.....@...	
00000080	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00

Decimal:	137	72	68	70	13	10	26	10
Hexadecimal:	89	48	44	46	0d	0a	1a	0a
ASCII C Notation:	\211	H	D	F	\r	\n	\032	\n

What is HDF5.jl?

HDF5.jl is a wrapper around the HDF5 C Library.

It consists of

- A low level interface, a direct mapping to the C API
- A mid level interface, lightweight helpers
- A high level interface, a Julia API

HDF5.jl Early Contributors

- There are many contributors
- Konrad Hisen initiated Julia's support for HDF5
- Tim Holy and Simon Kornblith were the initial primary authors
- Tom Short, Blake Johnson, Isaih Norton, Elliot Saba, Steven Johnson, Mike Nolta, Jameson Nash

HDF5.jl Current Developers

- Mustafa Mohamad is the current lead maintainer
- Mark Kittisopikul has been expanding API coverage, especially with chunking
- Simon Byrne has been working on package organization, filter interface
- Other recent contributors: t-bltg, Henrik Ranocha, Nathan Zimmerberg, Joshua Lampert, Tamas Gal, David MacMahon, Juan Ignacio Polanco, Michale Schlottke-Lakemper, linwaytin, Dmitri Iouchtchenko, Lorenzo Van Munoz, Jared Wahlstrand, Julian Samaroo, machakann, James Hester, Ralph Kube, Kristoffer Carlsson

How does HDF5.jl compare to h5py?

- h5py is a Python library that wraps the HDF5 C library.
- h5py uses Cython to build low-level wrappers
- HDF5.jl wraps the C library directly via `@ccall`
- HDF5.jl takes advantages of types and multiple dispatch

Basic HDF5.jl Usage


```
using HDF5


# Write a HDF5 file
h5open("mydata.h5", "w") do h5f
    h5f["group_A/group_B/array_C"] = rand(1024, 1024)
    attributes(h5f["group_A"])["access_date"] = "2023_07_21"
end


# Read a HDF5 file
C = h5open("mydata.h5") do h5f
    println(attrs(h5f["group_A"])["access_date"])
    h5f["group_A/group_B/array_C"][:, :]
end
```


Exploring a HDF5 file with HDF5.jl


```
julia> h5f = h5open("mydata.h5")
```

```
 HDF5.File: (read-only) mydata.h5
```

```
└─  group_A
```

```
    └─  access_date
```

```
    └─  group_B
```

```
        └─  array_C
```

```
julia> C = h5f["group_A"]["group_B"]["array_C"][1:16,1:16]
```

```
16×16 Matrix{Float64}:
```

```
...
```

```
julia> close(h5f)
```

Structs and HDF5 Types

```
julia> struct Foo
           x::Int64
           y::Float64
       end

julia> HDF5.datatype(Foo)
HDF5.Datatype: H5T_COMPOUND {
    H5T_STD_I64LE "x" : 0;
    H5T_IEEE_F64LE "y" : 8;
}
```

Reading and writing structs

```
julia> h5open("mystruct.h5", "w") do h5f
    h5f["Foo"] = [Foo(1, 3.0)]
end
```

```
1-element Vector{Foo}:
 Foo(1, 3.0)
```

```
julia> h5open("mystruct.h5", "r") do h5f
    h5f["Foo"][]
end
```

```
1-element Vector{NamedTuple{(:x, :y), Tuple{Int64, Float64}}}:
 (x = 1, y = 3.0)
```

```
julia> h5open("mystruct.h5", "r") do h5f
    read(h5f["Foo"], Foo)
end
```

```
1-element Vector{Foo}:
 Foo(1, 3.0)
```


Compression Filter Plugin Packages

Glue code written in Julia.

- H5Zblosc.jl - Blosc.jl (Thank you, Steven G. Johnson)
- H5Zzstd.jl - CodecZstd.jl
- H5Zlz4.jl - CodecLZ4.jl
- H5Zbzip2.jl - CodecBzip2.jl
- H5Zbitshuffle.jl

Chunking and Built-in Gzip Compression Usage

```
using HDF5

h5open("simple_chunked.h5", "w", libver_bounds=v"1.12") do h5f
    h5ds = create_dataset(h5f, "gzipped_data", UInt8, (16,16),
        chunk=(4,4),
        filters=[HDF5.Filters.Deflate()],
        alloc_time = :early
    )
end
```

Chunking and Filter Plugin Usage

```
using HDF5, H5Zzstd

h5open("zstd_chunked.h5", "w", libver_bounds=v"1.12") do h5f
    h5ds = create_dataset(h5f, "zstd_data", UInt8, (16,16),
        chunk=(4,4),
        filters=[ZstdFilter(3)]
    )
end
```

Future: Loading CodecZstd.jl will trigger a package extension

Other Related Julia Packages

- HDF5_jll.jl, C Library from HDF Group
- MAT.jl, MATLAB files
- JLD.jl, Julia Data Format
- JLD2.jl, Julia Data Format 2, Pure Julia implementation

Parallelization via Message Passing Interface (MPI)

