# Introduction to Julia: Why are we doing this to you?

Steven G. Johnson, MIT Applied Math

MIT classes 18.[C]06*, 18.3*, …

*these slides, cheatsheets, links:*

https://github.com/mitmath/julia-mit

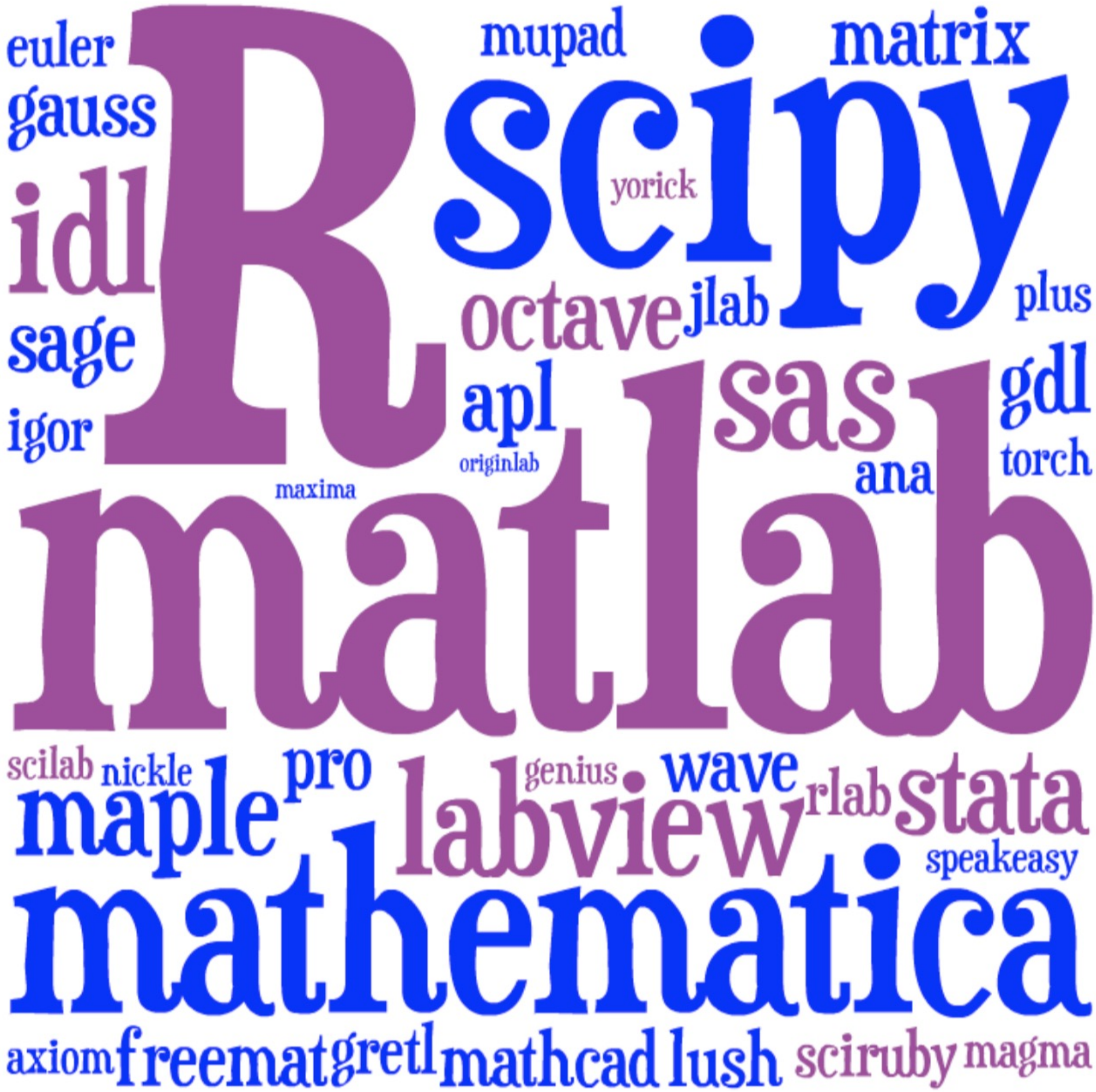
# What language for teaching scientific computing?

For the most part, these are not hard-core programming courses,
and we only need little "throw-away" scripts and toy numerical experiments.

Almost any high-level, interactive (dynamic) language with easy facilities for linear algebra ($Ax=b$, $Ax=\lambda x$), plotting, mathematical functions, and working with large arrays of data would be fine.

*And there are lots of choices…*

# Lots of choices for interactive math…




[ image: Viral Shah ]

Just pick the most popular?
*Matlab* or *Python* or *R*?

*We must often use another a language for our "real work".*

Traditional HL computing languages hit a performance wall in "real" work … eventually force you to C, Cython, Fortran, Numba…

(Also, it's always good to learn another programming language.

If you only know one language, it's easy to confuse the concepts for the syntax. And each language you learn makes the *next* language *much easier.*)

# A new programming language?

Viral Shah

Jeff Bezanson

Alan Edelman

[ MIT ]

Stefan Karpinski

julialang.org

[ 60+ developers with 100+ commits,
10,000+ external packages, 11th JuliaCon in 2024 ]

[begun 2009, “0.1” in 2013, ~50k commits,
1.0 release in 2018, 1.10 in Dec. 2023 ]

As high-level and interactive as Matlab or Python+IPython,
as general-purpose as Python,
as productive for technical work as Matlab or Python+SciPy,
but as **fast as C**.

Lots of performance discussions, benchmarks, tutorials online…

Let’s just look at one simple example.

# Generating Vandermonde matrices

given $x = [\alpha_1, \alpha_2, \ldots]$, generate:

$$V = \begin{bmatrix} 1 & \alpha_1 & \alpha_1^2 & \ldots & \alpha_1^{n-1} \\ 1 & \alpha_2 & \alpha_2^2 & \ldots & \alpha_2^{n-1} \\ 1 & \alpha_3 & \alpha_3^2 & \ldots & \alpha_3^{n-1} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & \alpha_m & \alpha_m^2 & \ldots & \alpha_m^{n-1} \end{bmatrix}$$

NumPy (`numpy.vander`): *[follow links]*

Python code …wraps C code

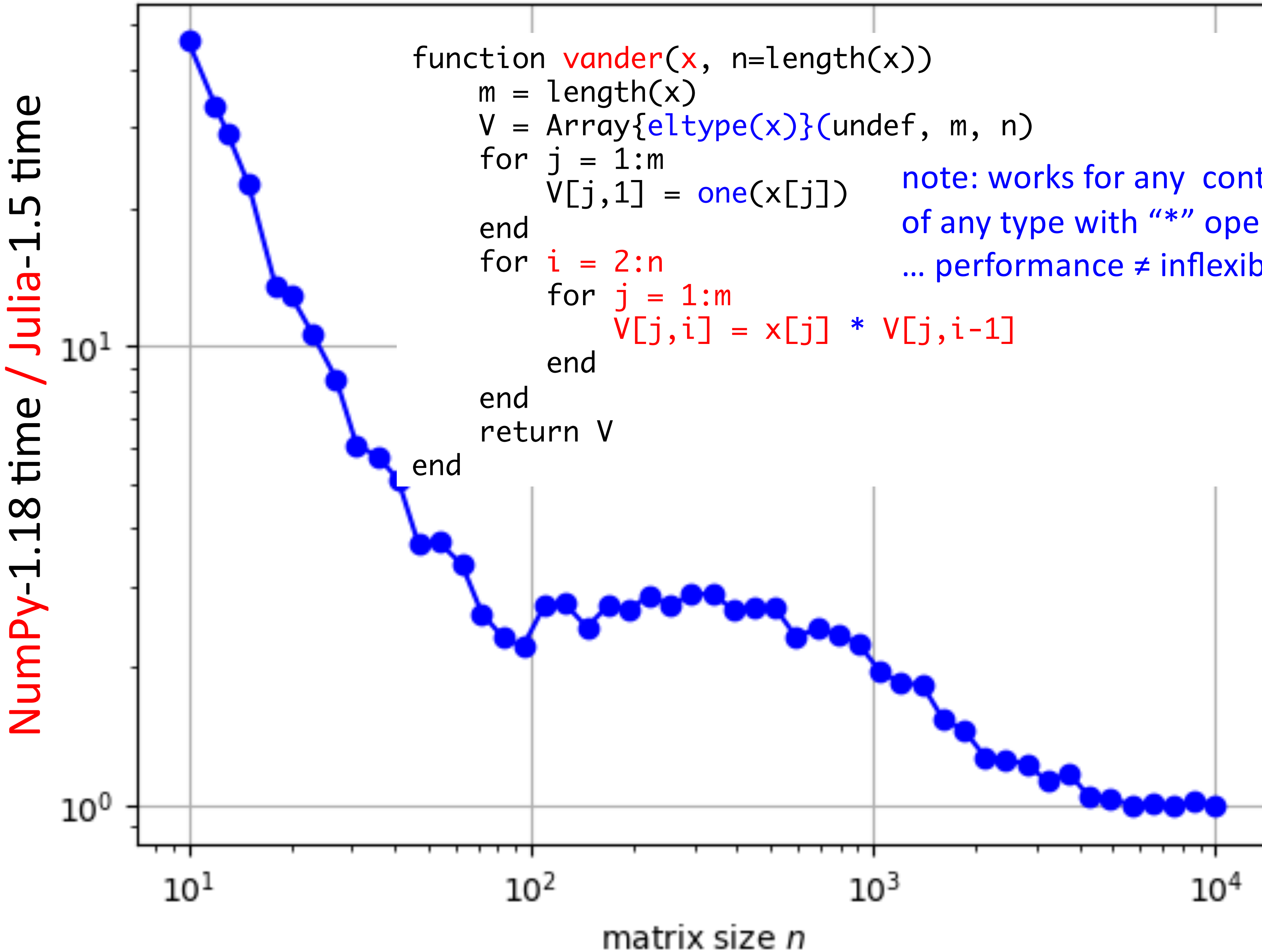
… wraps generated C code

type-generic at high-level, but
low level limited to small set of types.

Writing fast code "in" Python or Matlab = mining the standard library for pre-written functions (implemented in C or Fortran).

If the problem doesn't "vectorize" into built-in functions,
if you have to write your own inner loops … sucks for you.

# Vandermonde matrices: Julia vs NumPy

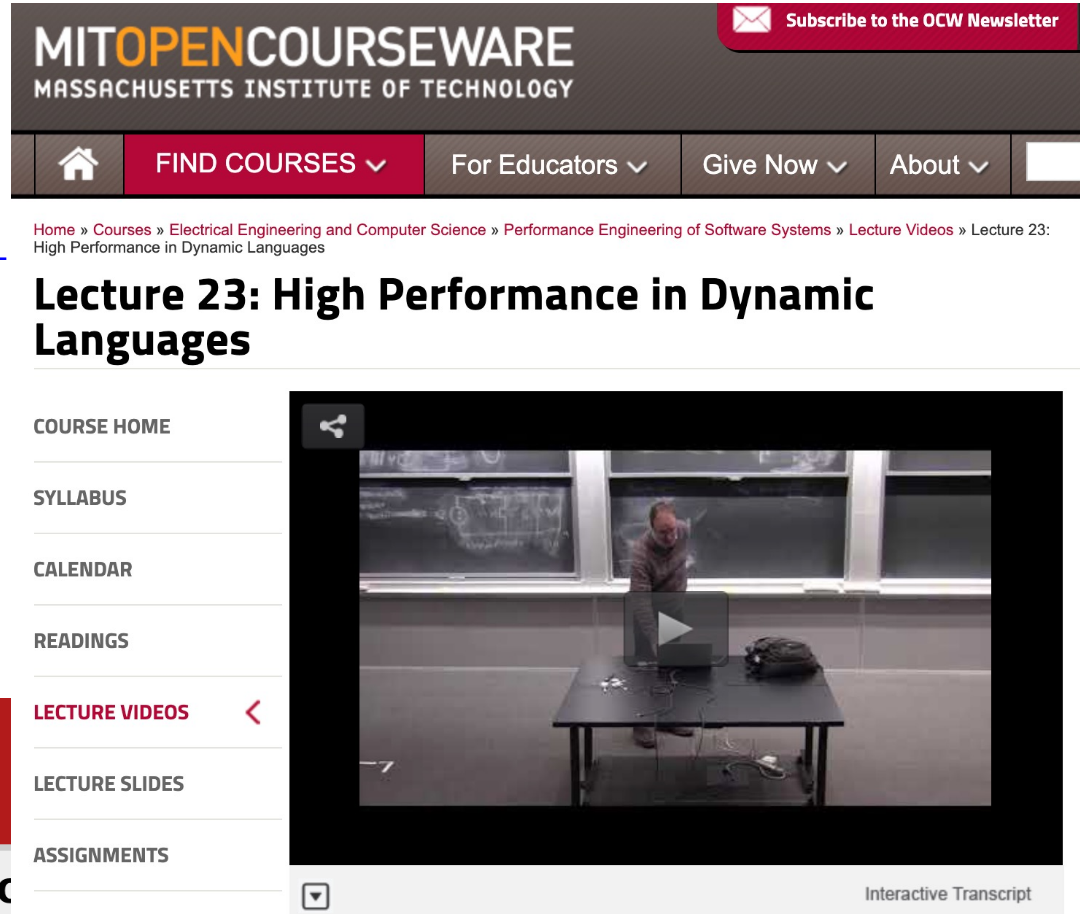



```
function vander(x, n=length(x))
    m = length(x)
    V = Array{eltype(x)}(undef, m, n)
    for j = 1:m
        V[j,1] = one(x[j])
    end
    for i = 2:n
        for j = 1:m
            V[j,i] = x[j] * V[j,i-1]
        end
    end
    return V
end
```

note: works for any container of any type with "*" operation … performance ≠ inflexibility

# Why is Julia fast? A topic for another day.

See my 6.172 “guest lecture” from 2018:
https://bit.ly/2QUrgB4




*The original paper:*

arXiv.org > cs > arXiv:1411.1607

**Computer Science > Mathematical Sc**

*[Submitted on 6 Nov 2014 (v1), last revised 19 Jul 2015 (this version, v4)]*

## Julia: A Fresh Approach to Numerical Computing

Jeff Bezanson, Alan Edelman, Stefan Karpinski, Viral B. Shah

# But I don't "need" performance!

For lots of problems, especially "toy" problems in courses, Matlab/Python performance is good enough.

But if use those languages for all of your "easy" problems, then you won't be prepared to switch when you hit a hard problem. When you **need** performance, it is too late.

You don't want to learn a new language at the same time that you are solving your first truly difficult computational problem.

# Just vectorize your code?

= rely on mature external libraries,
operating on large blocks of data,
for performance-critical code

## Good advice! But…

- Someone has to write those libraries.

- Eventually that person will be you.
  — some problems are impossible or
  just very awkward to vectorize.

# But everyone else is using Matlab/Python/R/…

Julia is still a young, niche language. That imposes real costs — lack of familiarity, rough edges, fewer external packages. These are real obstacles.

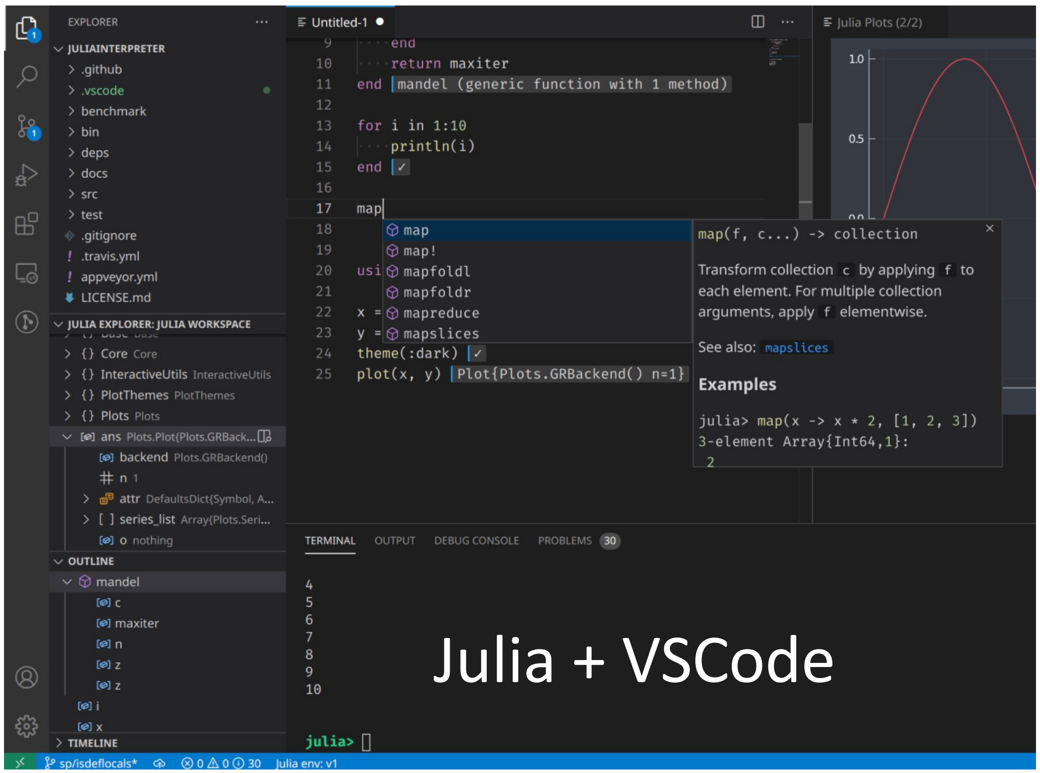
But it also gives you advantages that Matlab/Python users don't have.

# But I lose access to all the libraries available for other languages?

Very easy to call C/Fortran libraries from Julia, and also to call Python…

# Julia Coding Environments

Of course, full-featured "IDE" coding environments are available with VSCode, Atom, not to mention Emacs, Vim, …




and Julia has the usual features for organizing large programs into files, data structures, modules…

+ integrated hypertext documentation support…

+ built-in github-integrated package manager for distributing & installing packages and dependencies…

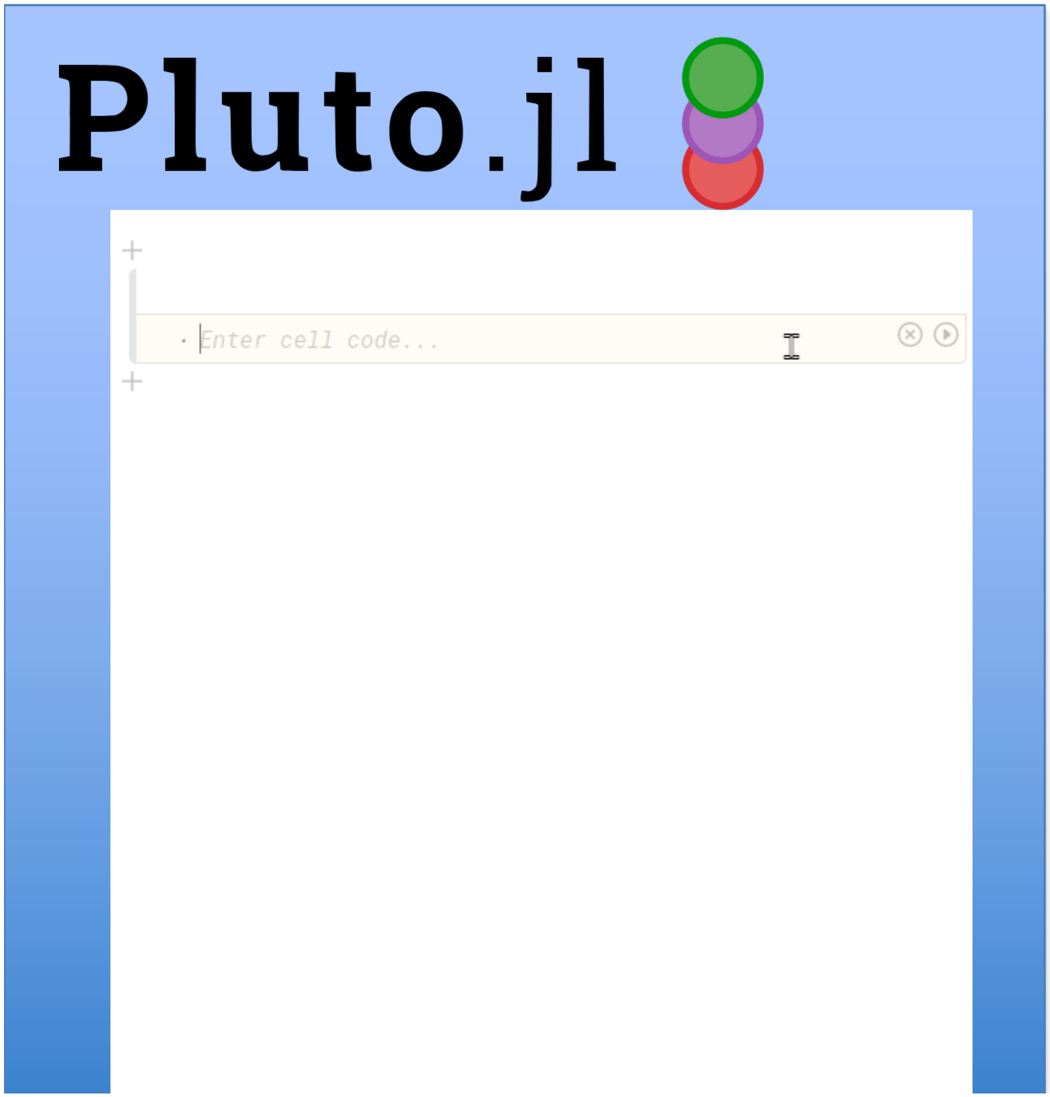
… but today we're only looking at interactive snippets of code:

Julia as a "glorified calculator."

# Julia Interactive-Computing Environments

Jupyter notebooks: code+text+equations+images+…

+ Julia backend = IJulia




### Fourier sine series

It is a remarkable fact that the sine functions $\sin(n\pi x)$ are **orthogonal** under the "dot" product:

$$\int_0^1 \sin(m\pi x)\sin(n\pi x)\,dx = \begin{cases} 0 & m \neq n \\ \frac{1}{2} & m = n \end{cases}.$$

Let's plot a few of these functions:

In [2]:

```
x = linspace(0,1,200)
for n = 1:4; plot(x, sin.(n*π*x), "-"); end
legend([L"\sin(\pi x)", L"\sin(2\pi x)", L"\sin(3\pi x)",
title("orthogonal sine functions")
```