Recent developments in histogram libraries

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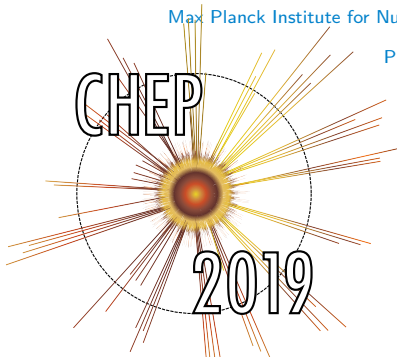

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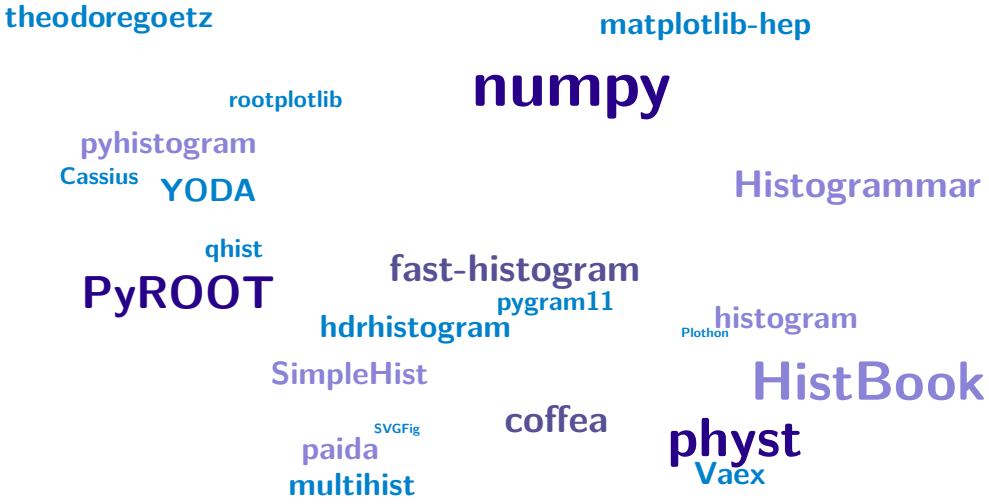
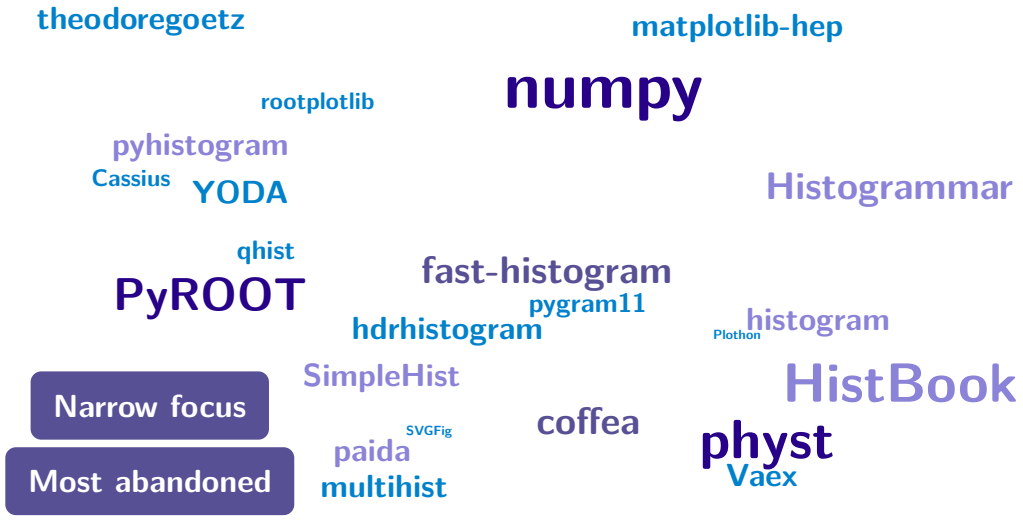
PRINCETON UNIVERSITY

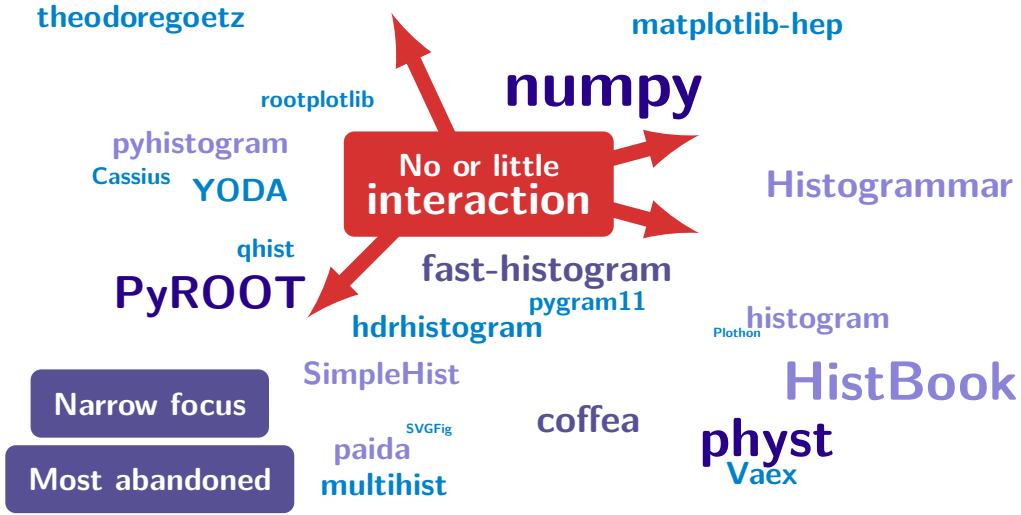
Histogram libraries (Python)



Histogram libraries (Python)

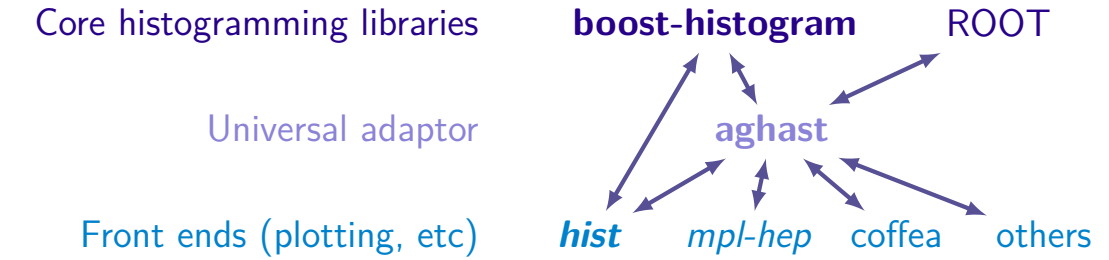


Histogram libraries (Python)



Scikit-HEP histogramming plan (Python)

- **boost-histogram**: Fast filling and manipulation (core library)
- ***hist***: Simple analysis frontend
- **aghast**: Conversions between histogram libraries
- **UHI** (Unified Histogram Indexing): Cross-library indexing proposal



- /boostorg/histogram
- Designed by Hans Dembinski

- Header only, with header only Boost
- Heavily unit-tested: 100% line coverage

Features

- Static / Dynamic storage (can avoid allocation!)
- Static fill becomes 57 lines of vectorized assembly
- Supports platforms without exceptions or RTTI
- Adding, scaling, slicing, rebinning, projections...
- High performance filling and bin iteration
- Unique memory-efficient dynamic storage

Customizable:

- storage
- allocator
- accumulator
- axes
- axis metadata
- axis transform

Boost histogram

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Accepted in Boost 1.70!

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Will not go away!

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Boost.Histogram C++14: Histogram concept

Histogram

- Axes
- Storage

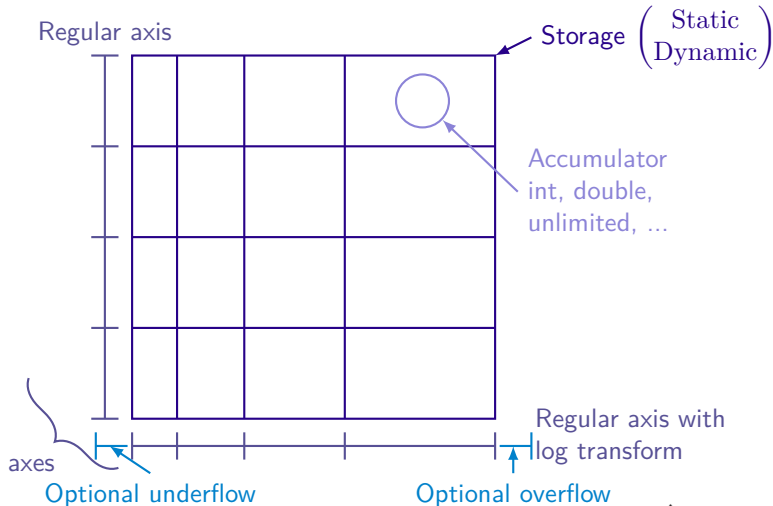
Axis types

- Regular (circular)
- Variable (circular)
- Integer (circular)
- Category

Accumulators

- Sum
- Mean

Single class replaces `TH1T`, `TH2T`, `TH3T`, `THnT`, `TProfile`, `TProfile2D`, `TProfile3D` and is more general!



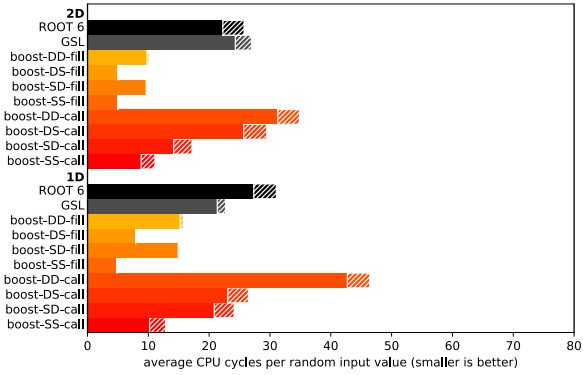
Boost.Histogram C++14: Elegant and powerful

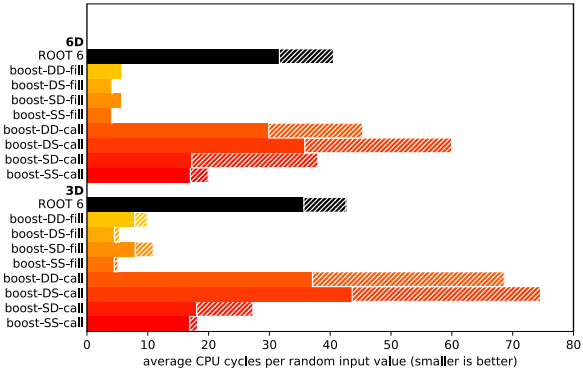
```cpp
#include <boost/histogram.hpp>
#include <boost/histogram/ostream.hpp>
#include <random>
#include <iostream>

int main() {
    namespace bh = boost::histogram;

    auto hist = bh::histogram(bh::axis::regular{20, -3, 3}); // C++17 version

    std::default_random_engine eng;
    std::normal_distribution<double> dist{0, 1};
    for(int n = 0; n < 10'000; ++n)
        hist(dist(eng));

    std::cout << hist << std::endl;
    return 0; }
```

Boost.Histogram C++14: Example output

```
histogram(regular(20, -3, 3, options=underflow | overflow))
                  +------------------------------------------------------------+
[-inf,   -3) 9    |                                                            |
[  -3, -2.7) 19   |=                                                           |
[-2.7, -2.4) 36   |==                                                          |
[-2.4, -2.1) 110  |=====                                                       |
[-2.1, -1.8) 191  |=========                                                   |
[-1.8, -1.5) 275  |=============                                               |
[-1.5, -1.2) 518  |=========================                                   |
[-1.2, -0.9) 644  |==============================                              |
[-0.9, -0.6) 914  |===========================================                 |
[-0.6, -0.3) 1107 |====================================================        |
[-0.3,    0) 1183 |========================================================== |
[   0,  0.3) 1185 |========================================================== |
[ 0.3,  0.6) 1120 |=====================================================       |
[ 0.6,  0.9) 874  |=========================================                   |
[ 0.9,  1.2) 663  |===============================                             |
[ 1.2,  1.5) 491  |=======================                                     |
[ 1.5,  1.8) 322  |===============                                             |
[ 1.8,  2.1) 172  |========                                                    |
[ 2.1,  2.4) 79   |====                                                        |
[ 2.4,  2.7) 38   |==                                                          |
[ 2.7,    3) 28   |=                                                           |
[   3,  inf) 22   |=                                                           |
                  +------------------------------------------------------------+
```

Boost.Histogram C++14: Performance





- `call` is one at a time fill
- `fill` is new (1.72) array fill

- `S` is static (fixed types)
- `D` is dynamic (unlimited storage)

boost-histogram: Python bindings

- Boost.Histogram developed with Python in mind
  - Original prototype bindings based on Boost::Python
- New bindings: /scikit-hep/boost-histogram
  - 0-dependency build (C++14 only)
  - State-of-the-art PyBind11
  - Designed with the original author, Hans Dembinski
- Public beta 0.5.2 currently available, 0.6 coming soon

Design | Flexibility | Speed | Distribution

Design

- 500+ unit tests run on Azure on Linux, macOS, and Windows
- Stays close to Boost.Histogram with Pythonizations

C++17

```cpp
#include <boost/histogram.hpp>
namespace bh = boost::histogram;

auto hist = bh::histogram(
  bh::axis::regular{2, 0, 1, "x"},
  bh::axis::regular{4, 0, 1, "y"});

hist(.2, .3); // Fill will also be
hist(.4, .5); // available in 1.72
hist(.3, .2);
```

Python

```python
import boost_histogram as bh

hist = bh.Histogram(
  bh.axis.Regular(2, 0, 1, metadata="x"),
  bh.axis.Regular(4, 0, 1, metadata="y"))

hist.fill(
    [.2, .4, .3],
    [.3, .5, .2])
```

Design: Manipulations

Combine two histograms
```
hist1 + hist2
```

Scale a histogram
```
hist * 2.0
```

Sum a histogram contents
```
hist.sum()
```

Access an axis
```
ax = hist.axes[0]
ax.edges   # The edges array
ax.centers # Centers of bins
ax.widths  # Width of each bin

hist.axes.centers # All centers
# Etc.
```

Fill 2D histogram with values or arrays
```
hist.fill(a1, a2, weights=[w1, w2],
                  samples=[s1, s2])
```

Convert contents to Numpy array
```
hist.view()
```

Convert to Numpy style histogram tuple
```
hist.to_numpy()
```

Pickle supported (multiprocessing)
```
pickle.dumps(hist, -1)
```

Copy/deepcopy supported
```
hist2 = copy.deepcopy(hist)
```

Numpy functions provided
```
H, E = bh.numpy.histogram(...)
```

Design: Unified Histogram Indexing (UHI)

The language here (`bh.loc`, etc) is defined in such a way that any library can provide them - "Unified".

Access

```
v = h[b]              # Returns bin contents, indexed by bin number
v = h[bh.loc(b)]      # Returns the bin containing the value
v = h[bh.underflow] # Underflow and overflow can be accessed with special tags
```

Setting

```
h[b] = v
h[bh.loc(b)] = v
h[bh.underflow] = v
```

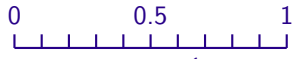
Design: Unified Histogram Indexing (UHI) (2)

```
h == h[:]                 # Slice over everything
h2 = h[a:b]               # Slice of histogram (includes flow bins)
h2 = h[:b]                # Leaving out endpoints is okay
h2 = h[bh.loc(v):]        # Slices can be in data coordinates, too
h2 = h[::bh.sum]          # Remove an axis by summation
h2 = h[0:5:bh.sum]        # Can add endpoints
h2 = h[::bh.rebin(2)]     # Modification operations (rebin)
h2 = h[a:b:bh.rebin(2)] # Modifications can combine with slices
h2 = h[a:b, ...]          # Ellipsis work just like normal numpy
```

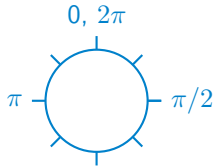
- Docs are here
- Description may move to a new repository

Flexibility: Axis types

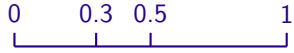
- `bh.axis.Regular`
  - `under/overflow`
  - `growth=True`
  - `circular=True`
  - `transform=Log()`
  - `transform=Sqrt()`
  - `transform=Pow(v)`
- `bh.axis.Integer`
  - `under/overflow`
  - `growth=True`
- `bh.axis.Variable`
  - `under/overflow`
  - `growth=True`
- `bh.axis.Category`
  - `int or str`
  - `growth=True`



`bh.axis.Regular(10, 0, 1)`



`bh.axis.Regular(8, 0, 2*np.pi, circular=True)`



`bh.axis.Variable([0, .3, .5, 1])`

`bh.axis.Integer(0, 5)`

`bh.axis.Category([2, 5, 8, 3, 7])`

Performance

- Factor of 2 faster than 1D regular binning in Numpy 1.17
  - Currently no specialization, just a 1D regular fill
  - Could be optimized further for common fills
- Factor of 6-10 faster than 2D regular binning Numpy

Distribution

If `pip install boost-histogram` fails, we have failed.

- Docker ManyLinux1 GCC 9.2: /scikit-hep/manylinuxgcc
- Used in /scikit-hep/iMinuit, /scikit-hep/awkward1
- Described on iscinumpy.gitlab.io, also see /scikit-hep/azure-wheel-helpers

Wheels

- manylinux1 32/64 bit, Py 2.7, 3.5, 3.6, 3.7
- manylinux2010 64 bit, Py 2.7, 3.5, 3.6, 3.7, 3.8
- macOS 10.9+ 64 bit, Py 2.7, 3.6, 3.7, 3.8
- Windows 32/64 bit, Py 2.7, 3.6, 3.7

Source

- SDist on PyPI
- Build directly from GitHub

Conda-Forge

- All (including 3.8) except 2.7 on Windows

```
python3 -m pip install boost-histogram
conda install -c conda-forge boost-histogram
```

Hist

`hist` is the 'wrapper' piece that does plotting and interacts with the rest of the ecosystem.

Plans

- Easy plotting adaptors (mpl-hep)
- Serialization formats via aghast (ROOT, HDF5)
- Implicit multithreading
- Statistical functions (Like TEfficiency)
- Multihistogram plotting (HistBook)
- Interaction with fitters (ZFit, GooFit, etc)
- Bayesian Blocks algorithm from Scikit-HEP
- Command line histograms for stream of numbers

Call for contributions

- What do you need?
- Looking for a student interested in development

Join in the development! This should combine the best features of other packages.

aghast

aghast is a histogramming library that does not fill histograms and does not plot them.

/scikit-hep/aghast

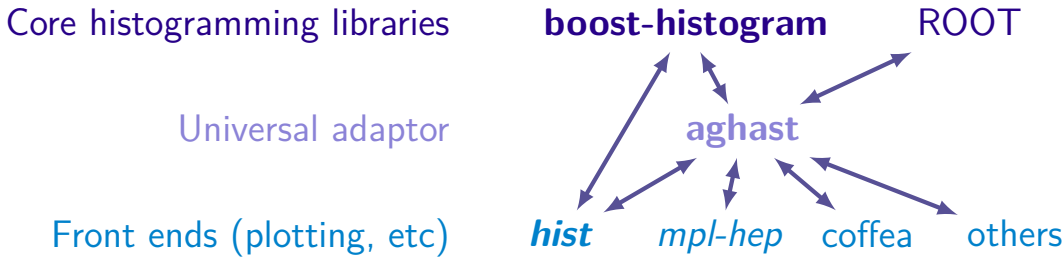
- A memory format for histograms, like Apache Arrow
- Converts to and from other libraries
- Uses flatbuffers to hold histograms
- Indexing ideas inspired the UHI

Available Binnings

- `IntegerBinning`
- `RegularBinning`
- `HexagonalBinning`
- `EdgesBinning`
- `IrregularBinning`
- `CategoryBinning`
- `SparseRegularBinning`
- `FractionBinning`
- `PredicateBinning`
- `VariationBinning`

Conclusions

- Boost.Histogram C++14 is a solid foundation
- boost-histogram for Python is a core histogramming library
- Hist will be developed next and is analysis friendly
- aghast is the glue to ROOT/everything else



Questions

Supported by

- IRIS-HEP, NSF OAC-1836650
- DIANA-HEP, NSF OAC-1558216, NSF OAC-1558233, NSF OAC-1558219

Storage types

- `bh.storage.Int`
- `bh.storage.Double`
- `bh.storage.Unlimited`
- `bh.storage.AtomicInt`
- `bh.storage.Weight`
- `bh.storage.Profile`
- `bh.storage.WeightedProfile`