

Introduction to Julia

Anthony Blaom, with help from Quinn Asena

November, 2021

Introducing Julia

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How to entertain your kids at home - the case for ML



Playmobil ©



Lego ©

3 models dinosaurs + 15 user contributed models

We **support** you in building your snake powered train



Introducing Julia

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Key take aways

- ▶ Julia let's you write **fast** code **fast**.
- ▶ Maximally hackable.
- ▶ Julia's design makes **extending** Julia code easy, promoting a relatively rapid expansion of third party libraries.

Julia's secret sauce

- ▶ **Just-in-time compilation**
- ▶ **Multiple dispatch**
- ▶ **Abstract type system** (typing is dynamic, nominative and parametric)

Workshop resources:

github.com/ablaom>HelloJulia.jl

Secret sauce demo:

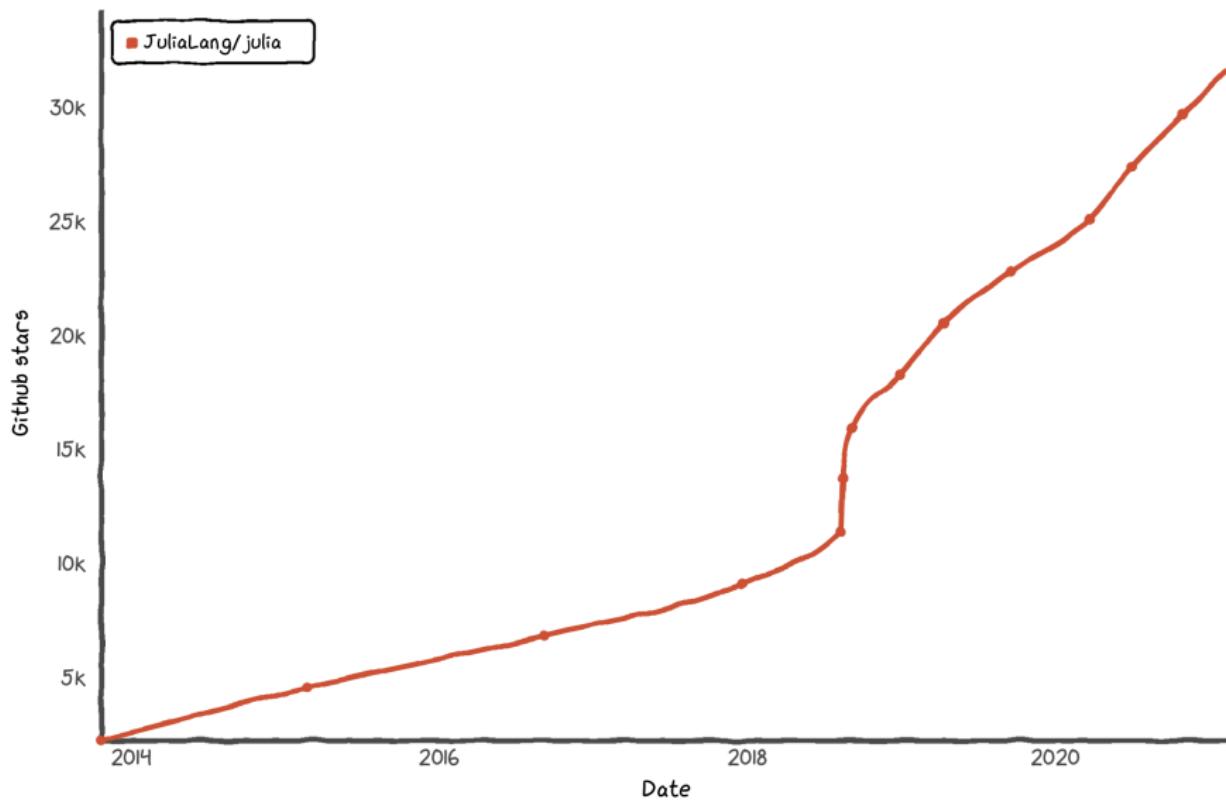
[github.com/ablaom>HelloJulia.jl/
blob/dev/demos/secret_sauce/notebook.ipynb](https://github.com/ablaom>HelloJulia.jl/blob/dev/demos/secret_sauce/notebook.ipynb)

Package composability demo:

`github.com/ablaom>HelloJulia.jl/
blob/dev/demos/pkg_composability/notebook.ipynb`

```
function mandel(z)
    c = z      # starting value and constant shift
    max_iterations = 20
    for n = 1:max_iterations
        if abs(z) > 2
            return n-1
        end
        z = z^2 + c
    end
    return max_iterations
end
```

Star history



JuliaCon 2018: 90 talks and 350 attendees

University College London



Julia adoption accelerated at a rapid pace in 2020.

| | Total Cumulative as of Jan 1, 2020 | Total Cumulative as of Jan 1, 2021 | Change |
|---|---------------------------------------|---------------------------------------|--------|
| Number of Julia Downloads (JuliaLang + Docker + JuliaPro) | 12,950,630 | 24,205,141 | +87% |
| Number of Julia Packages | 2,787 | 4,809 | +73% |
| GitHub stars (Julia language repo + registered packages) | 99,830 | 161,774 | +62% |
| YouTube views (Julia language channel) | 1,562,223 | 3,320,915 | +113% |
| Published citations of Julia: A Fast Dynamic Language for Technical Computing (2012) + Julia: A Fresh Approach to Numerical Computing (2017) | 1,680 | 2,531 | +51% |
| Discourse posts | 137,399 | 211,888 | +54% |
| TIOBE Index Rank | #47 | #23 | +24 |

Sloan Digital Sky Survey



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The Sloan Digital Sky Survey: Mapping the Universe

The Sloan Digital Sky Survey has created the most detailed three-dimensional maps of the Universe ever made, with deep multi-color images of one third of the sky, and spectra for more than three million astronomical objects. Learn and explore all phases and surveys—past, present, and future—of the SDSS.

Cataloging the Visible Universe through Bayesian Inference at Petascale

Jeffrey Regier*, Kiran Pamnany†, Keno Fischer‡, Andreas Noack§, Maximilian Lam*, Jarrett Revels§,
Steve Howard¶, Ryan Giordano¶, David Schlegel¶, Jon McAuliffe¶, Rollin Thomas¶, Prabhat||

*Department of Electrical Engineering and Computer Sciences, University of California, Berkeley

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‡Julia Computing

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¶Department of Statistics, University of California, Berkeley

||Lawrence Berkeley National Laboratory

Abstract—Astronomical catalogs derived from wide-field imaging surveys are an important tool for understanding the Universe. We construct an astronomical catalog from 55 TB of imaging data using Celeste, a Bayesian variational inference code written entirely in the high-productivity programming language Julia. Using over 1.3 million threads on 650,000 Intel Xeon Phi cores of the Cori Phase II supercomputer, Celeste achieves a peak rate of 1.54 PF PLOPs/s. Celeste is able to jointly optimize parameters for 188M stars and galaxies, loading and processing 178 TB across 8192 nodes in 14.6 minutes. To achieve this, Celeste exploits parallelism at multiple levels (cluster, node, and thread) and accelerates I/O through Cori’s Burst Buffer. Julia’s native performance enables Celeste to employ high-level constructs without resorting to handwritten or generated low-level code (C/C++/Fortran), and yet achieve petascale performance.

Keywords—astronomy, Bayesian, variational inference, Julia, high performance computing

I. INTRODUCTION

Modern astronomical surveys produce vast amounts of data. Our work uses images from the Sloan Digital Sky Survey (SDSS) [1] as a test case to demonstrate a new, highly scalable algorithm for constructing astronomical catalogs. SDSS produced 55 TB of images covering 35% of the sky and a catalog of 470 million unique light sources. Figure 1 shows image boundaries for a small region from SDSS. Advances in detector fabrication technology, computing power, and networking have enabled the development of a new generation of upcoming wide-field sky surveys orders of magnitude larger than SDSS. In 2020, the Large Synoptic Survey Telescope (LSST) will begin to obtain more than 15 TB of new images nightly [2]. The instrument will produce 10s–100s of PBs of imaging and catalog data over the lifetime of the project.

Producing an astronomical catalog is challenging in part because the parameters of overlapping light sources must be learned collectively: the optimal parameters for one light

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JULIA LANGUAGE DELIVERS PETASCALE HPC PERFORMANCE

November 28, 2017 Rob Farber



Written in the productivity language **Julia**, the **Celeste project**—which aims to catalogue all of the telescope data for the stars and galaxies in the visible universe—demonstrated the first Julia application to exceed 1 PF/s of double-precision floating-point performance (specifically 1.54 PF/s).

Federal Reserve Bank of New York



DSGE.jl

Home

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DSGE.jl

The DSGE.jl package implements the New York Fed DSGE model and provides general code to estimate many user-specified DSGE models. The package is introduced in the Liberty Street Economics blog post [The FRBNY DSGE Model Meets Julia](#).

This Julia-language implementation mirrors the MATLAB code included in the Liberty Street Economics blog post [The FRBNY DSGE Model Forecast](#).

The New York Fed DSGE team is currently working on adding methods to solve nonlinear and heterogeneous agent DSGE models. Extensions of the DSGE model code may be released in the future at the discretion of the New York Fed.

Table of Contents

- Model Design
- Special Model Types
 - The PoolModel Type
 - DSGE-VARs and the DSGEVAR Type
 - DSGE-VECMs and the DSGEVECM Type
 - Auxiliary Methods for DSGE-VARs and DSGE-VECMs

You may wonder why we wrote our code, which was originally in MATLAB and made available [here](#), in Julia. MATLAB is a widely used, mature programming language that has served our purposes very well for many years. However, Julia has two main advantages from our perspective. First, as free software, Julia is more accessible to users from academic institutions or organizations without the resources for purchasing a license. Now anyone, from Kathmandu to Timbuktu, can run our code at no cost. Second, as the models that we use for [forecasting](#) and policy analysis grow more complicated, we need a language that can perform computations at a high speed. Julia [boasts](#) performance as fast as that of languages like C or Fortran, and is still simple to learn. (Read this [post](#), written by the creators of the language, to understand why Julia fits the bill.) We want to address hard questions with our models—from understanding financial markets developments to modeling households' heterogeneity—and we can do so only if we are close to the frontier of programming.

We tested our code and found that the [model estimation](#) is about ten times faster with Julia than before, a very large improvement. Our ports (computer lingo for “translations”) of certain algorithms, such as Chris Sims’s gensys (which computes the model solution), also ran about six times faster in Julia than the MATLAB versions we had previously used. (These results should not be interpreted as a broad assessment of the speed of Julia relative to MATLAB, as they apply only to the code we have written.) This [document](#) written by the New York Fed and QuantEcon collaborators, who did the real work on the port, documents the speed improvements and offers an overview of the hurdles encountered in the translation of a large codebase from one language to another. We hope it will be of use to other central banks and researchers embarking on similar projects.

<https://libertystreeteconomics.newyorkfed.org/2015/12/the-frbny-dsge-model-meets-julia.html>



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CLIMATE MODELING ALLIANCE





São Paulo from Amazonia-1 Satellite

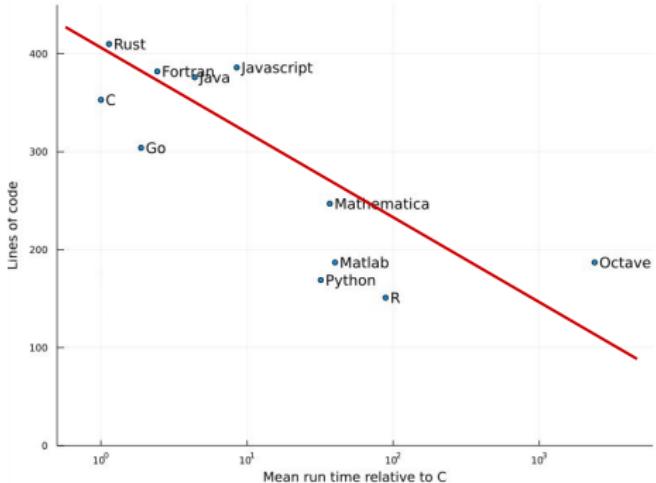
Popular libraries (packages)

These are all pretty mature:

- ▶ DataFrames.jl and CSV.jl - **in-memory data manipulation**
- ▶ Plots.jl (also easy to call R's ggplot())
- ▶ ★ JuMP.jl - **constrained optimization**
- ▶ ★ DifferentialEquations.jl
- ▶ StatsModels.jl, GLM.jl - **traditional stats models**
- ▶ Flux.jl - **deep learning**
- ▶ ★ Turing.jl, Soss.jl, ... **probabilistic programming**
- ▶ MLJ.jl - multi-paradigm **machine learning** platform
- ▶ Pluto.jl - “**reactive**” **notebooks**

The two-language problem

*Compiled,
statically typed*



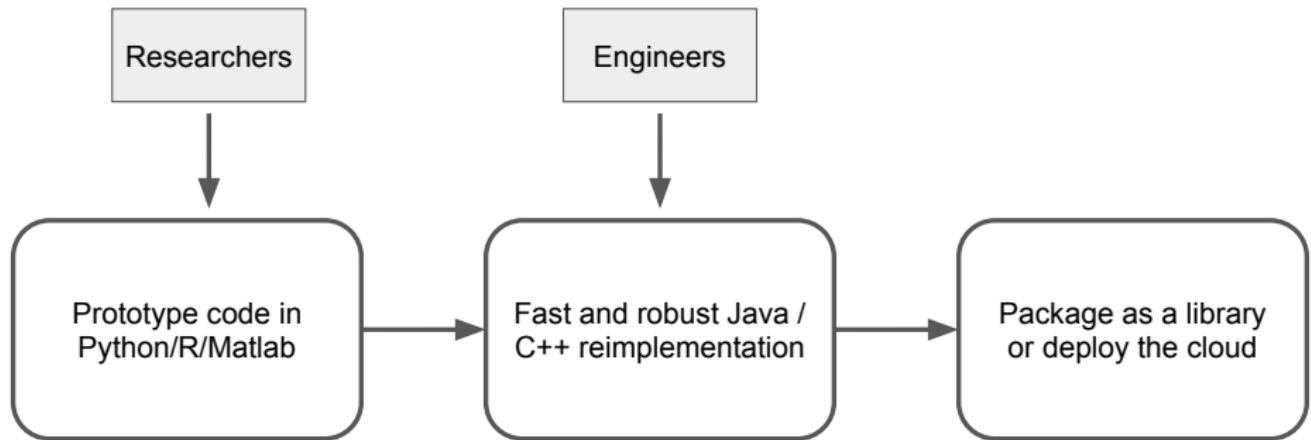
*Interactive,
dynamically typed*

<https://github.com/JuliaLang/Microbenchmarks>

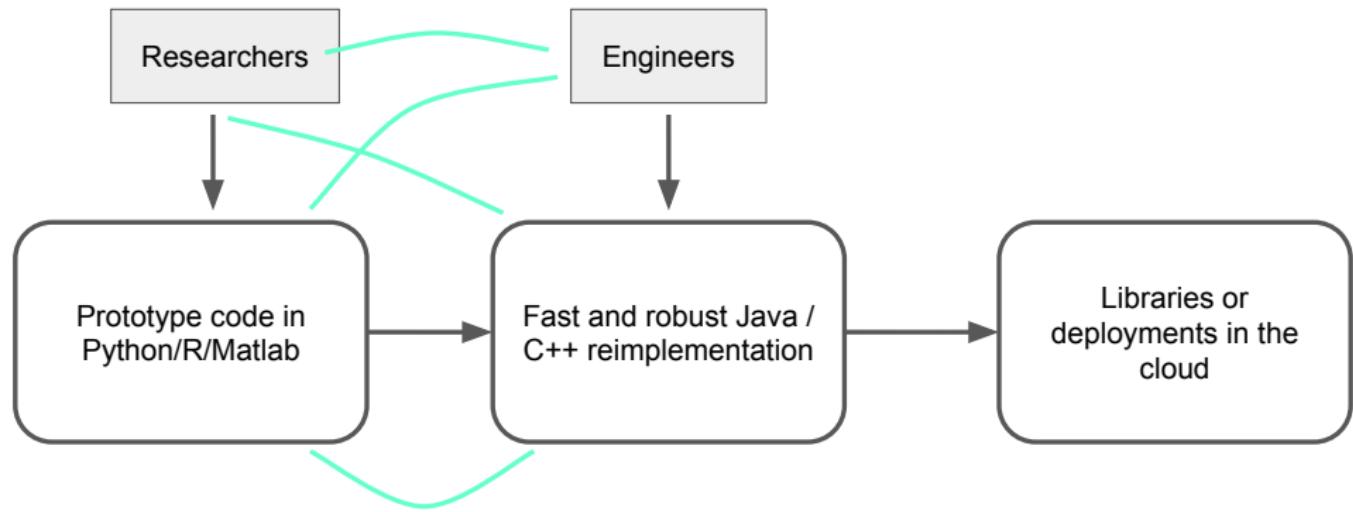
Why is two languages a problem ?

- ▶ Can't easily **modify** core algorithms
- ▶ Barrier to **understanding algorithms** even if not seeking to modify them
- ▶ Complicates installation of a complete software stack (package **dependency hell**, manual interventions)
- ▶ Barrier to **transparency** and **reproducibility**
- ▶ Barrier to **composing libraries** (e.g., automatic differentiation)
- ▶ **Hampers innovation**, development of novel algorithms

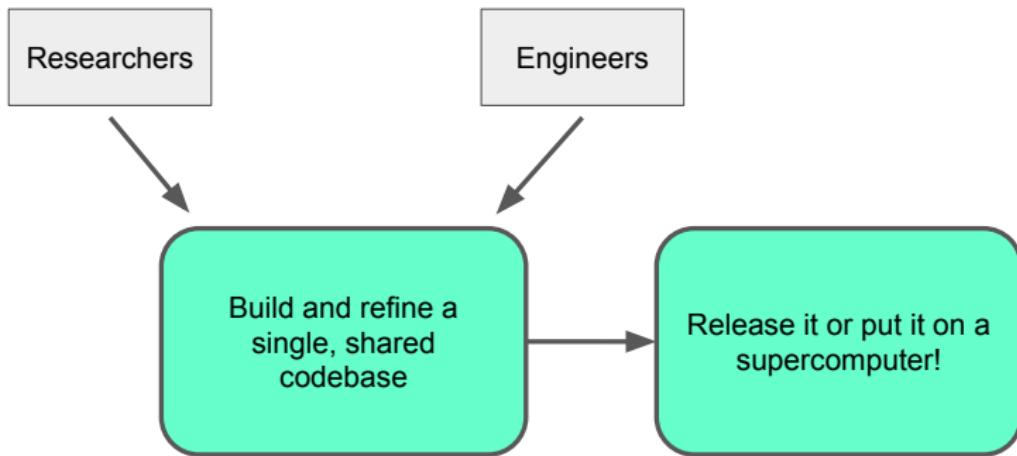
Data Science Pipeline



Data Science Pipeline: In Practice



Data Science Pipeline: A Fresh Approach



Fast code written fast: DifferentialEquations.jl

| Comparison Of Differential Equation Solver Software | | | | | | | | | | | | | | |
|--|-----------|----------|-----------|--------------------------|-----------------|-----------|------------------------------------|--------|----------|---------|------|-----------|-------------|-----------|
| Subject/Item | MATLAB | SciPy | deSolve | DifferentialEquations.jl | Sundials | Holger | ODEPACK/Nelib /NAG | JiCODE | PyDSTool | FATODE | GSL | BOOST | Mathematica | Maple |
| Language | MATLAB | Python | R | Julia | C++ and Fortran | Fortran | Fortran | Python | Python | Fortran | C | C++ | Mathematica | Maple |
| Selection of Methods for ODEs | Fair | Poor | Fair | Excellent | Good | Fair | Good | Poor | Poor | Fair | Poor | Fair | Fair | Fair |
| Efficiency* | Poor | Poor**** | Poor*** | Excellent | Excellent | Good | Good | Good | Good | Good | Fair | Fair | Fair | Good |
| Tweakability | Fair | Poor | Good | Excellent | Excellent | Good | Good | Fair | Fair | Fair | Fair | Fair | Good | Fair |
| Event Handling | Good | Good | Fair | Excellent | Good** | None | Good** | None | Fair | None | None | None | Good | Good |
| Symbolic Calculation of Jacobians and Auto-differentiation | None | None | None | Excellent | None | None | None | None | None | None | None | Excellent | Excellent | |
| Complex Numbers | Excellent | Good | Fair | Good | None | None | None | None | None | None | None | Good | Excellent | Excellent |
| Arbitrary Precision Numbers | None | None | None | Excellent | None | None | None | None | None | None | None | Excellent | Excellent | Excellent |
| Control Over Linear/Nonlinear Solvers | None | Poor | None | Excellent | Excellent | Good | Depends on the solver | None | None | None | None | Fair | Fair | None |
| Build-in Parallelism | None | None | None | Excellent | Excellent | None | None | None | None | None | None | Fair | None | None |
| Differential-Algebraic Equation (DAE) Solvers | Good | None | Good | Excellent | Good | Excellent | Good | None | Fair | Good | None | None | Good | Good |
| Implicitly-Defined DAE Solvers | Good | None | Excellent | Fair | Excellent | None | Excellent | None | None | None | None | None | Good | None |
| Constant-Log-Delay Differential Equation (DLDE) Solvers | Fair | None | Poor | Excellent | None | Good | Fair (via DDVERK) | Fair | None | None | None | None | Good | Excellent |
| State-Dependent DDE Solvers | Poor | None | Poor | Excellent | None | Excellent | Good | None | None | None | None | None | None | Excellent |
| Stochastic Differential Equation (SDE) Solvers | Poor | None | None | Excellent | None | None | None | Good | None | None | None | None | Fair | Poor |
| Specialized Methods for 2nd Order ODEs and Hamiltonians (and Symplectic Integrators) | None | None | None | Excellent | None | Good | None | None | None | None | None | Fair | Good | None |
| Boundary Value Problem (BVP) Solvers | Good | Fair | None | Good | None | None | Good | None | None | None | None | None | Good | Fair |
| GPU Compatibility | None | None | None | Excellent | Good | None | None | None | None | None | None | Good | None | None |
| Analytic Additions (Sensitivity Analysis, Parameter Estimation, etc.) | None | None | None | Excellent | Excellent | None | Good (for some methods like DASPK) | None | Poor | Good | None | None | Excellent | None |

Other features

- ▶ Fast user-defined composite types (C-like structs)
- ▶ Lisp-like macros/metaprogramming
- ▶ Call C functions directly
- ▶ Can wrap Python, R Java/Scala
- ▶ State-of-the-art distributed computing and multi-threading support

Other features (continued)

- ▶ First-class math support
- ▶ Excellent REPL (console)
- ▶ Built-in package manager
- ▶ Automatic differentiation (Zygote.jl)

Drawbacks

For most users all serious drawbacks derive from Julia's young age:

- ▶ Smaller number of libraries
- ▶ Smaller community of users
- ▶ Some interfaces and tooling less polished
- ▶ More bugs (in libraries, few in language itself)

Other drawbacks and annoyances:

- ▶ Limited support for exporting programs as stand-alone executables.
- ▶ Waiting for first-time/pre compilation.