for Machine Learning

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Machine Learning Group Tutorial
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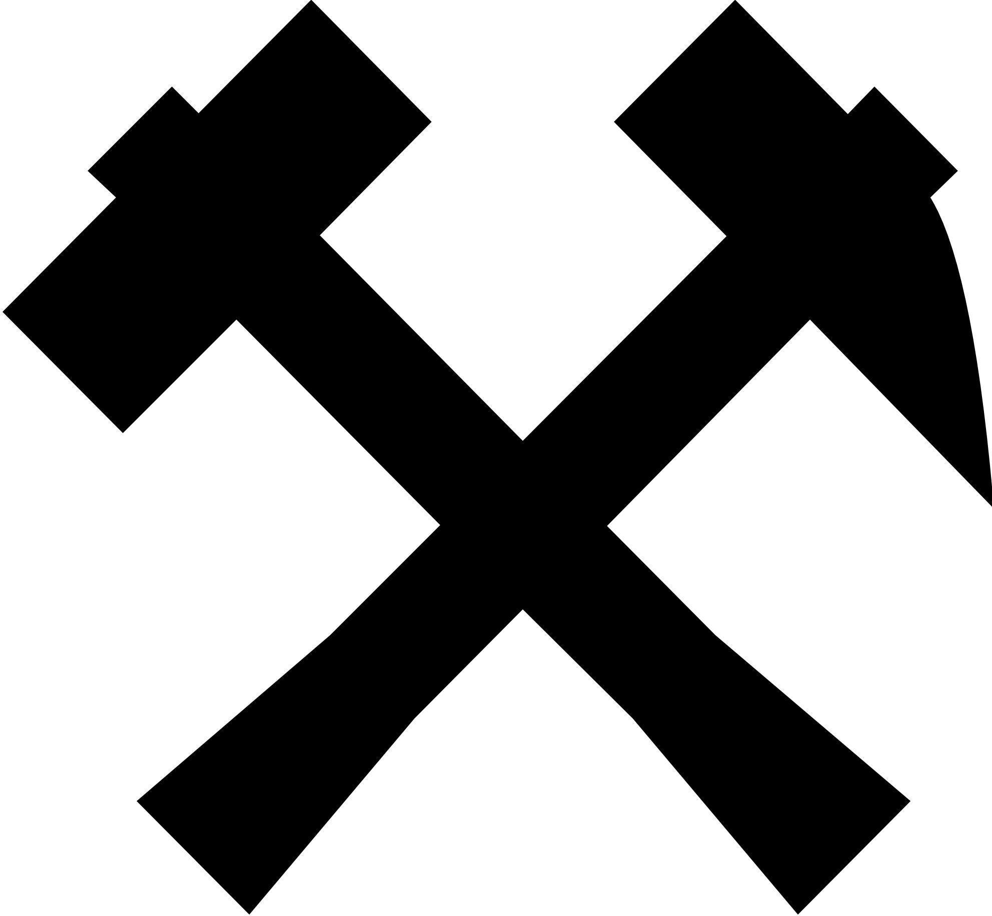

language

from Latin “lingua” (tongue)

- a system for the expression of thoughts, feelings, etc, by the use of spoken sounds or conventional symbols

Ideas

Programming Language

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Desiderata

- Syntax looks like pseudocode
- Vocabulary to talk about data & operations
- Large standard library
- Good performance

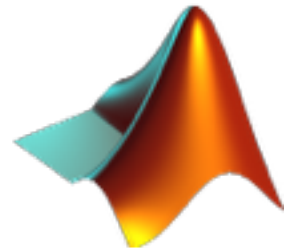
- High-level
- Dynamic type system
- Performance approaching statically-compiled languages
- Metaprogramming
- Parallelism
- Good interop with other languages
- MIT licensed

Outline

- Motivation
- Background
- Syntax
- Type system
- Speed
- Features
- Community
- Conclusion

Background

Technical Computing Landscape

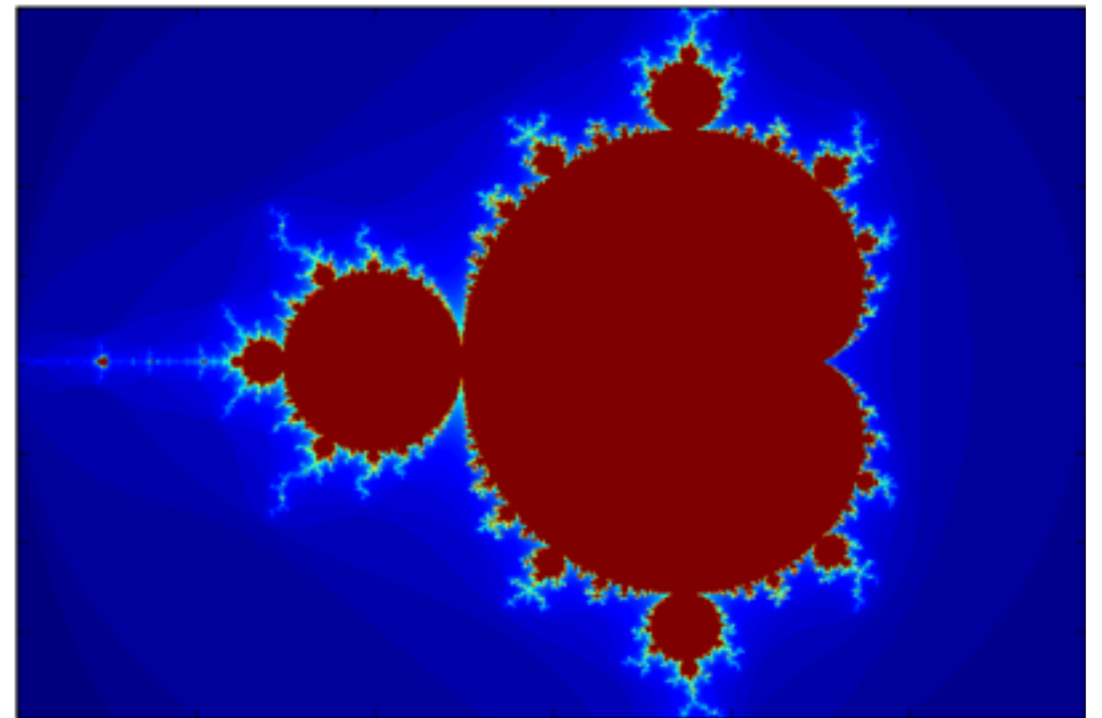
	 Matlab	Python	Julia
Introduced	1984	1991*	2012
Creators	MathWorks	Guido van Rossum	Jeff Bezanson, Stefan Karpinski, Viral Shah, Alan Edelman
License	Proprietary	BSD-style	MIT
Name	"Matrix Laboratory"	Monty Python	?

*NumPy introduced in 1995 as Numeric and 2006 as NumPy

Syntax

Mandelbrot

```
function mandel(z)
    c = z
    maxiter = 80
    for n = 1:maxiter
        if abs(z) > 2
            return n-1
        end
        z = z^2 + c
    end
    return maxiter
end
```



randmatstat

```
function randmatstat(t)
    n = 5
    v = zeros(t)
    w = zeros(t)
    for i = 1:t
        a = randn(n,n)
        b = randn(n,n)
        c = randn(n,n)
        d = randn(n,n)
        P = [a b c d]
        Q = [a b; c d]
        v[i] = trace((P'*P)^4)
        w[i] = trace((Q'*Q)^4)
    end
    std(v)/mean(v), std(w)/mean(w)
end
```

Fibonacci

```
fib(n) = n < 2 ? n : fib(n-1) + fib(n-2)

fib(20) # => 6765
```

Data Structures

- Vectors
- Matrices
- Strings
- Tuples
- Dictionaries
- Sets
- …

```julia
b = [4, 5, 6]
b[1] # => 4
b[end] # => 6

matrix = [1 2; 3 4]

tup = (1, 2, 3)
tup[1] # => 1
tup[1] = 3 # => ERROR

dict = ["one"=> 1, "two"=> 2, "three"=> 3]
dict["one"] # => 1

filled_set = Set(1,2,2,3,4) # => Set{Int64}(1,2,3,4)
```

Exception Handling

```
try
   error("help")
catch e
   println("caught it $e")
end
# => caught it ErrorException("help")
```

Strings

```
split("wow look at these words")
# => 5-element Array{SubString{ASCIIString},1}:
 "wow"
 "look"
 "at"
 "these"
 "words"

join(["We invited the rhinoceri", "Washington",
"and Lincoln"], ", ")
# => "We invited the rhinoceri, Washington, and
Lincoln"
```

Regexes

```
ismatch(r"^\s*(?:#|$)", "# a comment")
# => true

m = match(r"(a|b)(c)?(d)", "acd")
# => RegexMatch(“acd", 1="a", 2="c", 3="d")

m.captures
# => 3-element
Array{Union(SubString{UTF8String},Nothing),1}:
 "a"
 "c"
 "d"
```

Comprehensions

```
[i + j for i = 1:3, j = 1:5]
# => 3x5 Array{Int64,2}:
 2  3  4  5  6
 3  4  5  6  7
 4  5  6  7  8

[i => char(64 + i) for i = 1:5]
# => [5=>'E',4=>'D',2=>'B',3=>'C',1=>'A']
```

FP-style shenanigans

```
map(x -> x * 2, [1, 2, 3])
# => [2,4,6]

reduce(*, 1, [1, 2, 3])
# => 6

map(s -> (s, length(s)), subsets([1, 2, 3]))
# => [([],0),([1],1),([2],1),([1,2],2),([3],
1),([1,3],2),([2,3],2),([1,2,3],3)]
```

Matrix Operations

```
trace
det
eigfact
sparse
inv
kron
…
```

Shell Commands

```
a=readall(`echo hello`)
# => "hello\n"


file = "/etc/passwd"
# => "/etc/passwd"

`sort $file`
# => `sort /etc/passwd`

run(`echo world` & `echo hello` |> `sort`)
# => hello
world
```

Coroutines

```
function producer()
    produce("start")
    for n=1:4
        produce(2n)
    end
    produce("stop")
end
```

```
for x in Task(producer)
    println(x)
end
# => start
2
4
6
8
stop
```

Type System

Julia's Type System

- Dynamic
  - No "compile-time type"
  - Only values, not variables, have types
- Nominative
  - Relationships between types explicitly declared
  - Concrete types are final
- Parametric
  - Abstract and concrete types can be parameterized by other types & certain values

Multiple Dispatch

- All functions in Julia are generic
  - First-class objects
  - Can be passed around
  - Can be extended
- Function definition that is called depends on the types of all its argument

Multiple Dispatch Demo

- Notebook from Stefan Karpinski's talk at Strange Loop 2013

Speed

Traditional Language Split

- Prototype in high-level language
- Write performance critical code in a low-level language e.g. C or Fortran
- Tie together with
  - Mex
  - Ctypes
  - Cython
  - SWIG
  - …

…eating our cake too?

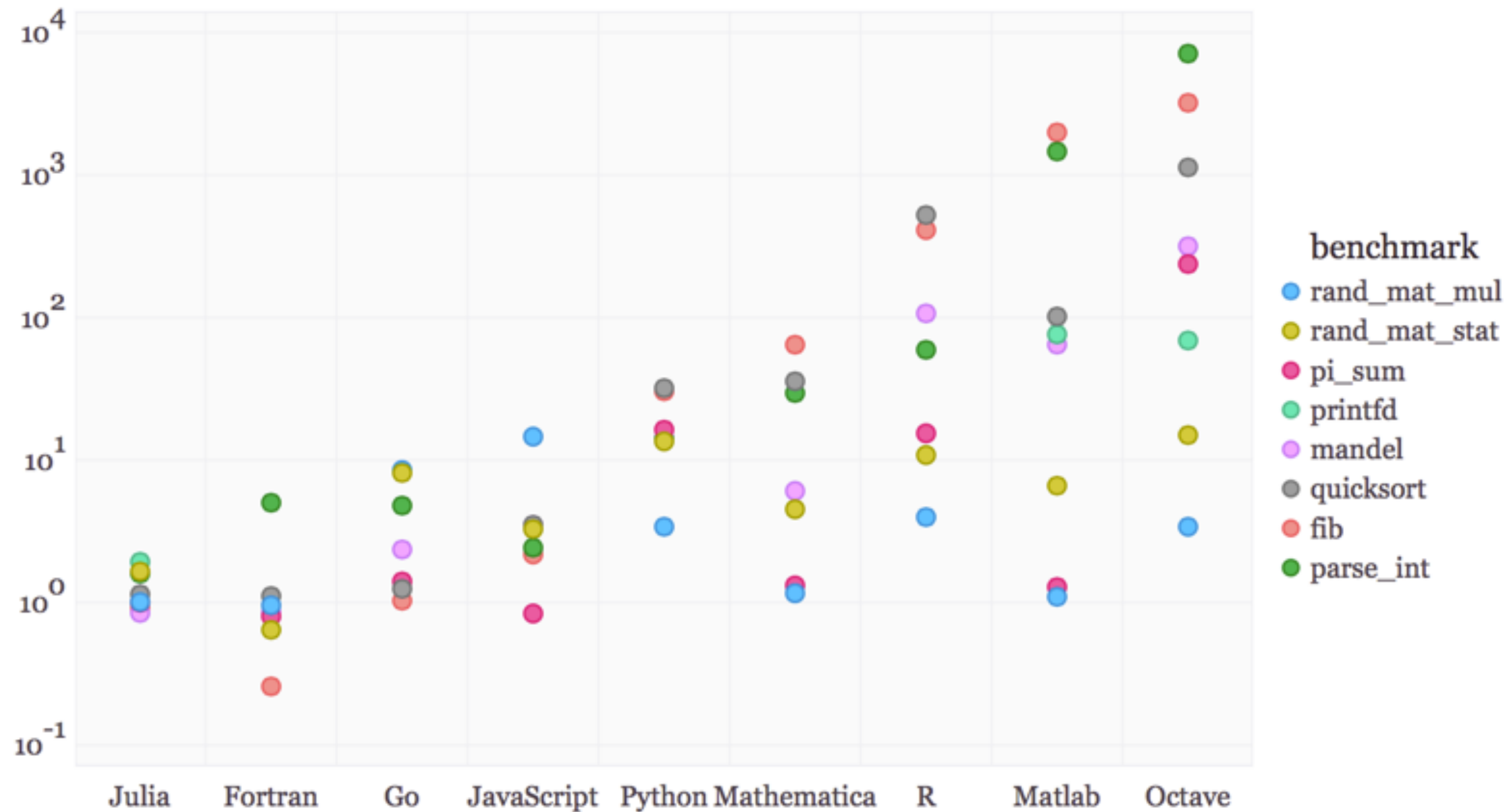


Figure: benchmark times relative to C (smaller is better, C performance = 1.0).

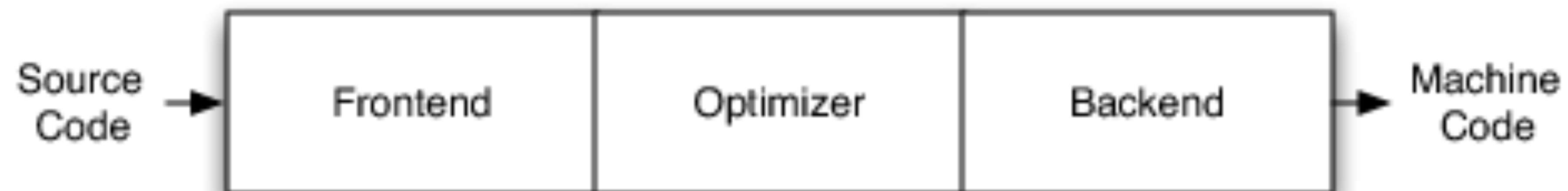
JIT

- Julia compiles the code it needs at run-time
  - JIT = “just in time”
  - Translates each method into machine code
- Utilizes LLVM for optimization and code generation.

LLVM

- Originally “Low level virtual machine”, now LLVM is the full name of the project
- Collection of modular compiler and toolchain technologies
- Introduced by Vikram Adve and Chris Lattner at University of Illinois in 2003
- Used by Apple as part of dev tools for Mac OS X and iOS

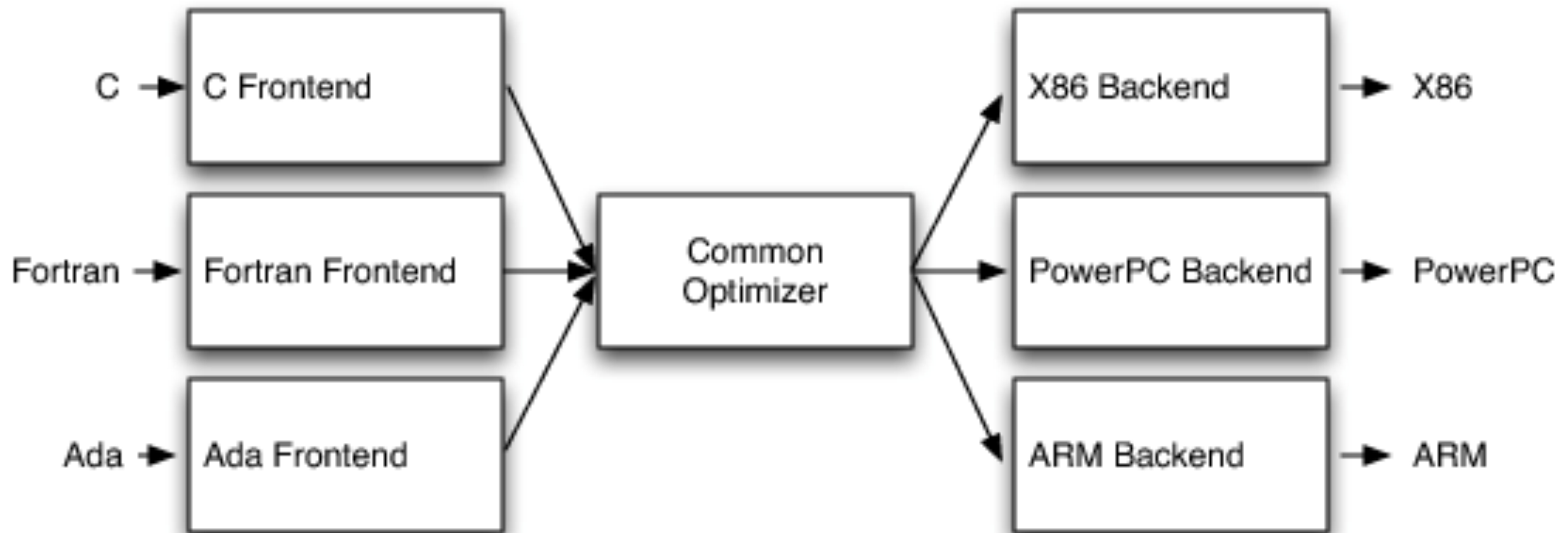
Traditional Approaches



Three-phase compiler

Bytecode Interpreter

LLVM Design



LLVM uses a common code representation

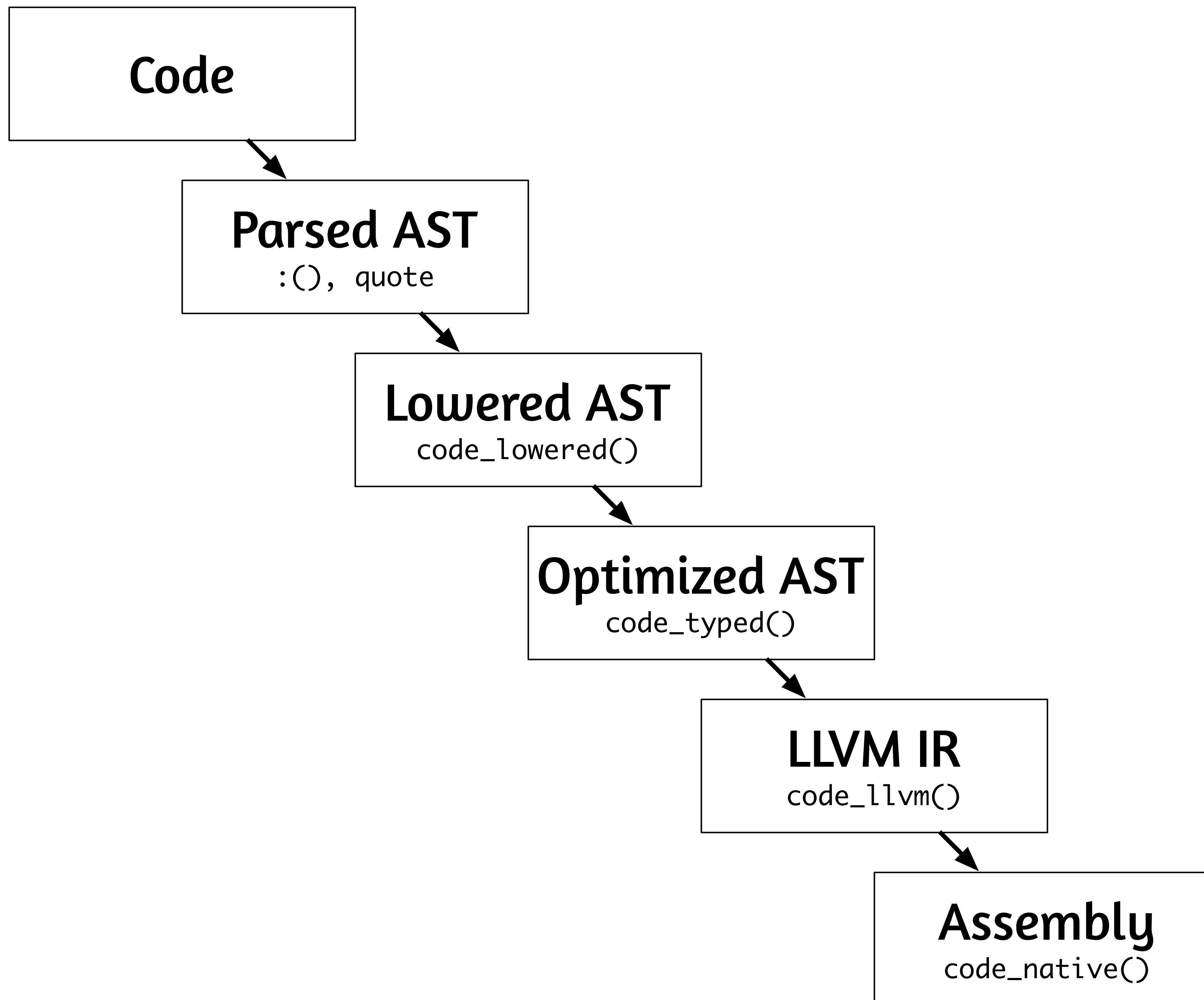
LLVM IR

- **IR = intermediate representation**

```
unsigned add1(unsigned a, unsigned b) {
      return a+b;
}
```

```
define i32 @add1(i32 %a, i32 %b) {
entry:
    %tmp1 = add i32 %a, %b
    ret i32 %tmp1
}
```

Julia’s JIT Pipeline



Types Help to Generate Efficient Code

- LLVM and types demo

Side benefit

- Since Julia is fast, most of Julia is written in itself
  - You can learn by poking around source of Julia and its standard library
  - Easy to contribute core components

Other JITted systems

- PyPy
  - Tracing JIT (vs method-at-a-time JIT)
  - No support for Numpy
- Numba
  - NumPy compatible, based on LLVM
  - Uses NumPy type information for inference
  - Doesn't remove dynamic indirection for less well-typed ordinary Python code
- Pyston
  - Announced earlier this month by Dropbox
  - Still in early phases, far from release

Metaprogramming

Homoiconicity

- Code lives in data structures that can be manipulated by the language itself.
- In Julia's case, `Expr` and `Symbol` types.

```
type Expr
  head::Symbol
  args::Array{Any,1}
  typ
end

ex = :(a+b*c+1)
# => :(+(a,*(b,c),1))

typeof(ex)
# => Expr

ex.head
# => :call


ex.args
# => [:+,:a,:(*(b,c)),1]
```

Macros

- Special functions to directly manipulate expressions

```
macro assert(ex)
    :($ex ? nothing : error("Assertion failed: ", $(string(ex))))
end

@assert 1==1.0
# =>

@assert 1 == 0
ERROR: assertion failed: 1 == 0
 in error at error.jl:21
```

Parallelism

@parallel

```
# parfor.jl
@time begin
    nheads = @parallel (+) for i=1:2000000000
        int(randbool())
    end
end
```

```
$ julia parfor.jl
elapsed time: 10.333040655 seconds (6323888 bytes
allocated)
```

```
$ julia -p 8 parfor.jl
elapsed time: 2.505858567 seconds (13534036 bytes
allocated)
```

pmap

```
# pmap.jl
M = {rand(1000,1000) for i=1:10}
@time pmap(svd, M)

$ julia pmap.jl
elapsed time: 7.620465569 seconds (575974660 bytes
allocated)

$ julia -p 8 pmap.jl
elapsed time: 4.206753903 seconds (524003124 bytes
allocated)
```

Cluster Computing

- Workers don’t have to be on the local machine
  - Passwordless SSH
  - ClusterManagers.jl: Sun Grid Engine, …
  - AWS.jl: interface to Amazon Web Services (EC2, S3)

And more

- Distributed arrays for splitting large matrices across workers
- Primitives for pushing data back and forth
- @sync, @async

Interop

Calling C

```
function getenv(var::String)
  val = ccall( (:getenv, "libc"),
               Ptr{Uint8}, (Ptr{Uint8},), bytestring(var))
  if val == C_NULL
    error("getenv: undefined variable: ", var)
  end
  bytestring(val)
end

getenv("SHELL")
# => "/bin/bash"
```

Calling Python

- PyCall.jl offers automatic conversion of types between Julia and Python
  - numeric, boolean, string, functions
  - tuples, arrays, and dictionaries of above
- Julia arrays are converted to NumPy arrays without making a copy
- Demo

Calling MATLAB

```
using MATLAB

function thinboundary(bmap::BitMatrix)
    @mput bmap
    @matlab bmapthin = bwmorph(bmap, "thin", inf)
    convert(BitArray, @mget bmapthin)
end
```

Calling C++

- More difficult
- Usually easiest to create thin C-language wrapper around the code you want to call
- Cpp.jl handles ABI name-mangling, but C++ objects cannot be converted

```
int timestwo(int x) {
    return 2*x;
}
```

```
x = 3.5
x2 = @cpp ccall((:timestwo, libdemo), Float64,
(Float64,), x)
```

Calling Julia

- From C/C++
  - Use Julia's C API
- From MATLAB
  - julia-matlab package
  - Can write performance critical code in Julia without resorting to MEX
- From Python
  - pyjulia: still experimental at this point

Interactivity

Environments

- REPL
- IJulia notebook
  - http://nbviewer.ipython.org to share notebooks
- Forio Julia Studio
  - Visual IDE

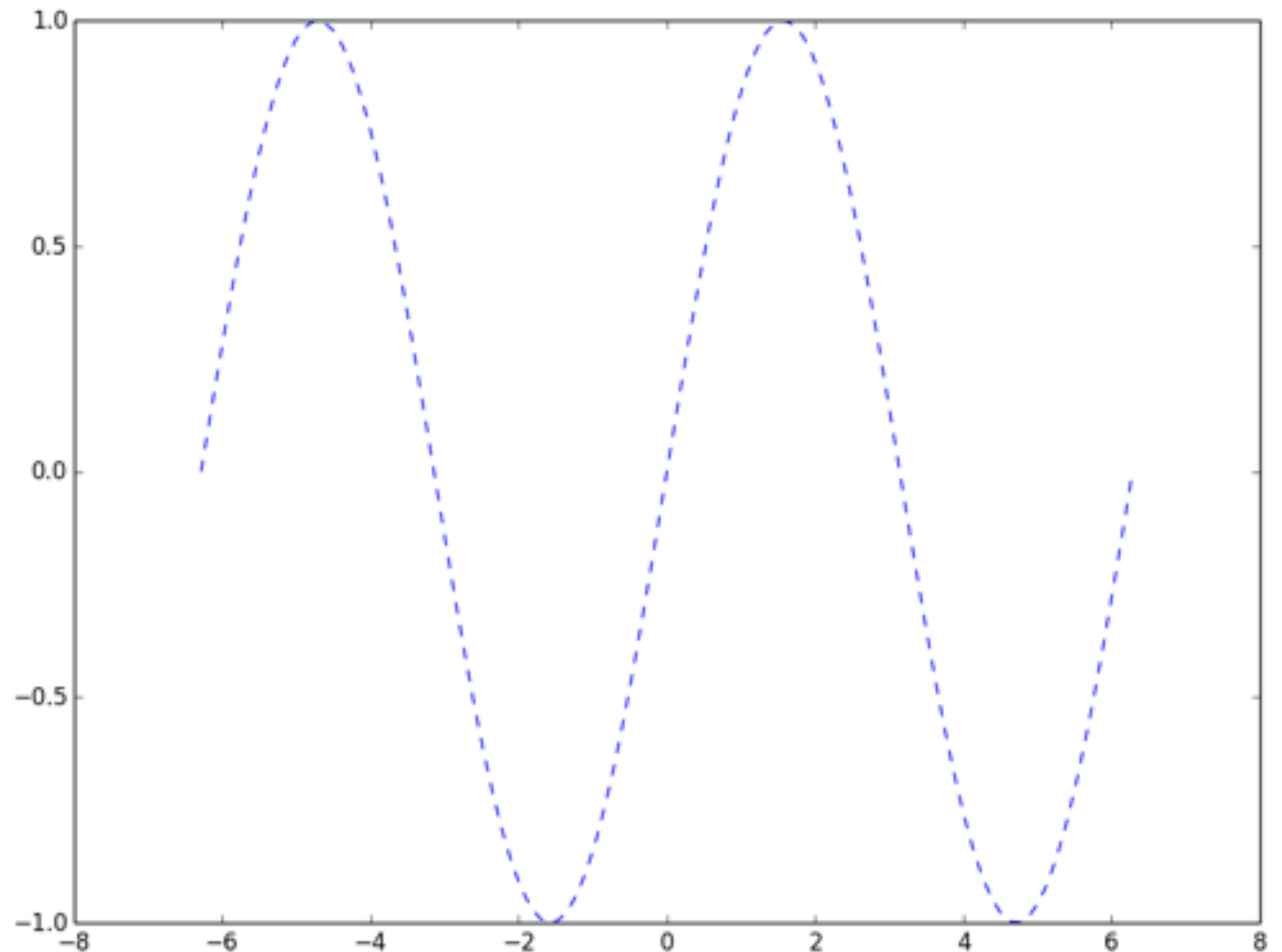
Plotting

- Several options
  - Gadfly.jl
    - similar to ggplot2
    - influenced by Leland Wilkinson's "Grammar of Graphics"
  - Winston.jl
    - similar to Matplotlib, still light on features
  - Gaston.jl
    - interface to gnuplot
- No clear winner yet

PyPlot.jl

- Wrapper around Matplotlib's API

```
using PyPlot
x = linspace(-2pi, 2pi)
y = sin(x)
plot(x, y, "--b")
```



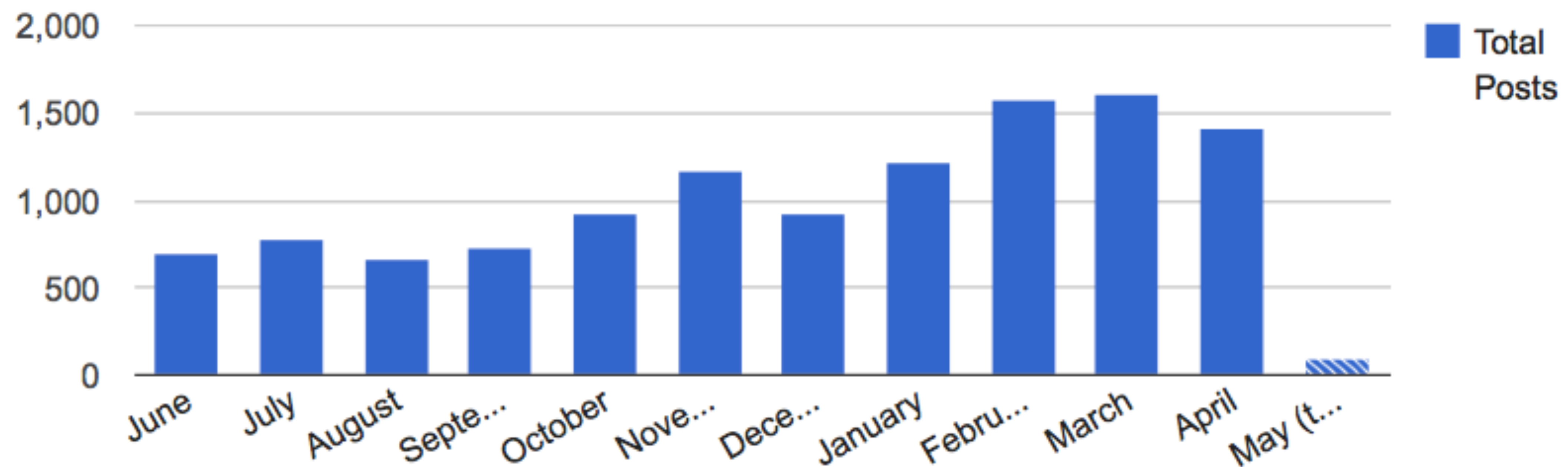
Community

Adoption

- Already used in courses at:
  - Stanford
  - Penn State
  - Cornell
  - MIT
  - Western

Community

- Small but active, helpful, growing
- Strong open-source culture
  - Design discussions take place in the julialang repo on Github



julia-users, posts from June 2013 - present

Package Manager

- git based, integrated with Github
- Installing a package

```
Pkg.add("Images")
```

- Creating a package for local development

```
Pkg.generate("FooBar","MIT")
```

- When you're ready to publish to Github

```
Pkg.register("FooBar")
```

- To make your package visible to everybody, submit a pull request to the METADATA repo

Packages

Lots of useful packages

- Images.jl
- Graphs.jl
- DataFrames.jl
- DimensionalityReduction.jl
- Distributions.jl
- NLOpt.jl
- ArgParse.jl
- Logging.jl
- FactCheck.jl
- Many more - check out https://github.com/JuliaLang/METADATA.jl for the full list

GPU Computing

- At this point: mostly low-level API wrappers
  - CUDA.jl
  - CUDArt.jl
  - OpenCL.jl

More on the way

- Google Summer of Code 2014 projects
  - Julia wrappers for high performance GPU programming
  - Computer vision using OpenCV
  - Julia frontend for Halide, an image processing language

⚖️ Assessment

Desiderata

- Syntax looks like pseudocode
- Vocabulary to talk about data & operations
- Large standard library
- Good performance

Reasons to choose Julia

- Fast prototyping without sacrificing speed
- Easy to parallelize code
- Types make expressing algorithms simpler
- Plays well with other languages
- Standard library written in Julia
- Friendly and helpful community

Reasons not to choose Julia

- You are primarily a NN researcher (not just a user)
  - GPU infrastructure not quite in place
- You need to write production code
  - Language is still growing, interfaces may change
- You want to write the next NLTK or other widely used package
  - May want to go with a more popular language

Resources

How to Try

- Try Julia online at http://forio.com/julia/repl/
- To install:

```
git clone https://github.com/JuliaLang/julia
cd julia
make
```

(or `make -j N`, where N is your desired number of parallel processes)

```
# ln -s $PWD/julia /usr/bin/julia
```

Resources

- Julia Manual
- Julia Standard Library
- Learn Julia in Y minutes
- User groups
  - julia-users
  - julia-dev
  - julia-stats
- Talks
  - Julia Tutorial at MIT, Jan 2013
  - Stefan Karpinski @ Code Mesh 2013
- Read the source, Luke!

Helpful Commands

`?map`

- display documentation for the map function

`apropos("reduce")`

- show all functions with the term "reduce" in their documentation

`methods(+)`

- display all instantiations of generic + function

`methodswith(BigInt)`

- display all functions involving BigInts

fin