Introduction to julia

Presentation and Workshop

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Overview

What is Julia?

Goal: Scientific Computing & Fast Prototyping

In scientific computing we need

- high performance to tackle large scale problems
  - $\Rightarrow$ compiled languages (C/C++, Rust)
  - all types are known at compile time
  - static, hence maybe missing flexibility

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Often: Fast code is written in C/C++ and is interfaced.

⇒ new users might have to compile the C/C++ (e.g. MEX files)

Combine both: Julia!

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A short history

2009 Adam Edelman starts the project with
Jeff Bezanson, Stefan Karpinski, Viral B. Shah

2012 first public version

2018 Julia 1.0, i.e. no breaking releases since then

2024 Julia 1.11

Resources

Main homepage https://julialang.org

Documentation https://docs.julialang.org/en/v1/

Modern Julia Workflows https://modernjuliaworkflows.org/

Discourse https://discourse.julialang.org

JuliaHub webfrontend for the General Registry
https://juliahub.com/ui/Packages

These slides
https://github.com/Julia-Users-Trondheim/Intro-to-Julia/blob/main/presentation/introduction-to-julia.pdf

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Installation & REPL

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Norwegian University of Science and Technology

Installation

Windows Install Julia from the Microsoft Store by running this in the command prompt

```
winget install julia -s msstore
```

Mac OS / Linux run the installer for example by

```
curl -fsSL https://install.julialang.org | sh
```

…or install `juliaup` via your favourite package manager

We can take a closer look at your individual installation after this presentation in the workshop.

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The Julia command line is called REPL.

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Quick commands

^ D Quit

^ L Clear console screen

Up Arrow last command

REPL modes

Starting with special characters on REPL enters specific modes

? help mode
quick access to the documentation of a function

Example:
`? sqrt` displays the help for the `sqrt` function on REPL, see also the (HTML) documentation
https://docs.julialang.org/en/v1/base/math/#Base.sqrt-Tuple{Number}

] package mode
quick access to manage packages

; shell mode
quick access to shell without exiting Julia,
e. g. to change folders

Main features

General philosophy & Code format

Philosophy

- Write functions not scripts
- Julia has data types, but not objects
- write generic code “acting” on data
- no need to write “vectorized code”
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Format

- blocks have an `end`
- Indentation with 4 spaces is recommended but not necessary
- functions that modify their data should be named with an `!`.

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A Package is a module (namespace) providing additional functionality.

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We will continue command demos in the Pluto notebook (similar to a Jupyter notebook, but with a persistent state)

Control flow I: for & while

Iterate with for-loops

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    print(i," ")
end # prints "1 2 3 4"
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Or through several of same length

```
for (i,j) ∈ zip(1:4, 5:8)
    print(i,"|",j," ")
end # prints 1|5 2|6 3|7 4|8
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```

or as a comprehension for vectors

```
x = [3*s for s ∈ 1:3 ]
```

creates `[3, 6, 9]`

Loops with “unknown end”

```
i = 1;
# do as long as i <= 4
while i <= 4
    print(i," ");
    i += 1
end # also prints "1 2 3 4"
```

Control flow II: Conditionals

Conditionals require an expression that evaluates to a `Bool`. Then

```
if (x > 3) || (z < 2) # brackets (x > 3) are optional
    print("x is at least 3")
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    print("x is 3 or less")
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Conditionals can be used inline with

```
y = (x > 4) ? 1 : 3*x
```

Defining functions

```
"""
    phase(z)

Compute the phase of a complex number z
"""
function phase(z)
    return atan(imag(z), real(z))
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- naming convention `snake_case`

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Shorter form

```
magnitude(z) = sqrt(imag(z)^2+real(z)^2)
```

More on functions I: positional & keyword args

- positional optional parameters: providing defaults

```
f(a, b=2, c=3) = a*exp(b/c)
f(1) #equals f(1,2,3)
f(1,3) #equals f(1,3,3)
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- You can "collect and pass on":
  - `h1(args...) = f(1, args...)`
  - `h2(; kwargs...) = g(1; kwargs...)`
  - or combine both as `h3(args...; kwargs...) = #def here`

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  ```
- functions can modify their input

  ```
  function add_scalar!(X, v)
      X .+= v  # X an array, v a scalar: add to every entry
      return X # the X we got passed is now changed
  end
  ```

  Convention: modifying function names end with `!`
  and return the modified variable.

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mutable struct TimeSeries2{T} <: ExperimentData
    param::T         # maybe some concentration
    data::Vector{T}  # actually parametrized by element-type
end # Constructor now maybe a bit clumsy:
ts2 = TimeSeries2{Float64}(3.1415, [1.2, 1.3])
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- makes the previous (implicit) `Vector{Any}` to a concrete type
- nicer constructor: Define a parametric function

```
function TimeSeries2(c::T, v::Vector{T}) where {T}
    return TimeSeries2{T}(c, v)
end # Then we have back
ts2 = TimeSeries2(3.1415, [1.2, 1.3])
```

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$\Rightarrow$ dispatch to “most fitting” method of a function

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end
function g(a::String, t::TimeSeries)
  TimeSeries("$(a) $(t.name)", t.data)
end
function g(a::Number, ts::TimeSeries2)
  TimeSeries2(a*t.param, a .* t)
end
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function g(a::Number, ts::TimeSeries2)
  TimeSeries2(a*t.param, a .* t)
end
```

Avoid ambiguities. Defining

```
g(a::Float64, b) = 2*a+b
g(a, b::Float64) = a+2*b
```

makes `g(1.0,2.0)` ambiguous.

Multiple Dispatch

Dispatch: "finding" the "best fitting version" of a function. For

```
f(x) = "A"
f(x::Number) = "B"
f(x::Float64) = "C"
```

We get that

```
f.(["a", 1, 1.0im, 2.0])
```

is

```
["A", "B", "B", "C"]
```

⇒ dispatch to "most fitting" method of a function

```
function g(a::Number, t::TimeSeries)
  TimeSeries(t.name, a .* t.data)
end
function g(a::String, t::TimeSeries)
  TimeSeries("$(a) $(t.name)", t.data)
end
function g(a::Number, ts::TimeSeries2)
  TimeSeries2(a*t.param, a .* t)
end
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Operators are Functions

Operators like +, *, ^ are functions. Add a method to + via

```
function Base.:+(t::TimeSeries, s::TimeSeries)
    if !(length(t.data)==length(s.data))
        error("Time series not of same length")
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returns `TimeSeries("A and B", [4, 6])`.

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returns `TimeSeries("A and B", [4, 6])`.

To ensure same type parameter, define a function with

```
Base.:+(t::TimeSeries2{T}, s::TimeSeries2{T}) where {T}
```

Functors: function-like structures

Consider (actually taken from the Julia documentation)

```
struct Polynomial{R}
    coeffs::Vector{R}
end
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We can turn a `Polynomial` into a function as well definiing

```julia
function (p::Polynomial)(x)
    v = p.coeffs[end] # Horner Schema, (a_2x + a_1)x + a_0
    for i = (length(p.coeffs)-1):-1:1
        v = v*x + p.coeffs[i]
    end
    return v
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For `p = Polynomial([1, 10, 100]); p(3)` we get
$100 \cdot 3^2 + 10 \cdot 3 + 1 = 931$

TLDR: Main differences to Python

- `for`, `if`, `while` etc. blocks are terminated by `end`
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- Julia is 1-indexed
- Strings have single `"quotation marks"`, multiline strings three

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- Matrix multiplication is `A * B`, element wise multiplication `A .* B`
- Julia has no objects/classes

TLDR: Main differences to R

- `'single'` quotation marks are for characters
- vectors are constructed with square brackets `v = [1,2,3]`
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- matrix multiplication is just `A * B`
- function arguments are not copied when calling a function
- `1:5` is an `AbstractRange`, use `collect(1:5)` to create the vector
- you do not need vectorization for performance
- logical indexing: in R `x[x>3]` has two alternatives in Julia
  - `x[ x .> 3]` (uses a temporary vector memory)
  - `filter(z->z>3, x)` might be nicer to read
  - `filter!(z->z>3, x)` updates `x` inplace (avoids the temporary memory)

TLDR: Main differences to Matlab

- array indexing uses square brackets `A[i,j]`
- Arrays are not copied by default `A=B` references the same, do `A=copy(B)` for an actual copy
- *similarly* function arguments are references, input variables can be modified
- 1-dimensional vectors exist and are not `Nx1` matrices
- `42` is an integer, not a float, use `42.0` for the float.
- `A == B` does not return a matrix of booleans but `true` or `false`
  use `A .== B` to get such a matrix
- dimensions are not “constant-broadcasted”:
  - `[1:10] + [1:10]'` creates a 10×10 matrix in Matlab
  - `[1:10] + [1:10]'` is a dimension mismatch,
    because a column vector can not be added to a row vector

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Packages

Namespaces & Modules

```
module MyModule #Same naming convention as types: CamelCase
    f(x) = x^2          # is exported
    struct MyField end # is not exported
    export f
end
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- Default packages are among others `Base` (loaded on start) `LinearAlgebra`, `Random`, `Statistics`, ...

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After a package is installed, it can be used with

```
using PackageName, PackageA, PackageB,
```

Package environments

- in package mode: `(@v1.11) pkg>` refers to current environment: by default the global one
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⇒ **Reproducible** environment / setup to run your experiments in

Pluto Notebooks

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plutojl.org

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- Live-docs – display the documentation of current function
- similar to Mathematica or Jupyter notebooks

On terminal `using Pluto; Pluto.run();` to start the webserver.

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  - ⊕ all cells always reflect the current global state of code
  - ⇒ you never have to remember to “execute cells in right order”

Live Demo

Further topics

- further default data structures
  - `Dict` dictionaries
  - `NamedTuple`s as “lightweight, flexible” struct
  - `IO` reading/writing files
  - further packages from the Standard Library
- `@macro`s – rewriting code
- VS Code extension & the debugger
- specific packages for your concrete problems
- `Test.jl` and running tests on your own package
- `Documenter.jl` and creating a documentation for your own package
- package extensions and weak dependencies

Thanks for your attention!

Are there (further) questions?

Workshop: Let’s get you started with Julia!