Julia

Feels like Python; Works like Lisp; Fast like C

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Resources at `github.com/nickeubank/JuliaOverview`

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Show of Hands...

Work primarily in R?

Show of Hands...

Work primarily in Python?

Show of Hands...

Work primarily in Matlab?

Show of Hands...

Work regularly in C?

Show of Hands...

Social sciences?

Show of Hands...

Natural sciences?

Goals for Today

1. Why the need for *yet another* language?
2. Overview of Julia features
3. Brief hands-on tutorial
4. Leave you with resources for future exploration!

Who am I?

- Post-Doc at Center for Study of Democratic Institutions
- Study social networks using cell-phone meta-data
  - Lots of tabular data manipulations
  - Lots of simulations on networks with >10,000,000 nodes
- Regularly work with Stata, R, Python, and Julia
  - Some contributions to Julia packages, but I am *not* a core Julia developer!

Easy To Use Languages

Python, R, Matlab

Fast Languages

C, Java

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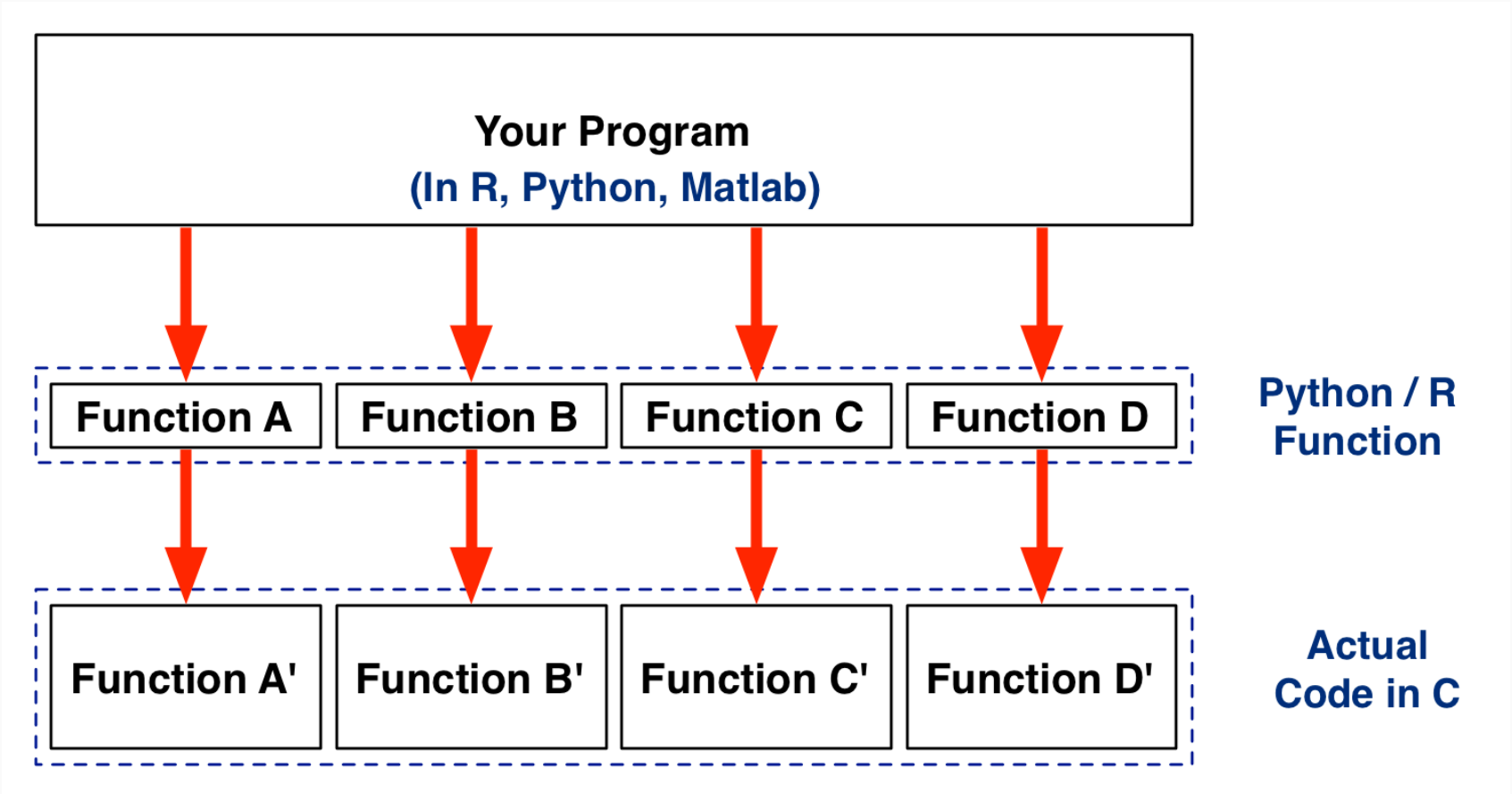
Hybrid Solution



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$\Rightarrow$ True if you know C...

$\Rightarrow$ *Extremely* true if you don't know C!

Julia: Solution Two Language Problem

Julia is a new, interactive, dynamic programming language written specifically with numerical computing in mind.
Base Julia is written *in Julia*

- Even things like definitions of integers!

Most packages written in pure Julia

```python
# Python
def sum_sequence(start, stop):
    total = 0
    for i in range(start, stop + 1):
        total = total + i
    return total

# Julia
function sum_sequence(start, stop)
    total = 0
    for i in start:stop
        total = total + i
    end
    return total
end
```

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# Julia
function sum_sequence(start, stop)
    total = 0
    for i in start:stop
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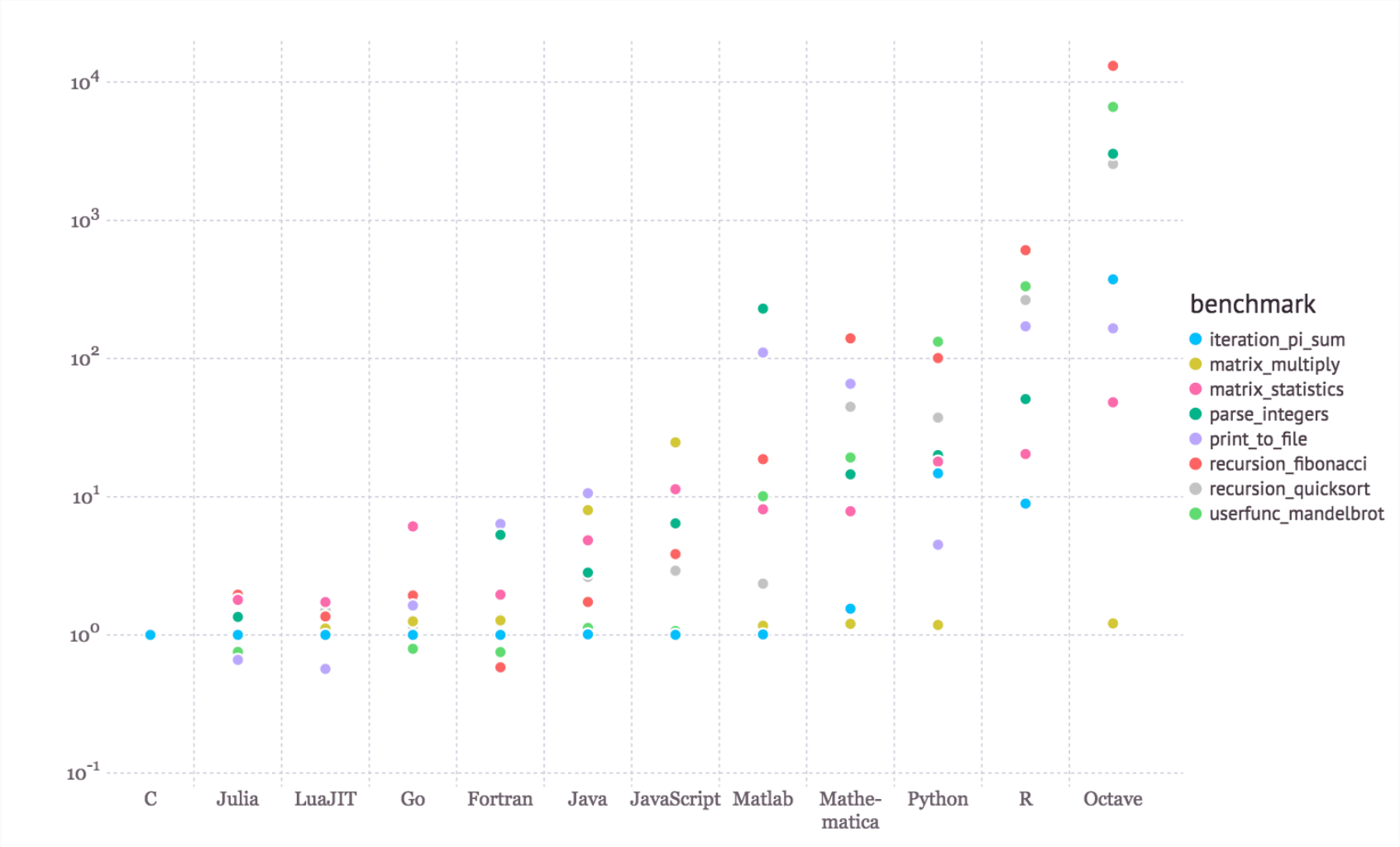
```

Python: `sum_sequence(0, 1000000)`: 78.8 milliseconds

R: `sum_sequence(0, 1000000)`: 274 miliseconds

Julia: `sum_sequence(0, 1_000_000)`: 0.0037 milliseconds


10^4
10^3
10^2
10^1
10^0
10^{-1}
C
Julia
LuaJIT
Go
Fortran
Java
JavaScript
Matlab
Mathe-
matica
Python
R
Octave
benchmark
iteration_pi_sum
matrix_multiply
matrix_statistics
parse_integers
print_to_file
recursion_fibonacci
recursion_quicksort
userfunc_mandelbrot

Why Python (and R) are slow

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⇒Checks type of `total`, type of `i`, and looks up appropriate function `+` one million times!

Why Julia is Fast

```julia
# Julia
function sum_sequence(start, stop)
    total = 0
    for i in start:stop
        total = total + i
    end
    return total
end
sum_sequence(0, 1_000_000)
```

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- Treats function as a small program.
- Realizes that `total` and `i` are always going to be integers, so only checks once.
- Keeps copy of machine code once created so doesn't have to re-evaluate every time function is called.

Corollary 1: Julia is only fast inside functions

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# Slow
total = 0
for i in 0:1_000_000
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# Slow
total = 0
for i in 0:1_000_000
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# Fast
function sum_sequence(start, stop)
    total = 0
    for i in start:stop
        total = total + i
    end
    return total
end
sum_sequence(0, 1_000_000)
```

Corollary 2: Type Stability for Max Speed

```
function return_if_even(a_number)
    if a_number % 2 == 0
        return a_number
    end
    if a_number % 2 != 0
        return "This is not even!"
    end
end
```

You can help the compiler by ensuring that, conditional on the type of arguments, all intermediate and output variables will always be of the same type.

Corollary 2: Type Stability for Max Speed

```
function return_if_even(a_number)
    if a_number % 2 == 0
        return a_number
    end
    if a_number % 2 != 0
        return "This is not even!"
    end
end
```

You can help the compiler by ensuring that, conditional on the type of arguments, all intermediate and output variables will always be of the same type.
This function is not type stable because:

- If `a_number` is an even integer, it returns an integer, but
- If `a_number` is an odd integer, it returns a string.

Features: Just Write the Loop

No more need to always vectorize!

```
x = rand(100)


# Loop
for i in 1:length(x)
    x[i] = sqrt(x[i])
end
```

But you can if you want with `.` notation.

```
# Vectorized
x = sqrt.(x)
```

Times: 6.651 ms (loop) and 7.682 ms (vectorized)

Features: Native Parallelism

Add workers:

```
addprocs(3)
```

Small jobs:

```
num_heads = @parallel (+) for i in 1:1_000_000
                rand(Bool)
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```

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Small jobs:

```
num_heads = @parallel (+) for i in 1:1_000_000
                rand(Bool)
            end
```

Or:

```
a = SharedArray{Float64}(1_000)
@parallel for i = 1:1_000
    a[i] = randn()
end
```

Features: Parallelism

Big jobs:

```
svds = pmap(svd, list_of_matrices)
```

Features: *Extensive* Linear Algebra Optimizations

```
julia> A = randn(n,n)
julia> Asym = A + A'
julia> issymmetric(Asym)
true
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Can also declare special structures (to deal with floating point errors):

- Triangular, Diagonal, Tridiagonal, Sparse Symmetric, etc..

(Factorizations done using LAPACK and UMFPACK libraries)

Features: Scientific / Math Types Inbuilt

Base types:

- Rationals
- Imaginary Numbers
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Plus, user types as fast as Base types.

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If you need it, use `ccall`. Here's a call to `clock` function in C library `libc` that takes no arguments and returns an `Int32` value:

```
t = ccall((:clock, "libc"), Int32, ())
```

Features: Easy Python Integration

Import python `math` function and use its functions in Julia.

```
using PyCall
@pyimport math
math.sin(math.pi / 4) - sin(pi / 4)
```

Features: Support for Unicode

Ordinary least squares with Unicode:

```
N = 4000
x = randn(N, 3)
ϵ = randn(N)
β = [2, 1, 90]
y = x * β + ϵ

β̂ = inv(x' * x) * x' * y
ϵ̂ = y - x * β̂
```

Features: Meta-Programming

You can write Julia code that writes Julia code!

Contrasts with Python

Familiar:

- Duck-typing
- Pass by reference
- Iterators
- List (and array) comprehensions

Unfamiliar:

- No integer overflow checking
  - `SafeInts` package available
- Built in Package Manager
  - No name spaces *yet*; coming in new package manager.
- Not white-space sensitive
- Indexes start at 1, not 0
- Multiple dispatch for functions

Contrasts with R

Familiar:

- Multiple dispatch
- Built in package manager

Unfamiliar:

- No integer overflow checking
- Pass-by-reference and mutable / immutable data types
    - See Eubank_PassByReference.pdf on github.
- Loops as fast as vectorized functions

Not 1.0 Yet...

Currently Stable Release: 0.6.2

Pending Release: 0.7

- Expected this summer ($\sim$ June 2018?)
- 0.7 is 1.0 with depreciation warnings
    - If your code works with 0.7, syntax won't change!

Expected changes

- Handful of syntax changes
- Major compiler improvements for missing data
- New package manager

Hands-on Tutorials!

Go to `juliabox.com`, create an account, and navigate to `tutorials/intro-to-julia`.
Today we'll do:

- 6. Functions
- 10. Multiple Dispatch

Next Steps

For information on:

- How to install Julia
- How to get help with Julia
- Where to find more tutorials
- Most-used packages

See `Eubank_JuliaResources.pdf` at

`www.github.com/nickeubank/JuliaOverview`