Analyzing Data with Awkward Arrays

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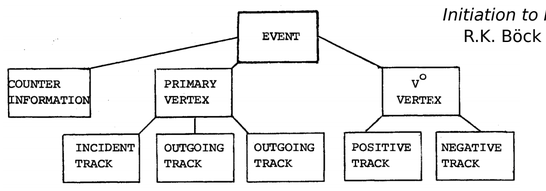
Why it's needed

Particle physicists have always needed **big datasets** of **nested, variable-sized data**.

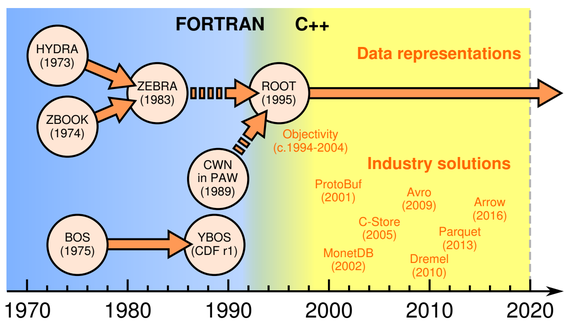
Figure from a 45-year old physics-software manual:



Initiation to HYDRA, R.K. Böck (1974).

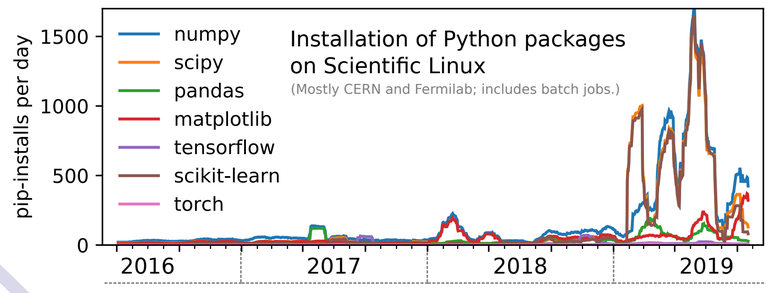
We'd draw similar figures today!

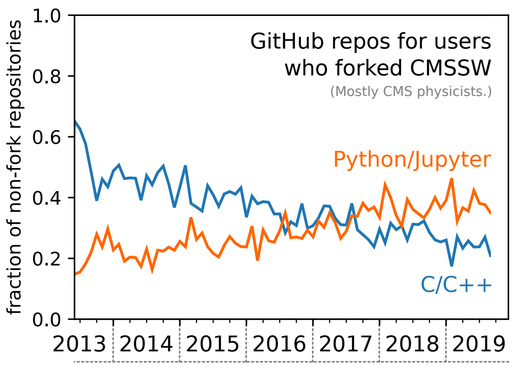
Traditionally, this problem was solved by making data analysts use ~~Fortran~~ C++.



Why now?

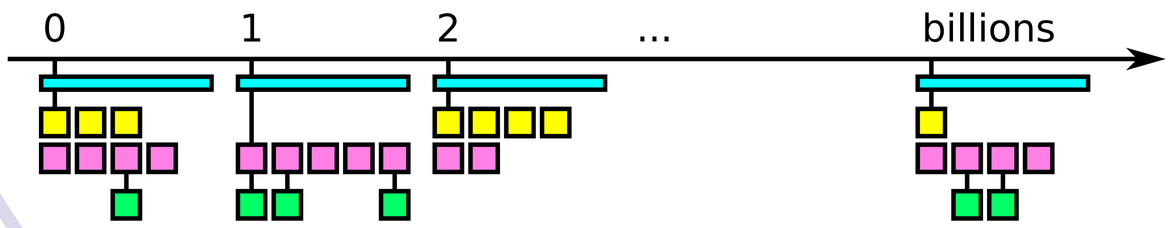
Python/NumPy is rapidly becoming a standard language for data analysis in particle physics.





Awkward Array

An array library for **nested, variable-sized data**, including arbitrary-length lists, records, mixed types, and missing data, using **NumPy-like idioms**.



Arrays are **dynamically typed**, but operations on them are **compiled and fast**.

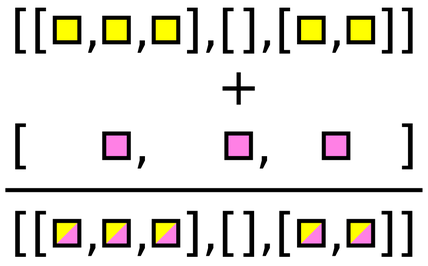
Coincides with NumPy when arrays are regular; generalizes when they're not.

But...

NumPy does not work on nested, variable-sized data!

What it does

Jagged broadcasting of NumPy “ufuncs”

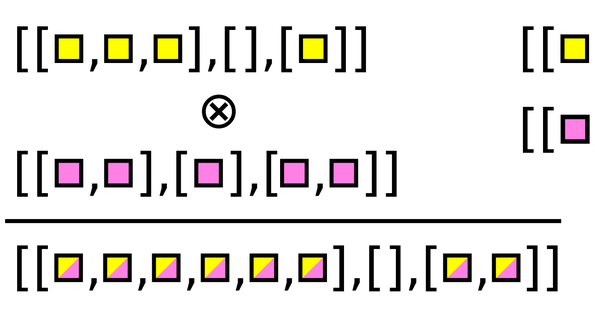


Advanced indexing

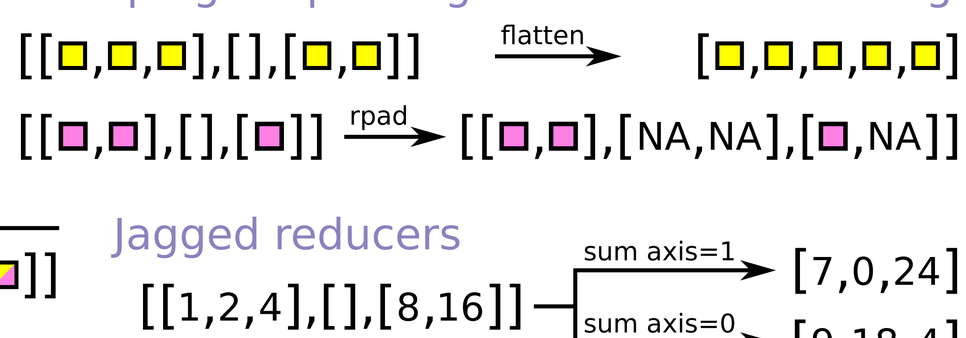
```
# select muons 0,1 from events
>>> events[:, "muons", [0,1]]

# select muons with pt > 50
>>> events[events["muons", "pt"] > 50]
```

Combinatorics



Reshaping for plotting and machine learning



Jagged reducers

ROOT & Arrow/Parquet I/O

Originally intended as an array type for ROOT files, Awkward Arrays are convertable to/from Apache Arrow and Parquet (sometimes zero-copy).

Interface with Numba

Awkward Arrays can be arguments and return values in Numba's JIT-compiled functions, enabling for-loop logic at the speed of compiled code.

...with Pandas

Awkward Arrays can be columns of a Pandas DataFrame.

...NumExpr, Autograd, ...

Jagged broadcasting is applied to all elementwise array calculations.

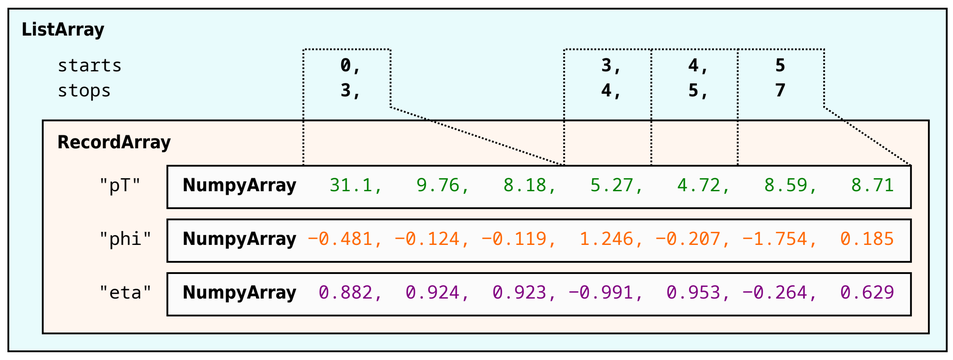
How it works

Arrays and their operations are **columnar**.

Consider these lists of particle objects:

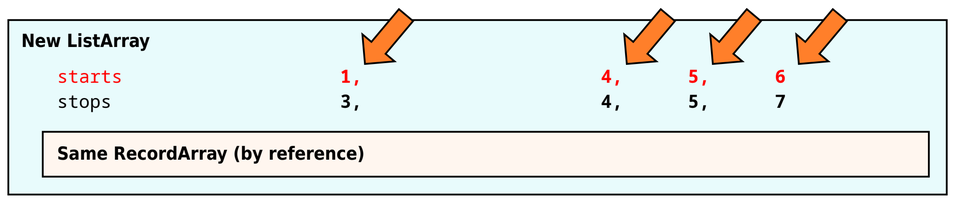
```
[[Muon(31.1, -0.481,  0.882), Muon(9.76, -0.124, 0.924), Muon(8.18, -0.119, 0.923)],
 [Muon(5.27,  1.246, -0.991)],
 [Muon(4.72, -0.207,  0.953)],
 [Muon(8.59, -1.754, -0.264), Muon(8.71,  0.185, 0.629)]]
```

We represent them in columnar arrays, contiguous by field:



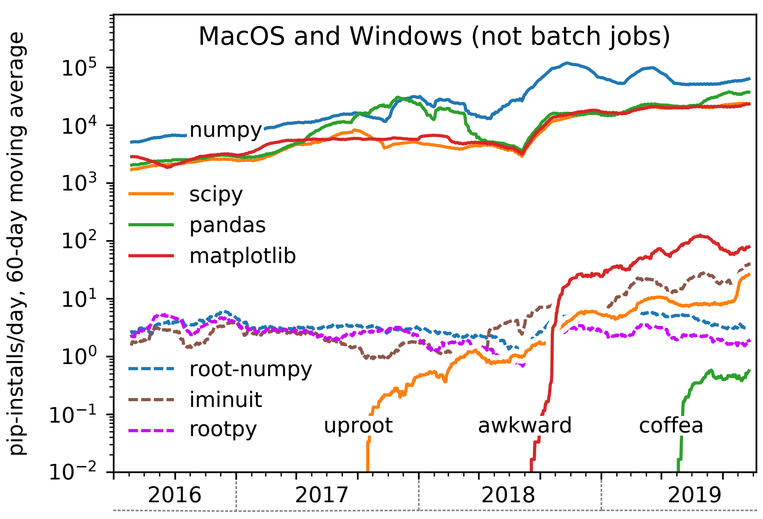
To transform the data, for example to remove the first element from each list, we only need to replace the ListArray:

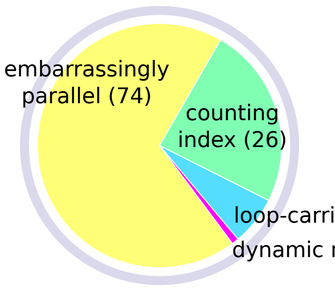
```
[[..., Muon(9.76, -0.124, 0.924), Muon(8.18, -0.119, 0.923)], [...], [...],
 [..., Muon(8.71,  0.185, 0.629)]]
```



Who uses it?

Mostly physicists, but a few geneticists and data scientists have expressed interest.





The library consists of a suite of “kernels” that transform arrays into arrays.

Most are embarrassingly parallel and are good candidates for GPU acceleration.

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