Mini course: Julia

Lecture 1: Introduction

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Why does Julia exist?

Key Points

1. Low-level languages are fast, but high level languages are readable.
2. Recent advances in compiler design could bridge these two aspects.
3. Julia is being openly developed by researchers, for researchers.

The old mission statement is available here and some good discussion is available at here.

My personal reason

A fast, open-source, high level language that is powerful enough to do serious numerical work, while being designed to encourage good code.

The other contenders

The typical languages used in science are

1. Python
2. Matlab
3. R

Once a problem is becoming to big we usually move to

1. C/C++
2. Fortran

This is called the 2+ language problem and Julia is trying to solve that.

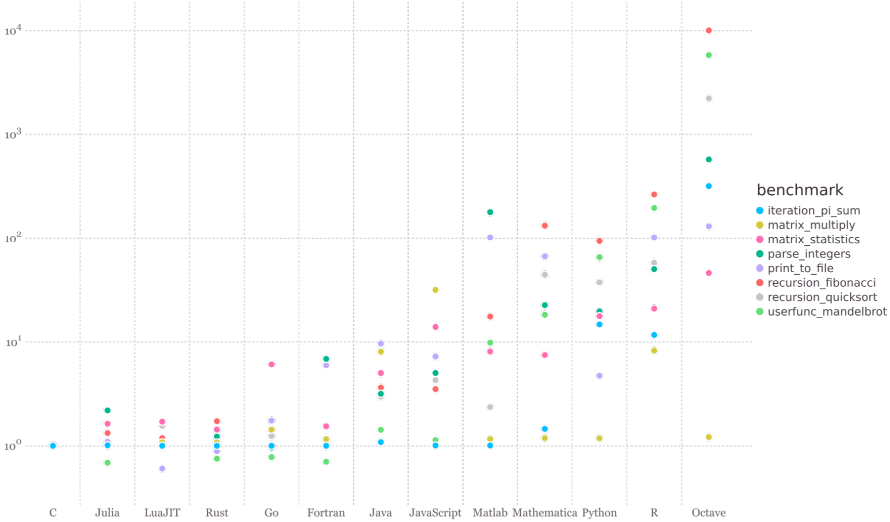
Python and Numpy

- The compilers that exist (Numba) only work on primitive types and not user defined ones.
- GIL (Global Interpreter Lock) mask multi-threading hard.
- For fast code you need to write it in C.
- Numpy is great, but awful syntax for math.

Matlab

- It costs a lot of money and is not open-source.
- Matlab will only be fast for a subset of operations.
- Matlab tends to hide the computer from the programmer.

A (biased) performance comparison



The REPL

The Read-Eval-Print-Loop

The REPL is a command-line interface to Julia and is ideal for short experiments.

```
               _
   _       _ _(_)_     |  Documentation: https://docs.julialang.org
  (_)     | (_) (_)    |
   _ _   _| |_  __ _   |  Type "?" for help, "]?" for Pkg help.
  | | | | | | |/ _` |  |
  | | |_| | | | (_| |  |  Version 1.5.3 (2020-11-09)
 _/ |\__'_|_|_|\__'_|  |  Official https://julialang.org/ release
|__/                   |

julia>
```

In the `REPL` you can use `?` to switch your `REPL` mode into help mode and get information about functions.

IDEs

There are two main IDEs that are *feature* complete and can be used for Julia. The main one is based on Atom and is called Juno `http://junolab.org/`.

The second one is based on on Visual Studio Code and available at `https://marketplace.visualstudio.com/items?itemName=julialang.language-julia`.

We will not be using these during the course, but you are welcome to try them out

Jupyter is an interactive web-based client for Python, Julia, R and many other languages. It offers a programming environment that is well suited for explorative data analysis or prototyping.

Installation

```
julia> ENV["JUPYTER"] = ""
julia> ] add IJulia
```

Starting a Jupyter session

```
julia> using IJulia
julia> notebook()
```

JuliaBox

There is an online service provided by JuliaComputing at `https://juliabox.com` that gives you a cloud version of Jupyter.

Variables and datatypes

Julia is a dynamic language and so you can create variables in any scope.

```julia
x = 1   # x will be of type Int64
y = 1.0 # y will be of type Float64
z = 1.0 - 2.0im # z will be an Complex{Float64}
1//2 # Rational numbers
"This is a String"
"""
This is a multiline
String
"""
'C' # Character literal
1.0f0 # Float32 literal
#=
This is a multiline comment
=#
```

Use `typeof(x)` to check the type of any variable `x`.

Variables and datatypes

Variable names can be unicode and so greek symbols can be used. In the REPL and most editors you can insert them by entering their LaTeXname and press[Tab].

Exercise

Create a variable λ that stores the value of π. Check the type of λ. Look up the docs for the convert function. Convert λ to float.

Solution

```
# \lambda + <tab> = \pi + <tab>
lambda = pi
typeof(lambda)
?convert
convert(Float32, lambda)
```

Data structures

```julia
# Tuple: (item1, item2, ...)
okinawa = ("Onna", "Nago", "Naha")
okinawa[1]

# NamedTuple: (name1 = item1, name2 = item2, ...)
okinawa = (central = "Onna", north = "Nago", south = "Naha")
okinawa.north

# Dictionaries: Dict(key1 => value1, key2 => value2, ...)
password = Dict("Jeremie" => "12345", "Juan" => nothing)
password["Juan"] = "4444"

# Arrays: [item1, item2, ...]
fibonacci = [1, 1, "two", 3, "five", 8, 13]
fibonacci[3] = 2
```

Julia is 1-based indexing, not 0-based like Python!!!

You can add or remove elements using `push!` and `pop!`.

Conditionals

Julia has all the typical conditionals `if`, `else`, `elseif` which have to end in an `end`. Blocks in Julia are not whitespace sensitive and conditionals do not need to be wrapped in round brackets.

```julia
if rand() < 0.5
  println("Gaston is awesome!")
elseif rand() >= 0.5
  println("Jeremie is awesome!")
else
  println("Juan is awesome!")
end

# Ternary operator: a ? b : c
rand() < 0.5 ? println("Gaston  is awesome!") : println("Juan
     is awesome!")
```

&& is the and operator, || is the or operator.

Exercise

Print an error message if a variable `x` is greater than zero

Solution

```
if (x > 0) error("x cannot be greater than 0") end

# Ternary operator
x > 0 ? error("x cannot be greater than 0") : nothing

# Short-circuit evaluation
(x > 0) && error("x cannot be greater than 0")
```

Loops

Julia has `for` and `while` loops. A `while` loop takes a condition and a `for` loop takes an iterator. One can use `break` to break out of a loop and `continue` to skip to the next iteration.

```julia
for (i, x) in enumerate(['A', 'B', 'C'])
  if x == 'B'
    continue
  end
  println(i)
end

while true
  rand() < 0.1 ? break : println("You are trapped!")
end
```

Exercise

Create a dictionary that holds integers (up to the value 100) and their squares as key, value pairs.

Solution

```julia
squares = Dict()
for i in 1:100
  squares[i] = i^2
end
println(squares)

# Array comprehension
squares_array = [i^2 for i in 1:100]
```

Functions and lambdas

Julia uses functions to organize operations. Every function is compiled for the combination of input parameters.

```
function f(x, y)
  return x + y
end

g(x) = x^2
h = x -> 1/x

# map takes a function as input and applies that function to
    every element of the data structure you pass it.
map(lowercase, ['A', 'B', 'C'])
map(x->x+2, [1, 2, 3])
```

By convention, functions followed by ! alter their contents and functions lacking ! do not, e.g. `sort()` vs. `sort!()`.

The `::` operator annotates the type of variables. For example, `x::Int8` means that the value of `x` is an instance of `Int8`. There are abstract types (`Integer`, `Number`) and concrete types (`Int8`, `Float64`) and their relationships form a type graph.

In Julia a function is a set of multiple methods. Each method is defined for particular argument types and comes with its own implementation. When you call a function the most specific method is executed (dispatched).

```
h(x::Number) = println("x is most definitly a number.")

h(x::Integer) = println("x is an integer")

h(x::Int8) = println("Specific method for Int8")
```

Multiple dispatch makes your code generic and fast!

You can create your own types using `struct`.

```
abstract type Coordinate end

mutable struct Cartesian <: Coordinate
  position::Tuple{Float64, Float64}
end

struct Polar <: Coordinate
  radius::Float64
  phi::Real
end

point = Polar(1,pi)
point.radius
```

Keep in mind: Julia is not an Object-Oriented programming language so functions do not belong to an object!

Exercise

Create a struct `Point` with two field names `x,y` both being of type Real. Implement a function `add` that takes two arguments of type `Point` and returns the sum of their x's and the difference of their y's.

Solution

```
struct Point
  x::Real
  y::Real
end

function add(arg1::Point, arg2::Point)
  return arg1.x + arg2.x, arg1.y - arg2.y
end
```

```julia
# Specifying a return type will convert the returned value
g(x, y)::Int8 = x * y

# Varargs functions (variable number of arguments functions)
h(a,b,x...) = (a,b,x)

# Optional arguments
f(x, y=1, z::Int64=2) = x + y + z

# Keyword arguments (seperated by a semicolon)
g(x, y; a=2, b::String="hallo") = x+y+a, b
```

Everything above can be combined arbitrarily, e.g. keyword arguments can be collected using ...

Running julia scripts

There are mainly two different ways to run your julia scripts:

```
# in your command prompt or terminal
julia script.jl

# inside the REPL
include("script.jl")
```

Working from the `REPL` is preferred since all methods inside the script are compiled the first time and stay available as long as the session is not closed.

Try to break your programs down into lots of small specialized functions to really take advantage of the julia compiler and its speed-up.

Modules

If your julia files are becoming too large, organize them into modules (namespaces). Module names are capitalised and you can also nest them.

```
module MyModule
  export f

  g() = "Internal function"
  f() = println(g())
end

# inside the REPL
include("MyModule.jl")

# Loading the module in a different file
using Main.MyModule
```

Additional advantage: Modules can be precompiled and saved to hard-drive which means precompiled code won't disappear when closing the REPL.

Installing packages

Julia has an inbuilt package manager called `Pkg`. You can access it from the `REPL` by entering `]`. For example, to install and load the Julia package `Distributions.jl` in the `REPL` just run:

```
# Installing a package
] add Distributions
# Loading it afterwards
using Distributions
```

A few other commands:

```
# Updating all installed packages
] update
# What packages are installed?
] status
```

Look here for more information about Julia packages.

Documentation	`https://docs.julialang.org/en/v1.5/`
Forum	`https://discourse.julialang.org`
GitHub	`https://github.com/JuliaLang/julia`
Slack	`https://julialang.org/slack/`
YouTube	`https://www.youtube.com/user/JuliaLanguage`
Learning	`https://julialang.org/learning/`

OIST also has a Slack workspace: julia@oist

What is next?

Question?!

What do you want to hear/learn more about?

Wednesday	How to use Julia for computation and plotting
Friday	Problem sets and ???

Exercise: Calculate π

Pseudocode

1. For each of N iterations
    1. Select a random point inside a square of area $4r^2$ as Cartesian, (x, y), coordinates. (You can choose $r = 1$ for simplicity.)
    2. Determine if the point also falls inside the circle embedded within this square of area πr^2.
    3. Keep track of whether or not this point fell inside the circle. At the end of N iterations, you want to know M – the number of the N random points that fell inside the circle!
2. Calculate π as $4\frac{M}{N}$

Solution

```julia
function calculate_pi(N::Integer = 1000)
  M = 0
  for i in 1:N
    x = 1-2*rand()
    y = 1-2*rand()
    # Check if the distance to (x, y) from (0, 0) is less than
        the radius of 1
    if x^2 + y^2 < 1
      M += 1
    end
  end
  return 4 * M / N
end

map(calculate_pi, [10, 100, 1000, 10000, 100000])
```