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Bridging Worlds:

Achieving Language Interoperability between Julia and Python in Scientific Computing

Ianna Osborne, Jim Pivarski, Jerry Ling, 13 Mar 2024

ACAT 2024

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The Landscape of Scientific Computing

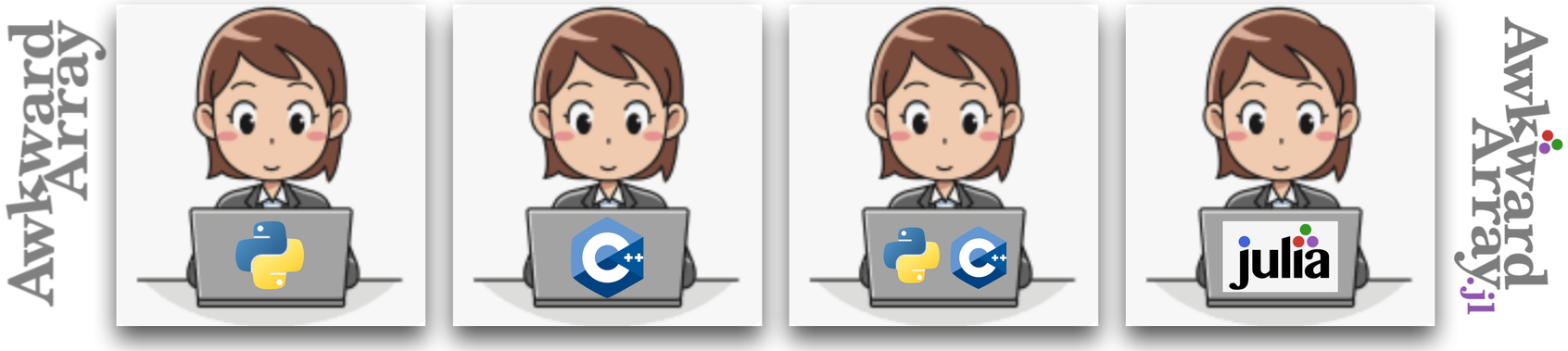
Python and Awkward Array at this workshop

- Python has long been a favorite for its simplicity and vast ecosystem:
  - 108. Awkward Family: expanding functionality through interrelated Python packages by Jim Pivarski
  - 31. Describe Data to get Science-Data-Ready Tooling: Awkward as a Target for Kaitai Struct YAML by Manasvi Goyal
  - 100. Using Legacy ATLAS C++ Calibration Tools in Modern Columnar Analysis Environments by Matthias Vigl
  - 122. Easy columnar file conversions with "hepconvert" by Zoë Bilodeau
  - 84. ServiceX, the novel data delivery system, for physics analysis by Kyungeon Choi
  - 104. dilax: Differentiable Binned Likelihoods in JAX by Manfred Peter Fackeldey

AwkwardArray.jl

Julia Introduction to Python Community

- Physicists are using Awkward Array in Python and data format conversion is the hardest part of language boundary-hopping
- Sharing Awkward Array data structures between Python and Julia to encourage the Python users to run their analysis both in an eco-system of their choice and in Julia
- See Jim's talk "Engaging the HEP community in Julia"



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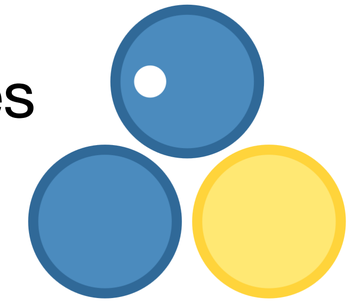
Interoperability
and GIL

- PythonCall and Julia Call allow to call Python code from Julia and Julia code from Python via a symmetric interface
  - Software that connects Julia and Python languages 14 repositories



- Dropping GIL when calling Julia from Python (JuliaCall):
  - “If you can guarantee your Julia code doesn't call back into Python, you can release the GIL yourself. A future version of JuliaCall will allow something like *some_julia_function.jl_call_nogil(x, y, z)* to make this a bit easier.”

```
pythread = PythonCall.C.PyEval_SaveThread()
try
    # code which doesn't touch Python
finally
    PythonCall.C.PyEval_RestoreThread(pythread)
end
```

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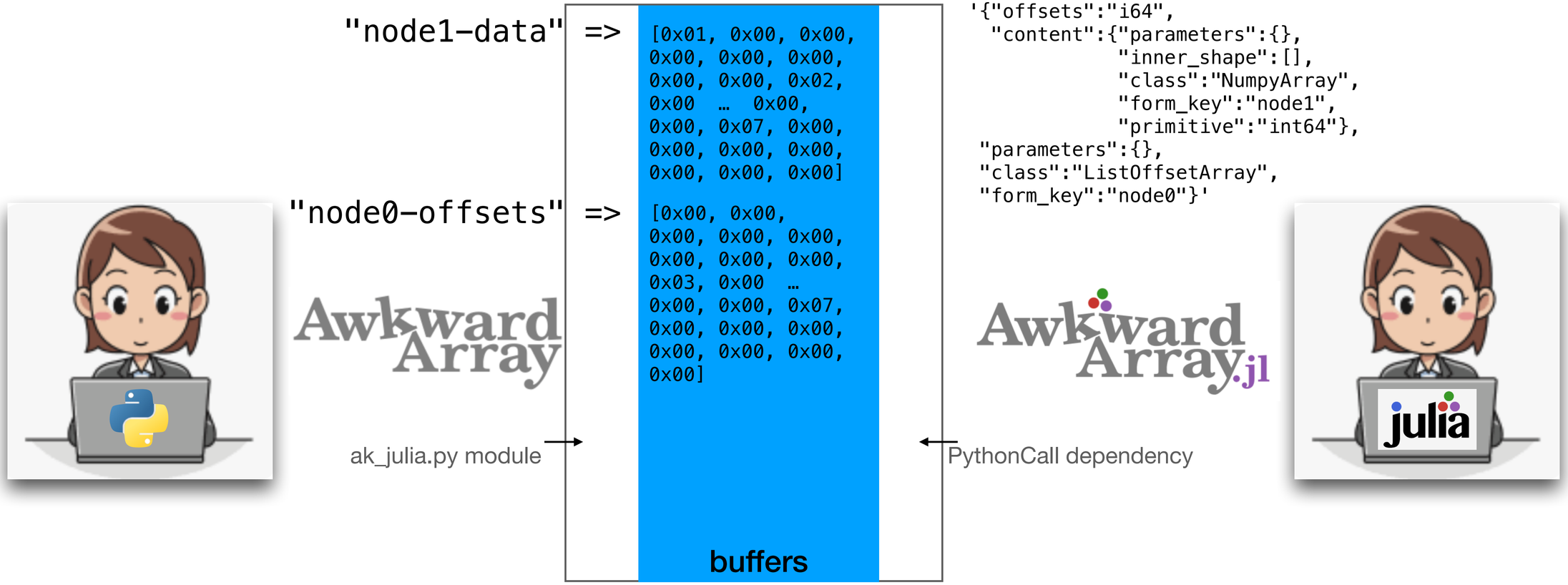
PythonCall and JuliaCall facilitate seamless Awkward Array data exchange between Python and Julia




```
array = ak.from_buffers(form, len, containers)
form, len, containers = ak.to_buffers(array)
```

```
array = AwkwardArray.from_iter([[1, 2, 3], [4], [5, 6, 7]])
form, len, containers = AwkwardArray.to_buffers(array)
array = AwkwardArray.from_buffers(form, len, containers)
```

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Converting Awkward Arrays

from Julia to Python and from Python to Julia

```julia
using PythonCall
using AwkwardArray: convert

   array = AwkwardArray.ListOffsetArray(
        [0, 3, 3, 5],
        AwkwardArray.PrimitiveArray([1.1, 2.2, 3.3, 4.4, 5.5]),
    )
    py_array = convert(array)

    # Check if the function returns an awkward array
    py_array isa Py

    # Check if the awkward array has the correct layout
    typeof(py_array) == Py

    ak_array = pyconvert(Vector, pyimport("awkward").to_list(py_array))
    ak_array == [[1.1, 2.2, 3.3], [], [4.4, 5.5]]
```

```julia
   py_array = pyimport("awkward").Array([[1.1, 2.2, 3.3], [], [4.4, 5.5]])

   # Check if the function returns an awkward array
   array = convert(py_array)
   array isa AwkwardArray.ListOffsetArray

   array == [[1.1, 2.2, 3.3], [], [4.4, 5.5]]
```

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Runtime Environment

and Julia package manager

- Conda.jl package allows one to use conda as a cross-platform binary provider for Julia for other Julia packages, especially to install binaries that have complicated dependencies like Python.

- The package dependencies are described in the Project.toml:

```
[deps]
Conda = "8f4d0f93-b110-5947-807f-2305c1781a2d"
JSON = "682c06a0-de6a-54ab-a142-c8b1cf79cde6"
PythonCall = "6099a3de-0909-46bc-b1f4-468b9a2dfc0d"
Tables = "bd369af6-aec1-5ad0-b16a-f7cc5008161c"
```

```
% julia
               _
   _       _ _(_)_     |  Documentation: https://docs.julialang.org
  (_)     | (_) (_)    |
   _ _   _| |_  __ _   |  Type "?" for help, "]?" for Pkg help.
  | | | | | | |/ _` |  |
  | | |_| | | | (_| |  |  Version 1.9.3 (2023-08-24)
 _/ |\__'_|_|_|\__'_|  |  https://github.com/conda-forge/julia-feedstock
|__/                   |

julia> using AwkwardArray

(@ak-julia) pkg> st
Status `~/anaconda3/envs/ak-julia/share/julia/environments/ak-julia/Project.toml`
  [7d259134] AwkwardArray v0.1.2
  [6e4b80f9] BenchmarkTools v1.4.0
  [992eb4ea] CondaPkg v0.2.22
  [a93c6f00] DataFrames v1.6.1
  [31a5f54b] Debugger v0.7.8
  [e30172f5] Documenter v1.2.1
  [682c06a0] JSON v0.21.4
  [98e50ef6] JuliaFormatter v1.0.45
  [6099a3de] PythonCall v0.9.15
  [295af30f] Revise v3.5.10
  [fd094767] Suppressor v0.2.6
  [bd369af6] Tables v1.11.1
  [3cd96dde] UnROOT v0.10.20
```

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Python module JuliaCall

- The Python module JuliaCall can be installed with *pip install juliacall*

```
% python
Python 3.12.0 | packaged by conda-forge | (main, Oct  3 2023, 08:43:38) [Clang 15.0.7 ] on darwin
Type "help", "copyright", "credits" or "license" for more information.

>>> from juliacall import Main as jl

[juliapkg] Locating Julia ^1.6.1
[juliapkg] Using Julia 1.9.3 at /Users/yana/anaconda3/envs/ak-julia/bin/julia
[juliapkg] Using Julia project at /Users/yana/anaconda3/envs/ak-julia/julia_env
[juliapkg] Installing packages:
           julia> import Pkg
           julia> Pkg.add([Pkg.PackageSpec(name="PythonCall", uuid="6099a3de-0909-46bc-b1f4-468b9a2dfc0d")])
           julia> Pkg.resolve()
           julia> Pkg.precompile()
   Resolving package versions...
    Updating `~/anaconda3/envs/ak-julia/julia_env/Project.toml`
  [6099a3de] + PythonCall v0.9.15
    Updating `~/anaconda3/envs/ak-julia/julia_env/Manifest.toml`
  [992eb4ea] + CondaPkg v0.2.22
  [9a962f9c] + DataAPI v1.15.0
  [e2d170a0] + DataValueInterfaces v1.0.0
  [82899510] + IteratorInterfaceExtensions v1.0.0
  [692b3bcd] + JLLWrappers v1.5.0
  [0f8b85d8] + JSON3 v1.14.0
  [1914dd2f] + MacroTools v0.5.11
  [0b3b1443] + MicroMamba v0.1.14
```

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Runtime Environment

and Python package dependencies

- AwkwardArray installed in conda environment

```
% conda list
# packages in environment at /Users/y/anaconda3/envs/ak-julia:
#
# Name                    Version                   Build  Channel
awkward                   2.4.6              pyhd8ed1ab_0    conda-forge
awkward-cpp               24                 py312h49ebfd2_0    conda-forge
```

```
>>> import awkward as ak
>>> jl.seval("using AwkwardArray")
```

julia

```
julia> using PythonCall

julia> py_array = pyimport("awkward").Array([[1.1, 2.2, 3.3], [], [4.4, 5.5]])
Python: <Array [[1.1, 2.2, 3.3], [], [4.4, 5.5]] type='3 * var * float64'>
```

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Calling Julia from Python

```
>>> import awkward as ak
>>> jl.seval("using AwkwardArray")
>>> array = ak.Array([[1,2,3],[],[4,5]])
>>> array
<Array [[1, 2, 3], [], [4, 5]] type='3 * var * int64'>
```

```
>>> jl.seval("""
... function path_length(array)
...     total = 0.0
...         for i in 1:length(array)
...             for j in 1:length(array[i])
...                 total += array[i][j]
...             end
...         end
...     return total
... end
... """
... )
Julia: path_length (generic function with 1 method)
```

```
>>> jl.path_length(array)
15.0
```

- Performance critical code should be inside a function
- Functions should take arguments, instead of operating on global variables

julia

```
function path_length(array)
    total = 0.0
        for i in 1:length(array)
            for j in 1:length(array[i])
                total += array[i][j]
            end
        end
    return total
end
```

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Conversion to Julia

1. define custom conversion rule

- The conversion rules used whenever converting a Python object to a Julia object:

```
jl.seval("""
function pyconvert_rule_awkward_array_primitive(::Type{AwkwardArray.PrimitiveArray}, x::Py)
    array = AwkwardArray.convert(x)
    return PythonCall.pyconvert_return(array)
end
""")
jl.seval("""
function pyconvert_rule_awkward_array_empty(::Type{AwkwardArray.EmptyArray}, x::Py)
    array = AwkwardArray.convert(x)
    return PythonCall.pyconvert_return(array)
end
""")
jl.seval("""
function pyconvert_rule_awkward_array_listoffset(::Type{AwkwardArray.ListOffsetArray}, x::Py)
    array = AwkwardArray.convert(x)
    return PythonCall.pyconvert_return(array)
end
""")
```

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Custom Conversion Rules

2. register it with PythonCall

```
jl.seval("""
    PythonCall.pyconvert_add_rule("awkward.highlevel:Array", AwkwardArray.PrimitiveArray,
pyconvert_rule_awkward_array_primitive, PythonCall.PYCONVERT_PRIORITY_ARRAY)
""")
```

```
jl.seval("""
    PythonCall.pyconvert_add_rule("awkward.highlevel:Array", AwkwardArray.EmptyArray,
pyconvert_rule_awkward_array_empty, PythonCall.PYCONVERT_PRIORITY_ARRAY)
""")
```

```
jl.seval("""
    PythonCall.pyconvert_add_rule("awkward.highlevel:Array", AwkwardArray.ListOffsetArray,
pyconvert_rule_awkward_array_listoffset, PythonCall.PYCONVERT_PRIORITY_ARRAY)
""")
```

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Potential Issues

Record Array example

- Create an Awkward Array in Julia and convert it to an Awkward Array in Python:

```
>>> jl.seval("""
... content_layout = AwkwardArray.RecordArray((a = AwkwardArray.PrimitiveArray([1, 2, 3, 4, 5]),
...                                            b = AwkwardArray.PrimitiveArray([1.1, 2.2, 3.3, 4.4, 5.5])))
... """)
Julia:
5-element AwkwardArray.RecordArray{(:a, :b), Tuple{AwkwardArray.PrimitiveArray{Int64, Vector{Int64}, :default},
AwkwardArray.PrimitiveArray{Float64, Vector{Float64}, :default}}, :default}:
 {a: 1, b: 1.1}
 {a: 2, b: 2.2}
 {a: 3, b: 3.3}
 {a: 4, b: 4.4}
 {a: 5, b: 5.5}
>>> py_rec_arr = jl.convert(jl.content_layout)
>>> py_rec_arr
<Array [{a: 1, b: 1.1}, ..., {a: 5, ...}] type='5 * {a: int64, b: float64}'>
```

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Potential Issues

Fields in Record Array

- One possible solution is to restrict the interface of the Record Array, for instance, by providing a 'field' attribute.

```
>>> jl.seval("""
... content_layout[:a]
... """)
Julia:
5-element AwkwardArray.PrimitiveArray{Int64, Vector{Int64}, :default}:
 1
 2
 3
 4
 5
>>> py_rec_arr = jl.convert(jl.content_layout)
>>> py_rec_arr["a"]
<Array [1, 2, 3, 4, 5] type='5 * int64'>
```

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Potential Issues

first element indexing

- It's important to note that in Julia, container indexing starts with 1, unlike some other languages where indexing starts with 0
- One solution to ensure portability in code is to avoid hardcoding numbers for indexing and instead use the *firstindex* function, which adjusts based on the indexing conventions of the language.

```
>>> jl.content_layout[0]
Julia: {a: 1, b: 1.1}
>>> jl.content_layout[2]
Julia: {a: 3, b: 3.3}
>>> jl.content_layout[3]
Julia: {a: 4, b: 4.4}
>>> jl.seval("""
... content_layout[0]
... """)
juliacall.JuliaError: BoundsError: attempt to access 5-element Vector{Int64} at index [0]
```

```
>>> jl.seval("""
... content_layout[1]
... """)
Julia: {a: 1, b: 1.1}
```

```
>>> jl.seval("""
... firstindex(content_layout)
... """)
1
```

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Use Cases

- Integrating high-performance Julia libraries into existing Python projects.
- Leveraging Python's extensive data analysis and visualization libraries in Julia workflows.
- Building hybrid applications that combine Python's ease of use with Julia's speed.

```
>>> cms_file = jl.ROOTFile("/PyHEP2023/Run2012BC_DoubleMuParked_Muons.root")
>>> cms_mumu_tree = jl.LazyTree(cms_file, "Events")
```

UnROOT.jl

```
>>> cms_mumu_tree
Julia:
```

Row	Muon_phi SubArray{Float3	nMuon UInt32	Muon_pt SubArray{Float3	Muon_eta SubArray{Float3	Muon_charge SubArray{Int	…
1	[-0.0343, 2.5	2	[10.8, 15.7]	[1.07, -0.564	[-1, -1]	…
2	[-0.275, 2.54	2	[10.5, 16.3]	[-0.428, 0.34	[1, -1]	…
3	[-1.22]	1	[3.28]	[2.21]	[1]	…
4	[-2.08, 0.251	4	[11.4, 17.6,	[-1.59, -1.75	[1, 1, 1, 1]	…
5	[-2.37, -2.31	4	[3.28, 3.64,	[-2.17, -2.18	[-1, -1, 1,	…
6	[-2.91, 2.46,	3	[3.57, 4.57,	[-1.37, -0.70	[-1, 1, -1]	…
7	[-0.0718, 3.0	2	[57.6, 53.0]	[-0.532, -1.0	[-1, 1]	…
8	[-2.25, -2.18	2	[11.3, 23.9]	[-0.772, -0.7	[1, -1]	…
9	[0.678, -2.03	2	[10.2, 14.2]	[0.442, 0.702	[-1, 1]	…
10	[3.13, 3.02]	2	[11.5, 3.47]	[2.34, 2.35]	[-1, 1]	…
11	[-3.07, -0.38	2	[8.82, 17.6]	[1.65, 0.715]	[1, -1]	…
12	[1.0, 0.024]	2	[14.6, 12.3]	[1.26, -1.29]	[1, 1]	…
13	[-2.3, 0.34,	6	[35.6, 15.1,	[-2.15, 0.176	[1, 1, 1, -1	…
14	[0.549, -2.27	3	[21.8, 9.55,	[-1.38, -0.77	[1, 1, 1]	…
⋮	⋮	⋮	⋮	⋮	⋮	⋱

2 columns and 61540399 rows omitted

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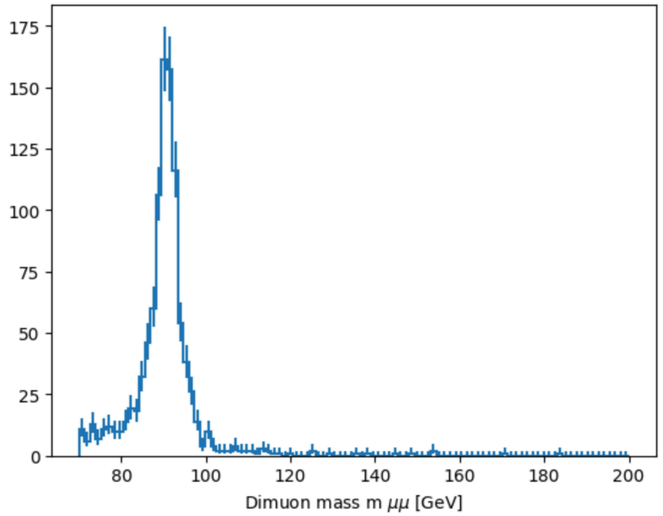
CMS Data Analysis Example

from CERN Open Data portal DOI:10.7483/OPENDATA.CMS.LVG5.QT81

```
jl.seval("""
function invariant_mass(tree)
  layout = AwkwardArray.PrimitiveArray{Float64}()
  for event in tree
    if event.nMuon == 2
      if event.Muon_charge[1] != event.Muon_charge[2]
        result = sqrt(2 * event.Muon_pt[1] * event.Muon_pt[2] *
                  (cosh(event.Muon_eta[1] - event.Muon_eta[2]) -
                   cos(event.Muon_phi[1] - event.Muon_phi[2])))
        if result > 70
          push!(layout, result)
        end
      end
    end
  end
  layout
end
""")
Julia: invariant_mass (generic function with 1 method)
```

- Tutorial in Python with RDataFrame




```
>>> ak.mean(result[:1000])
91.43827227020263
```

```
>>> result = jl.invariant_mass(cms_mumu_tree)
5638140-element AwkwardArray.PrimitiveArray{Float32, Vector{Float32}, :default}:
```

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Conclusions

and questions

- Physicists are using Awkward Array in Python and data format conversion is the hardest part of language boundary-hopping.
  - Having access to this data structure will smooth the way for physicists to try Julia
- PythonCall and JuliaCall enable seamless data sharing between Python and Julia, eliminating the need for costly data copying operations.
  - We want to apply the zero-copy judiciously
  - If GIL is an issue it has to be handled manually
- Your feedback is welcome

Thank you!

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