Julia for Scientists

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School of Psychology, University of Nottingham
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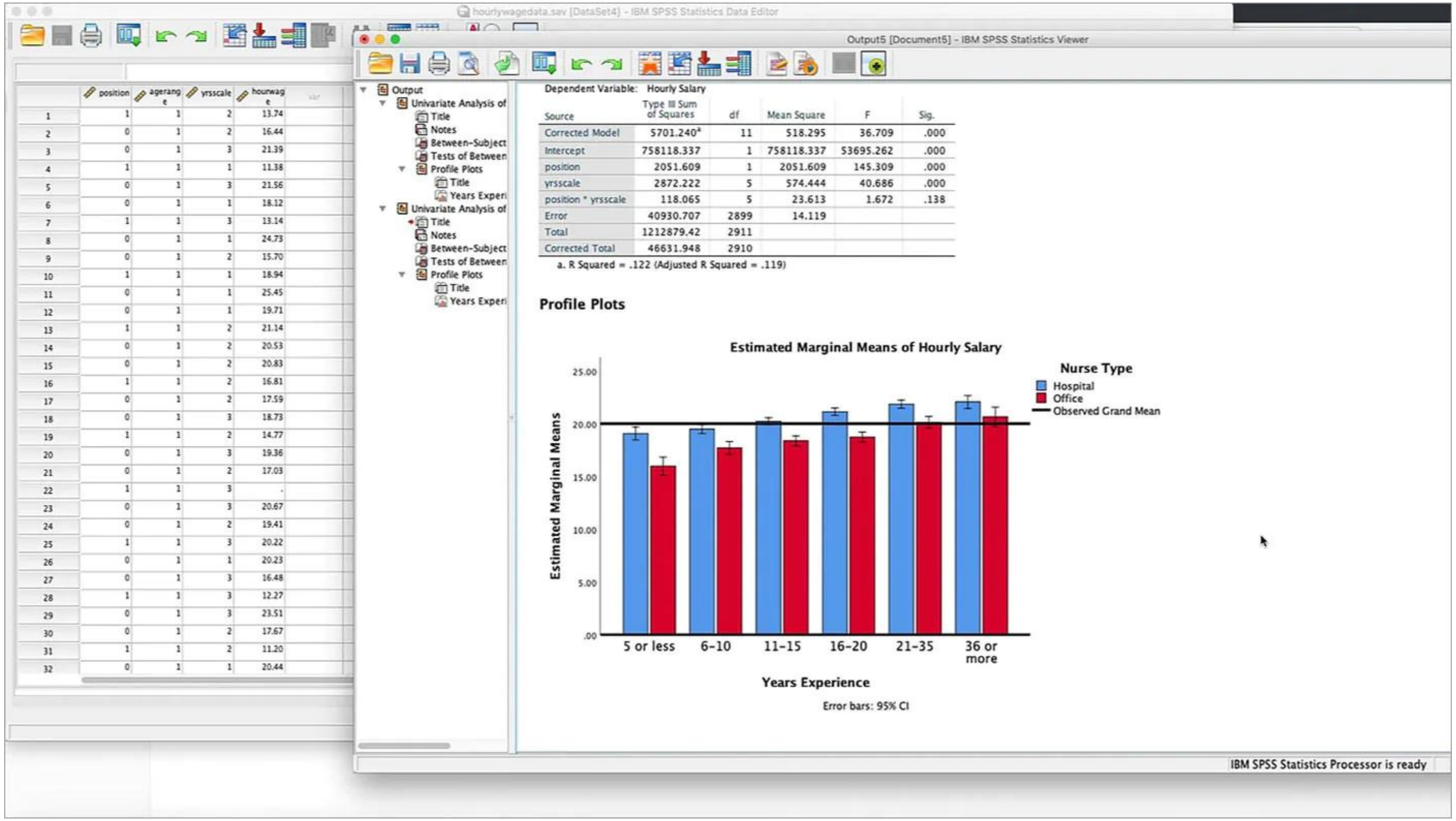
If you're using Excel, SPSS, Stata, JASP, …

Why learn a programming language?



Why program?

- Automate analyses
  → less error-prone

..which goes hand in hand with:

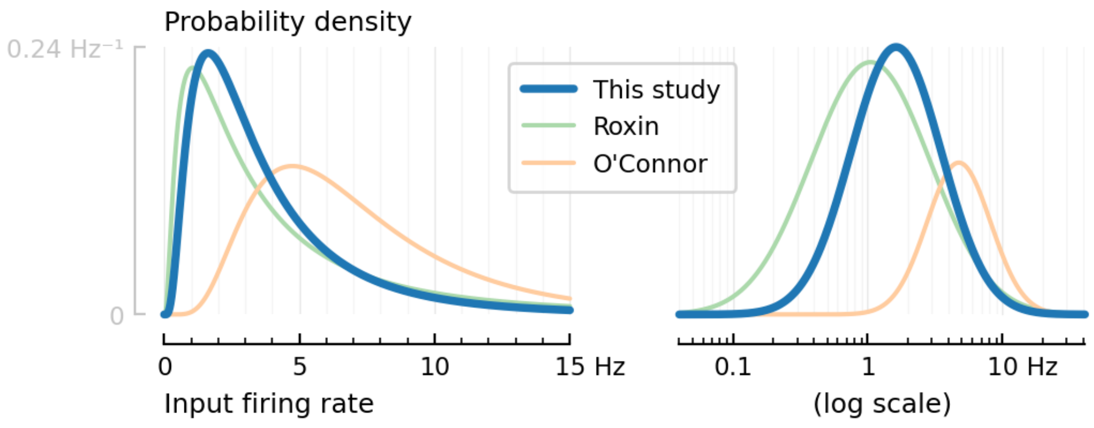
- **Reproducibility**

- Customize:
  - Special plots
  - Tweak analyses

- Run simulations

- For fun

An example custom plot:



Choosing a programming language

as a researcher

	First released (The new builds on & learns from the old)	Free & open? (Hackable, "own your code-running environment")	Online community (→ Learning resources & documentation iterations)
• Main choices:			
R	1995 / 1976 (S)	Yes	Huge
Python	1991	Yes	Huge
• Others			
Julia	2012	Yes	Medium
Matlab	1979	No	Large

- ..is also choosing a community

🤍❤️🤍 🇺🇦 **Vic✈or**
@vzverovich

Replying to @lefticus

Julia is Matlab without users

3:28 AM · Feb 21, 2022

Guillaume Dalle
@giomdal

Matlab is Julia without open source contributors 🤷

> 🤍❤️🤍 🇺🇦 **Vic✈or** @vzverovich · Feb 21
> Replying to @lefticus
> Julia is Matlab without users

8:59 AM · Mar 20, 2022

Julia syntax

```julia
using Unitful: MΩ, pF, mV          # Import names from a package

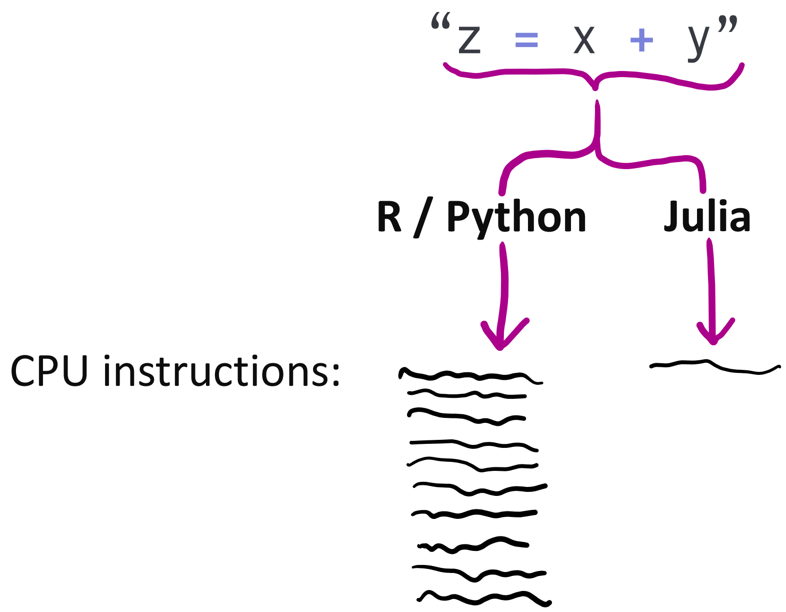
"""
Simulate a simple leaky-integrate-and-fire (LIF) neuron, given
input current `I` and a timestep `Δt`.
Return when the neuron fires its first spike.

The neuron's input resistance `R` and time constant `τ` can be
customized by keyword argument.
"""
function first_spike(I, Δt; R = 100MΩ, τ = 200pF)
    N = length(I)                  # Number of samples
    v = -70mV                      # Resting membrane potential
    for i in 1:N
        dv = -v + R*I[i]           # Leaky current integration
        v += dv/τ * Δt             # Euler integration of ODE
        if v > -55mV               # Spike!
            return time = i * Δt
        end
    end
    return nothing                 # Never spiked
end
```

In Python / R / Matlab:
"Avoid for-loops"
"Write vectorized code"

Compilation: Your code ⇝ the CPU

- If **one line** of Julia code corresponds to just a few CPU instructions
- ..then the same line in base Python / R / Matlab will often correspond to an order of magnitude **more CPU instructions** *
  - ..That's why the code that does the 'real' numeric work in these languages is actually written in C / C++
    NumPy, PyTorch, Tensorflow, dplyr, …: all have their core written in a different language
  - ..That's why, to have your code run fast, you're discouraged from writing `for`-loops for numeric code ..
  - .. and instead use the provided library functions
    e.g. `np.where(…)`
  - Python is often used as "glue-code" (see next slide)
  - If you want a custom numeric algorithm that's not provided by the libraries, you need to learn C / C++
    The "two languages-problem"

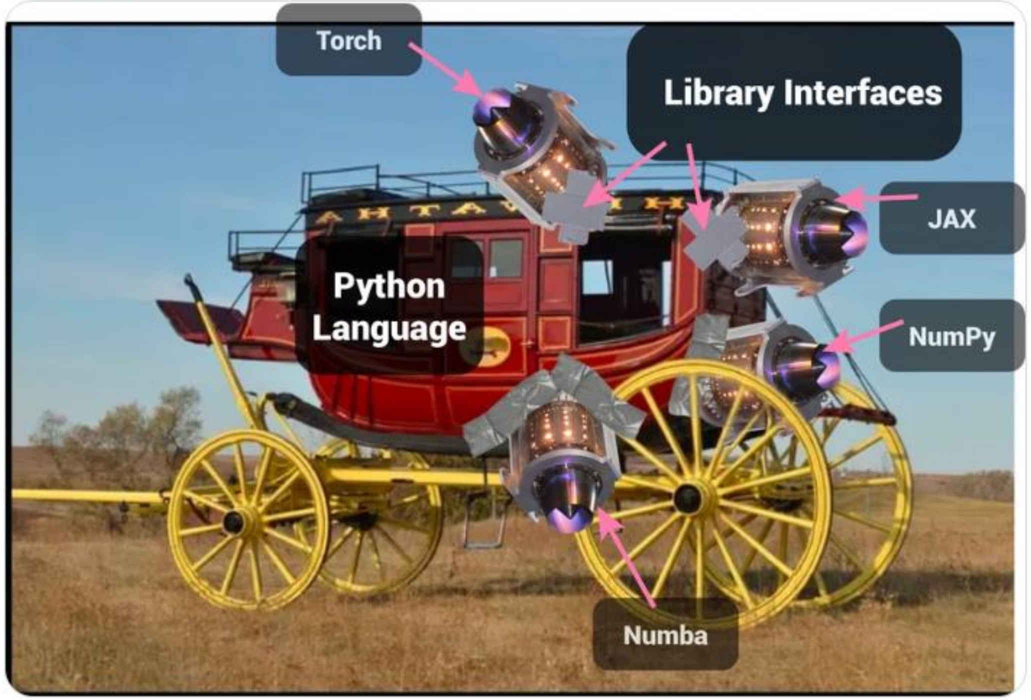


* Matlab added JIT compilation in 2015 (but it's rather opaque)
Python can have JIT compilation via the fantastic **Numba** package. (But you can only use base Python with Numba, not arbitrary other packages).

Miles Cranmer
@MilesCranmer

The more I use Julia, the more Python and its numeric libraries look like a Victorian-era stagecoach with jet engines duct-taped to it, each pointing a different direction (=mutually incompatible).

It's such a weird ecosystem, and makes it so much harder for users to contribute.



5:50 PM · Nov 7, 2022

JIT compilation

- If **one line** of Julia code corresponds to just a few CPU instructions
- ..then the same line in base Python / R / Matlab* will often correspond to an order of magnitude **more CPU instructions**

- Why is this ↑ ?
  - The same line of code (say, `z = x + y`) does different things, based on the **type** of `x` and `y`
    - If they're integers (8 + 3), use the \`leaq\` CPU instruction
    - If one is a float (8 + 3.3), call \`convert\` and use the floating point processor unit
    - If they're both *plots*, call subroutines, to compose the plots together into a bigger figure
    - …
  - Python, R, and Matlab need to check the types of `x` and `y` *every time the line is run,* and then call the appropriate subroutines
    - Hence all these extra CPU instructions

  - Julia will ***infer*** the types of x and y
    - When? <u>The first time the function that contains our line of code is called</u>
    - It does this type inference based on the arguments that the function was called with (more specifically, their types), and by analyzing the function's source code you wrote
  - I then compiles a fast version of the function
    This is just-in-time (JIT) compilation

Data analysis in Julia

- DataFrames.jl
  - Tidyverse's dplyr & Python's Pandas equivalent
    - Better API than Pandas, imho
  - In the very capable hands of Bogumił Kamiński
    - Check out his tutorials: github.com/bkamins/Julia-DataFrames-Tutorial

- Work in Jupyter notebooks
  - Via IJulia.jl
  - Ju stands for Julia (r for R).

- `missing` datatype is built-in in Julia
  - distinct from `nothing`

- I plot using Python's matplotlib 😄
  - Via PyPlot.jl
  - There's also Makie.jl
  - ..and Gadfly.jl, which is ggplot-inspired

Example of working with a DataFrame containing missing values, in a Jupyter notebook
(loading data from Arrow, which is useful for data interchange with R or Python):

```
In [30]:  y = Arrow.Table("x.arrow") |> DataFrame
```

Out[30]: 3×4 DataFrame

Row	A	B	C	D
	Bool	Int64?	String?	Char?
1	true	1	*missing*	a
2	false	2	b	*missing*
3	true	*missing*	c	c

Source: https://github.com/bkamins/Julia-DataFrames-Tutorial/blob/master/04_loadsave.ipynb

Julia likes

- Unicode variable names & operators
  - Easy input of LaTeX & Unicode names:

```
julia> \partial<tab>
julia> ∂
```

  - Plus reverse lookup:

```
help?> δ
"δ" can be typed by \delta<tab>
```

  - Some code is read much more than it is written. There, readability counts!
  - For throwaway / exploratory code, not worth the slower input though
  - Real-life example from my own code:

```
izh() = begin
    # Conductance-based synaptic current
    I_syn = gₑ*(v-Eₑ) + gᵢ*(v-Eᵢ)
    # Izhikevich 2D system
    Δ.v = (k*(v-vₗ)*(v-vₜ) - u - I_syn) / C  # Membrane potential
    Δ.u = a*(b*(v-vᵣ) - u)                   # Adaptation current
    # Synaptic conductance decay
    Δ.gₑ = -gₑ / τ   # (gₑ is sum over all exc synapses)
    Δ.gᵢ = -gᵢ / τ
end
has_spiked() = (v ≥ vₛ)
on_self_spike() = begin
    v = vᵣ
    u += Δu
end
```

Compact operator :)

Julia likes

- Community
  - Discourse forum & Slack
  - Scientists
  - Contribute to ecosystem (open source, build upon others)
- As close-to-the-metal as you like
  - Look under the hood. Understand why something is slow/fast, and how it works
- “data structures + functions” design style
  - Decoupling is good
  - Versus: when you’re designing software in Python, you’re often pushed towards a coupled OOP design, with inheritance
- Keyword argument syntax sugar:
  - ```
    options = [some object]
    simulate(x, options = options)  # Python
    simulate(x; options)            # Julia
    ```
- Inspectability
  - `@edit` to jump to source code of anything… amazing
  - `@code_native` to see cpu instructions
  - `?` for documentation
- Dependency management
  - Single, ergonomic tool (↔ Python)
    - Pkg.jl, with `]` REPL mode
  - Easy **reproducibility** via thin environments
    - Project.toml & Manifest.toml
  - Not just for Julia code, for e.g. data too!
    - Artifacts.jl, DataDeps.jl
    - And for binaries: Yggdrasil & BinaryBuilder.jl
- Macro’s
  - Lisp-like. ‘Code as data’
    ```

Julia annoyances

- **Package startup time** 💀 (“time-to-first-plot”)
  - Language developers are working hard this year to improve this
- No winning plotting package yet
- \`name.<tab>\` autocompletion (API discovery) not as good as Python
  - “Power of the dot” in OOP languages
- Getting floats to print with lower precision is way more difficult than it should be for new users
- Traits / interfaces (lack of)
- Error handling is underdeveloped / under-practiced (“→ silent fails & crashes”)
- See also:
  - yuri.is/not-julia
  - danluu.com/julialang
  - viralinstruction.com/posts/badjulia

“Julia has a correctness problem”

- (i.e. *there’s nasty hidden bugs everywhere*)
- Not true for Base Julia:
  - every line there is pored over by many language developers
  - automatic test coverage is very comprehensive
- For other people’s packages:
  - Not a problem in my experience.
  - But you have to inspect the packages that you use, if they’re not in Julia Base; and make a value judgement about their quality
  - A lot of Julia packages are of *very* high quality in my experience
    - Except for the lack of error checking (of inputs and outputs)
      - Julia doesn’t hold your hand:
        you gotta know what you’re doing mathematically / numerically / statistically

Why did I switch to Julia?

- 🎄 [Advent of Code](https://adventofcode.com) :) (2021)
- Physical units in neuron simulations:
- I could keep using:
  - my Jupyter notebook workflow
  - my Matplotlib experience

```julia
parameters = (
    # Izhikevich neuron
    C  =  100     * pF
    k  =    0.7   * (nS/mV)
    vₗ  = - 60     * mV
    vₜ  = - 40     * mV
    a  =    0.03  / ms
    b  = -  2     * nS
    vₛ  =   35     * mV
    vᵣ  = - 50     * mV
    Δu =  100     * pA
    # Synapses
    Eₑ  =   0 * mV
    Eᵢ  = -80 * mV
    τ  =   7 * ms
    # Inputs
    Nₑ  = 40
    Nᵢ  = 10
    N = Nₑ + Nᵢ
    Δgₑ = 60nS / Nₑ
    Δgᵢ = 60nS / Nᵢ
    # Integration
    Δt = 0.1ms
    T  = 10seconds
)
```

julia Tips

- Code must be type-inferable ("type-stable")
  - Put everything in (small) functions
  - If using globals: `const`, or typed
- Read the manual
  - Especially the "Performance tips" section, if you're wondering why your code is not as fast as promised. Also:
- **Ask questions on the forum**
  - discourse.julialang.org
  - People are very eager to help, and the community managers do a great job
- Use Revise.jl (Use all of Tim Holy's packages actually).
  - This minizes nr. of times you have to restart the Julia session (re: time-to-first-X problem)
  - Plus:
  - If using VS Code, there's a plugin for Julia. Also: the JuliaMono font :) Example: ----------→
  - On Windows, use the Julia REPL in the Windows Terminal
  - Put commonly used snippets in your startup.jl
- Don't load unnecessary packages
  - Julia *Base* has no real latency (time-to-first-X) problem. It's loading many packages that gets you
    - Especially packages that have many dependencies themselves (looking at you SciML ecosystem :P)
  - Do you really need this package? Can you just implement it yourself / copy the relevant part?
- Learn by doing
  - Like by doing some Advent of Code puzzles!

```
# Code excerpt from the
# JuliaMono homepage.
# Original by Zygmunt Szpak
⊗ = kron
N = length(𝒟[1])
ℳ, ℳ′ = 𝒟
Λ₁, Λ₂ = 𝒞
𝐞₁ = @SMatrix [1.0; 0.0; 0.0]
𝐞₂ = @SMatrix [0.0; 1.0; 0.0]
for n = 1:N
    index = SVector(1,2)
    𝚲ₙ[1:2,1:2] .=  Λ₁[n][index,i
    𝚲ₙ[3:4,3:4] .=  Λ₂[n][index,i
    𝐦    = hom(ℳ[n])
    𝐦′   = hom(ℳ′[n])
    𝐔ₙ   = (𝐦 ⊗ 𝐦′)
    ∂ₓ𝐮ₙ = [(𝐞₁ ⊗ 𝐦′) (𝐞₂ ⊗ 𝐦′)
    𝐁ₙ   = ∂ₓ𝐮ₙ * 𝚲ₙ * ∂ₓ𝐮ₙ'
    𝚺ₙ   = 𝛉' * 𝐁ₙ * 𝛉
    𝚺ₙ⁻¹ = inv(𝚺ₙ)
    …
end
```

Should you use Julia?

- Do you ‘just’ need data analysis, automation, and pretty, customized plots?
  - Then, no

- Or do you also write custom numeric algorithms / simulations?
  - Then, yes :)
  - ..Unless you already know Matlab and don’t have the time
  - ..Plus, Python and R have huge ecosystems of packages that might already do your custom thing
    - A concrete example in computational neuroscience: **Brian** Python package for spiking neural network simulations (core written in C++)
    - Also, Python has **Numba** for JIT-optimization of hot inner loops (numba.pydata.org). That might be enough for your use case

Links

- “Seven Lines of Julia”: examples of Julia, in different applications.
    - “What cool thing can you do in seven lines of code?”

- tfiers.github.io/phd
    - made with JupyterBook
    - auto-built and -published with GitHub Actions on GitHub Pages

- github.com/schluppeck/ng-data-club
    - Repo of the Lunchtime data club

- Discussion of these slides on Julia Discourse
    - (woah meta)