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Julia: A Fresh Approach to Numerical Computing

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Knowledge Quarter Codes Tech Social

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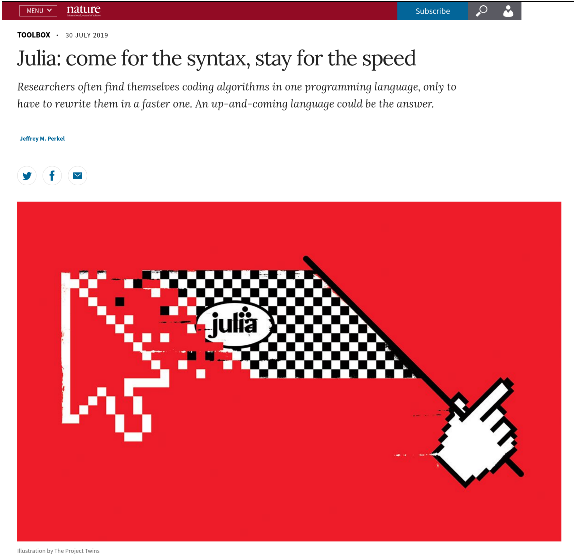
Julia's Facts

- v1.0.0 released in 2018 at UCL
- Development started in 2009 at MIT, first public release in 2012
- Julia co-creators won the 2019 James H. Wilkinson Prize for Numerical Software
- Julia adoption is growing rapidly in numerical optimisation, differential equations, machine learning, differentiable programming
- It is used and taught in several universities (`https://julialang.org/teaching/`)

Julia on Nature



TOOLBOX · 30 JULY 2019

Julia: come for the syntax, stay for the speed

Researchers often find themselves coding algorithms in one programming language, only to have to rewrite them in a faster one. An up-and-coming language could be the answer.

Jeffrey M. Perkel

Illustration by The Project Twins

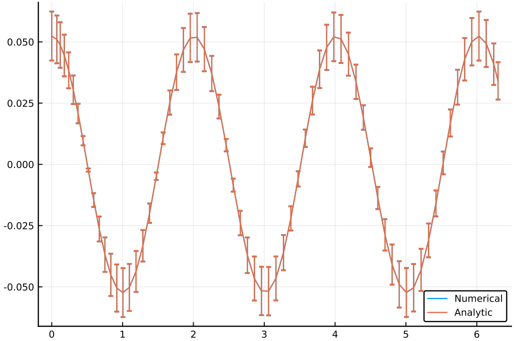
Nature **572**, 141-142 (2019). DOI: 10.1038/d41586-019-02310-3

Solving the Two-Language Problem: Julia

- Multiple dispatch
- Dynamic type system
- Good performance, approaching that of statically-compiled languages
- JIT-compiled scripts
- User-defined types are as fast and compact as built-ins
- Lisp-like macros and other metaprogramming facilities
- No need to vectorise: `for` loops are fast
- Garbage collection: no manual memory management
- Interactive shell (REPL) for exploratory work
- Call C and Fortran functions directly: no wrappers or special APIs
- Call Python functions: use the `PyCall` package
- Designed for parallelism and distributed computation

Multiple Dispatch

```julia
using DifferentialEquations, Measurements,
      Plots

g = 9.79 ± 0.02; # Gravitational constant
L = 1.00 ± 0.01; # Length of the pendulum

# Initial speed & angle, time span
u₀ = [0 ± 0, π / 60 ± 0.01]
tspan = (0.0, 6.3)

# Define the problem
function pendulum(du,u,p,t)
    θ  = u[1]
    dθ = u[2]
    du[1] = dθ
    du[2] = -(g/L)*θ
end

# Pass to solvers
prob = ODEProblem(pendulum, u₀, tspan)
sol = solve(prob, Tsit5(), reltol = 1e-6)

# Analytic solution
u = u₀[2] .* cos.(sqrt(g / L) .* sol.t)

plot(sol.t, getindex.(sol.u, 2),
     label = "Numerical")
plot!(sol.t, u, label = "Analytic")
```



From `DifferentialEquations.jl` tutorial “Numbers with Uncertainties”, by Mosè Giordano & Chris Rackauckas

JuliaCon 2019 talk “The Unreasonable Effectiveness of Multiple Dispatch”: `https://www.youtube.com/watch?v=kc9HwsxE1OY`

Multiple Dispatch: An Example

Define the types

```
# The abstract type `Shape`
abstract type Shape end
# Followings are subtypes of the abstract type `Shape`
struct Paper    <: Shape end
struct Rock     <: Shape end
struct Scissors <: Shape end
```

Define the rules of the game

```
play(::Type{Paper}, ::Type{Rock})     = "Paper wins"
play(::Type{Paper}, ::Type{Scissors}) = "Scissors win"
play(::Type{Rock},  ::Type{Scissors}) = "Rock wins"
play(::Type{T},     ::Type{T}) where {T<:Shape} =
    "Tie, try again"
play(a::Type{<:Shape}, b::Type{<:Shape}) =
    play(b, a) # Commutativity
```

Multiple Dispatch: An Example (cont.)

Let's play!

```
julia> play(Scissors, Rock)
"Rock wins"

julia> play(Scissors, Scissors)
"Tie, try again"

julia> play(Rock, Paper)
"Paper wins"

julia> play(Scissors, Paper)
"Scissors win"
```

Multiple Dispatch: An Example (cont.)

Extend the game by adding a new shape

```
julia> struct Well <: Shape end

julia> play(::Type{Well}, ::Type{Rock})     = "Well wins";

julia> play(::Type{Well}, ::Type{Scissors}) = "Well wins";

julia> play(::Type{Well}, ::Type{Paper})    = "Paper wins";

julia> play(Paper, Well)
"Paper wins"

julia> play(Well, Rock)
"Well wins"

julia> play(Well, Well)
"Tie, try again"
```

https://giordano.github.io/blog/2017-11-03-rock-paper-scissors/

Metaprogramming

- Like Lisp, Julia is homoiconic: it represents its own code as a data structure of the language itself
- Since code is represented by objects that can be created and manipulated from within the language, it is possible for a program to transform and generate its own code. This allows sophisticated code generation without extra build steps, and also allows true Lisp-style macros operating at the level of abstract syntax trees (ASTs)
- In contrast, preprocessor "macro" systems, like that of C and C++, perform textual manipulation and substitution before any actual parsing or interpretation occurs
- Julia's macros allow you to modify an unevaluated expression and return a new expression at parsing-time
- Macros allows the creation of domain-specific languages (DSLs). See `https://julialang.org/blog/2017/08/dsl`

For more information, read the manual: `https://docs.julialang.org/en/v1/manual/metaprogramming/`. MP is powerful but hard: `https://www.youtube.com/watch?v=mSgXWpvQEHE`

Domain-Specifc Languages

Lotka-Volterra equations (predator-prey model):

$$\frac{\mathrm{d}x}{\mathrm{d}t} = ax - bxy$$
$$\frac{\mathrm{d}y}{\mathrm{d}t} = -cy + dxy$$

You can define this problem as follows:

```julia
function lotka_volterra!(du,u,p,t)
  du[1] = p[1]*u[1] - p[2]*u[1]*u[2]
  du[2] = -p[3]*u[2] + p[4]*u[1]*u[2]
end
```

Domain-Specifc Languages

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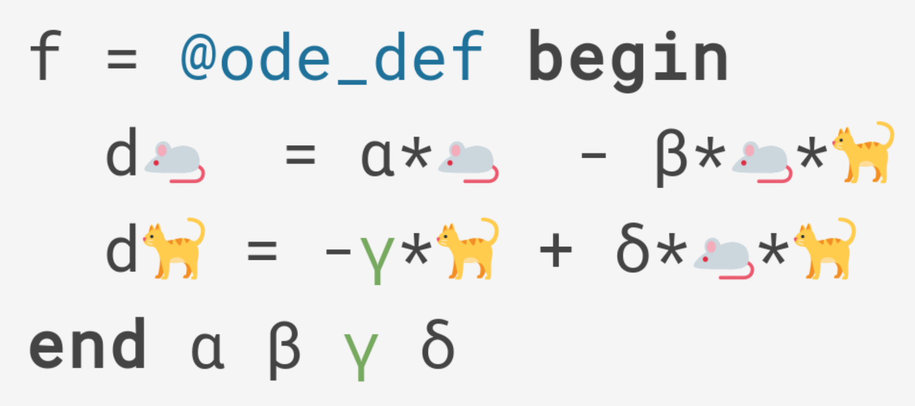
end
```

Or use `@ode_def` macro from `ParameterizedFunctions.jl`:

```
lotka_volterra! = @ode_def LotkaVolterra begin
  dx = a*x - b*x*y
  dy = -c*y + d*x*y
end a b c d
```

Domain-Specifc Languages (cont.)



```
f = @ode_def begin
  d🐁  = α*🐁  - β*🐁*🐈
  d🐈 = -γ*🐈 + δ*🐁*🐈
end α β γ δ
```

Calling Other Languages

Do you have code in other languages that you want to be able to use? Don't worry!

```
julia> ccall((:exp, "libm.so.6"), Cdouble, (Cdouble,), 1.57)
4.806648193775178

julia> my_shell = ccall((:getenv, "libc.so.6"),
                        Cstring, (Cstring,), "SHELL")
Cstring(0x00007ffdf927c6b6)

julia> unsafe_string(my_shell)
"/bin/zsh"
```

Some examples about playing with pointers at `https://giordano.github.io/blog/2019-05-03-julia-get-pointer-value/`.

JuliaCon 2019 talk: `https://www.youtube.com/watch?v=ez-KVi0le0w`

Calling Other Languages (cont.)

```
julia> using PyCall

julia> const math = pyimport("math");

julia> math.sin(math.pi / 4) - sin(pi / 4)
0.0

julia> const np = pyimport("numpy");

julia> np.random.rand(3, 4)
3×4 Array{Float64,2}:
 0.423639  0.863076  0.164781  0.160279
 0.452385  0.368733  0.779607  0.474547
 0.139557  0.777287  0.226157  0.493904
```

If you come to Julia from another language, keep in mind the following differences:
`https://docs.julialang.org/en/v1/manual/noteworthy-differences/`

Best Programming Practices

- Packages are git repositories
- Testing framework in standard library
- Continuous integration with several different services (Travis, AppVeyor, Cirrus, Drone, Gitlab Pipelines, Azure Pipelines, GitHub Actions, etc. . .)
- Code coverage: Coveralls, Codecov
- Documentation: docstrings, doctests
- PkgEval: test all registered packages

Tutorial on how to develop Julia packages:
`https://www.youtube.com/watch?v=QVmU29rCjaA`

Reproducibility

- Package manager integrated with the language
- “Artifacts” (binary packages, data, etc. . .) treated as packages
- Reproducible environments:
  - `Project.toml`: direct dependencies and their minimum required versions
  - `Manifest.toml`: complete checkout of the environment (all “packages” with fixed versions). It allows full reproducibility

What's Bad About Julia

JuliaCon 2019 | What's Bad About Julia | Jeff Bezanson

Laundry list (just so you know I know)

- Compiler latency (time to first plot)
- Better static compilation support
- Better support for immutable arrays
- What am I allowed to mutate?
- Array optimizations + need too many manual in-place ops
- Need protocols ("what do I implement?")
- Better traits (to replace big Unions)
- Parser error messages, other error messages
- Macro hygiene needs a lot of work
- Incomplete notation, e.g. for N-d arrays
- Special objects: `Array`, `String`, `Symbol`
- `map(f, [])`
- `missing` vs. `DataValue` vs. `nothing` vs. ... ?

stuff about variable scope

memory isn't zero'd

static typing?

MOAR PERFORMANCE

printing is too verbose

compiled code is too big

unreachable code isn't GC'd

unreachable reached

+ Distributed ??

better tutorials/docs

MOAR PERFORMANCE

MOAR PERFORMANCE

MOAR PERFORMANCE

Jeff Bezanson
Julia Computing

JuliaCon 2019 talk: `https://www.youtube.com/watch?v=TPuJsgyu87U`

What's Bad About Julia (cont.)

- Compilation latency can be annoying during development
- Plotting framework not exciting
- Global variables are bad
- Ecosystem still young

Platforms 1: GPU

- High-level programming without GPU experience
- Low-level programming for high-performance and flexibility
- Rich ecosystem: `CUDAnative.jl`, `CuArrays.jl`, `GPUifyLoops.jl`, etc...

Platforms 1: GPU (cont.)

```
julia> f(x) = 3x^2 + 5x + 2;

julia> A = [1f0, 2f0, 3f0];

julia> A .= f.(2 .* A.^2 .+ 6 .* A.^3 .- sqrt.(A))
3-element Array{Float32,1}:
   184.0
  9213.753
 96231.72

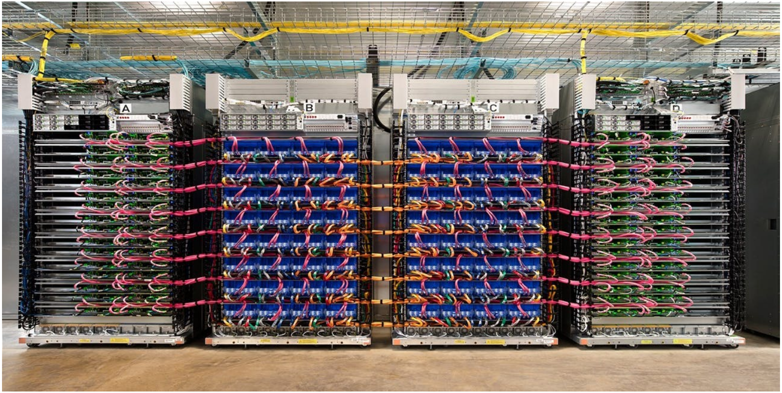
julia> using CuArrays

julia> B = CuArray([1f0, 2f0, 3f0]);

julia> B .= f.(2 .* B.^2 .+ 6 .* B.^3 .- sqrt.(B))
3-element CuArray{Float32,1}:
   184.0
  9213.753
 96231.72
```

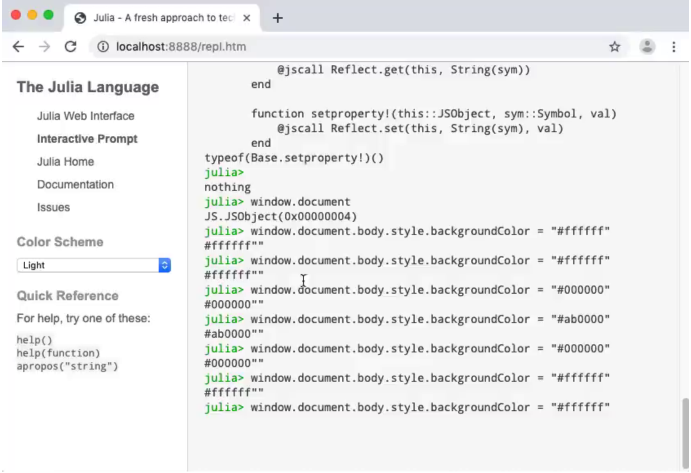
More info in `https://doi.org/10.1109/TPDS.2018.2872064`

Platforms 2: TPU



- Tensor Processing Units are developed by Google for neural network machine learning
- Julia supports TPUs via `https://github.com/JuliaTPU/XLA.jl`
- Kernels are pure Julia code, but calls require `@tpu` macro
- JuliaCon 2019 talk: `https://www.youtube.com/watch?v=QeG1IWeVKek`
- Paper: `https://arxiv.org/abs/1810.09868`

Platforms 3: WebAssembly (*experimental*)



For help, try one of these:

```
help()
help(function)
apropos("string")
```

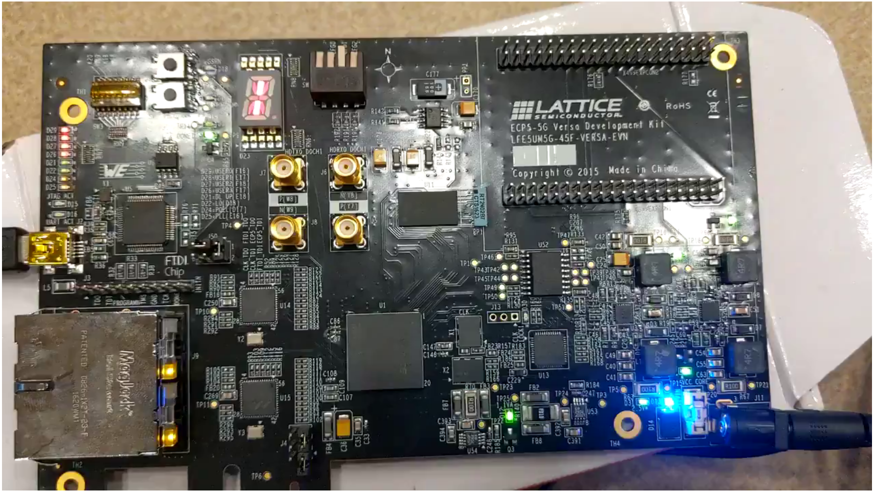
```
           @jscall Reflect.get(this, String(sym))
       end

       function setproperty!(this::JSObject, sym::Symbol, val)
           @jscall Reflect.set(this, String(sym), val)
       end
typeof(Base.setproperty!)()
julia>
nothing
julia> window.document
JS.JSObject(0x00000004)
julia> window.document.body.style.backgroundColor = "#ffffff"
#ffffff""
julia> window.document.body.style.backgroundColor = "#ffffff"
#ffffff""
julia> window.document.body.style.backgroundColor = "#000000"
#000000""
julia> window.document.body.style.backgroundColor = "#ab0000"
#ab0000""
julia> window.document.body.style.backgroundColor = "#000000"
#000000""
julia> window.document.body.style.backgroundColor = "#ffffff"
#ffffff""
julia> window.document.body.style.backgroundColor = "#ffffff"
```

Credits: Keno Fisher on Twitter: `https://twitter.com/KenoFischer/status/1158517084642582529`

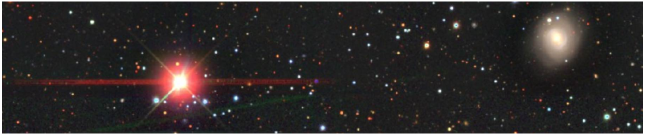
Mozilla awarded a grant to develop Julia support for WebAssembly

Platforms 4: FPGA (*very experimental*)



Credits: Keno Fisher on Twitter: `https://twitter.com/KenoFischer/status/1154865907472183296`

Applications: Past – `Celeste.jl`



Project goals:

1. Catalog all galaxies and stars that are visible through the next generation of telescopes
   - The Large Synoptic Survey Telescope (LSST) will house a 3200-megapixel camera producing 15 TB of images nightly
2. Replace non-statistical approaches to building astronomical catalogs from photometrical data
3. Identify promising galaxies for spectrograph targeting
   - Better understand dark energy and the geometry of the Universe
4. Develop and extensible model and inference procedure, for use by the astronomical community
   - Future applications might include finding supernovae and detecting near-Earth asteroids

Applications: Past – `Celeste.jl` (cont.)

Accomplishments:

1. Reached 1.54 petaFLOPS performance (first First Julia application to exceed 1 petaFLOPS)
    - Julia is probably the first dynamic high-level language to enter the petaFLOPS club (other languages in it: Assembly, Fortran, C/C++)
    - Code ran on 9568 Intel Xeon Phi nodes of Cori (Phase II)
    - 1.3 milion threads on 650 000 KNL cores
2. Processed most of SDSS dataset in 14.6 minutes
    - Loaded and analysed 178 TB
    - Optimised 188 million stars and galaxies
3. First comprehensive catalog of visible objects with state-of-the-art point and uncertainty estimates
4. Demonstration of Variational Inference on 8 billion parameters
    - 2 orders of mangnitude larger than other reported results

Discover more:

- `https://github.com/jeff-regier/Celeste.jl`
- JuliaCon 2017 talk: `https://www.youtube.com/watch?v=uecdcADM3hY`

Applications: Present – PuMaS

PharmaceUtical Modeling And Simulation

- Suite of tools for developing, simulating, fitting, and analyzing pharmaceutical models
- Bring efficient implementations of all aspects of pharmaceutical modeling under one cohesive package
- Deliver personalised treatment schedules for each individual
- Seemless integration with the rest of Julia ecosystem (`Measurements.jl`, `JuliaDB.jl`, `Query.jl`, etc.)
- Collaboration between Center for Translational Medicine of University of Maryland, Baltimore and Julia Computing

Talks at JuliaCon 2018: `https://www.youtube.com/watch?v=KQ4Vtsd9XNw` and JuliaCon 2019: `https://www.youtube.com/watch?v=i8LGmTOmKnE`

Applications: Future – CLIMA

CliMA
CLIMATE MODELING ALLIANCE

- Collaboration between Caltech, NASA JPL, MIT, Naval Postgraduate School, funded among others by NSF: `https://clima.caltech.edu/`
- First Earth model that automatically learns from diverse data sources
- Modeling platform that is scalable and built for growth
- It will need to run on the world's fastest supercomputers and on the cloud, using both GPU and CPUs
- Scalable for different resolutions, to have local and global climate
- Julia chosen to ensure performance on modern heterogeneous architectures without sacrificing scientific productivity information

Talk at JuliaCon 2019: `https://www.youtube.com/watch?v=gD5U_U9kZk8`

Take-Home Messages

- Great composability: complex packages can work together
- Incremental optimisation: from prototype to final product step by step
    - `https://docs.julialang.org/en/v1/manual/performance-tips/`
    - `https://mitmath.github.io/18337/lecture2/optimizing`
- Julia programs are organised around multiple dispatch
- Metaprogramming capabilities
- Most of Julia is written in Julia itself
- My 2 cents: main Julia's strength is genericity, which increases productivity

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Got interested?

- Official website: `https://julialang.org/`
- Manual: `https://docs.julialang.org/en/`
- List of registered packages: `https://pkg.julialang.org/`
- GitHub repository: `https://github.com/JuliaLang/julia`
- Discussion forum: `https://discourse.julialang.org/`
- Slack workspace: `https://slackinvite.julialang.org/`

JuliaCon 2020 in Lisbon!

JuliaCon is coming to Lisbon

Monday 27th to Friday 31st of July, 2020

at the ISCTE - Instituto Universitário de Lisboa (ISCTE-IUL)

Lisbon, Portugal

`https://juliacon.org/2020/`

Come for the Pizza, Stay for the Language