A Journey Through Julia

A DYNAMIC AND FAST LANGUAGE

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Actually, Julia solves the two-language problem: no need for one nice language (such as Python or R) and one fast language (like C or Fortran). The whole code can be written in the same language.

Compilation: unlike C or C++ or Fortran... or MATLAB’s MEX.
Can reach performance of C or Fortran code!
Performance relative to C.

OK, that is becoming old (Julia 0.6 is being released).
How to install Julia?

- Website: http://julialang.org/

- IDEs?
  - Juno: Atom with Julia extensions
  - Install Atom: https://atom.io/
  - Install Juno: in Atom, File > Settings > Install, search for uber-juno
  - JuliaDT: Eclipse with Julia extensions

- Also: JuliaPro, a Julia distribution “with batteries included”

- Notebook environment?
  - IJulia (think IPython)
Notebook environment

- The default console is not the sexiest interface
  - The community provides better ones!

- **Purely online**, free: JuliaBox
  - [https://juliabox.com/](https://juliabox.com/)

- Offline, based on Jupyter (still in the browser): IJulia
  - Install with:
    - `julia> Pkg.add("IJulia")`
  - Run with:
    - `julia> using IJulia; notebook()`
Contents of this presentation

• Basic syntax
• Core concepts
• Julia community
  ◦ Plotting
  ◦ Image processing
  ◦ Mathematical optimisation
  ◦ Data science
• Parallel computing
  ◦ Message passing (MPI-like)
  ◦ Multithreading (OpenMP-like)
  ◦ GPUs
• Concluding words
Julia’s syntax is quite intuitive: very similar to that of MATLAB. For those who come from other languages: mostly, blocks start with a keyword and end with end.

If you need a syntax help: http://cheatsheets.quantecon.org/
A small taste of Julia

```julia
# Solves $\theta = ax^2 + bx + c$ for $x$
function quad(a::Float64, b::Float64, c::Float64)
    discriminant = b^2 - 4a * c
    r1 = (-b + sqrt(discriminant)) / 2a
    r2 = (-b - sqrt(discriminant)) / 2a
    println(r1, r2)
end
```

Particular parts of the syntax:
- Typing not necessary for variables or arguments, but still very useful!
- Can do products by a constant without operator: code more readable
- Automatically returns the last expression
- Can return more than one value for a function
The most important points when trying to better exploit the language.
How can Julia be fast?
What makes Julia dynamic?

- Dynamic type system with type inference
  - Multiple dispatch (see later)
  - But static typing is preferable for performance

- Macros to generate code on the fly
  - See later

- Garbage collection
  - Automatic memory management
  - No destructors, memory freeing

- Shell (REPL)
Function overloading

• A function may have multiple implementations, depending on its arguments
  • One version specialised for integers
  • One version specialised for floats
  • Etc.

• In Julia parlance:
  • A function is just a name (for example, +)
  • A method is a “behaviour” for the function that may depend on the types of its arguments
    • +(:Int, :Int)
    • +(::Float32, ::Float64)
    • +(::Number, ::Number)
    • +(x, y)

Integers, floating-point numbers, generic numbers (any kind of number), and... no type (if no other method applies).
Virtual methods: dynamic dispatch is made on the object, not the other arguments (i.e. the type of *this).

Example: the standard implementation will be used, unfortunately (due to static dispatch).
Julia is as specific as possible: it uses the most precise method for the arguments at hand. Here, for a diagonal matrix, no way to use the first method. But if a sparse matrix is defined and comes with no such + function, then Julia will have to rely on the first method.
If a variable can change type in a function, then Julia must use multiple dispatch at each operation.

JIT can choose the right method to call, instead of relying on multiple dispatch at run time. Hence: multiple dispatch performed at JIT time.
Object-oriented code?

- Usual syntax makes little sense for mathematical operations
  - `+(::Int, ::Float64)` belongs to Int or Float64?
- Hence: syntax very similar to that of C
  - `f(a, args)` instead of `o.f(args)`

- However, Julia has:
  - A type hierarchy, including abstract types
  - Constructors
Real macros

- C-like macros are limited
  - Only text replacement

- Julia macros: can rewrite code!
  - Function that takes code in argument and outputs code

- Basic example:
  ```julia
  julia> @show sqrt(complex(-1.0))
  sqrt(complex(-1.0)) = 0.0 + 1.0im
  0.0 + 1.0im
  ```
Details for the packages needed for this: http://docs.juliadiffeq.org/stable/tutorials/ode_example.html#Defining-Systems-of-Equations-Using-ParameterizedFunctions.jl-1
Community and packages

Julia has a truckload of packages, and that is a great selling point for the language: its community.
A vibrant community

- Julia has a large community with many extension packages available:
  - For plotting: Plots.jl, Gadfly, Winston, etc.
  - For graphs: Graphs.jl, LightGraph.jl, Graft.jl, etc.
  - For statistics: DataFrames.jl, Distributions.jl, TimeSeries.jl, etc.
  - For machine learning: JuliaML, ScikitLearn.jl, etc.
  - For Web development: Mux.jl, Escher.jl, WebSockets.jl, etc.
  - For mathematical optimisation: JuMP.jl, Convex.jl, Optim.jl, etc.

- A list of all registered packages: [http://pkg.julialang.org/](http://pkg.julialang.org/)

Package directory: list many existing packages (not all, often due to development in progress).
Directly used for the package manager.
Other interest groups:
- JuliaGPU, BioJulia, JuliaAstro, etc.
For scientific applications, plots are a must-have to graphically represent data, an algorithm’s behaviour, etc. Julia has quite a few native rendering engines, but also packages that allow using existing plotting engines (such as Matplotlib or GR). It also has one common interface for those many plotting engine, which is the topic now.
Quit PowerPoint, move on to Ijulia, show how the plots integrate into the interface.

- **Creating plots: Plots.jl**
  - Plots.jl: an interface to multiple plotting engines (e.g. GR or matplotlib)
  - Install the interface and one plotting engine (GR is fast):
    ```julia
    julia> Pkg.add("Plots")
    julia> Pkg.add("GR")
    julia> using Plots
    ```
  - Documentation: [https://juliaplots.github.io/](https://juliaplots.github.io/)
Basic plots

• Basic plot:
\[
\text{Julia}\texttt{> plot(1:5, sin(1:5))}
\]

• Plotting a mathematical function:
\[
\text{Julia}\texttt{> plot(sin, 1:1:5)}
\]
More plots

- Scatter plot: `julia> scatter(rand(1000))`
- Histogram: `julia> histogram(rand(1000), nbins=20)`
Albeit made for scientific computations, Julia is also open to the Web. Lightweight Web frameworks, Web servers... and frameworks to build Web UIs.
Basic processing: Images.jl and family

- Part of the JuliaImages organisation
- MATLAB-like interface, with many features:
  - Filtering: ImageFiltering
  - Feature extraction: ImageFeatures
  - Not full yet

- A repository of test images: TestImages
- Standalone visualisation (outside IJulia): ImageView
Show and process an image

using Images, TestImages, ImageView, ImageFiltering

img = testimage("mandrill")
imshow(img)

imgg = imfilter(img, Kernel.gaussian(3))
imshow(imgg)
Albeit made for scientific computations, Julia is also open to the Web. Lightweight Web frameworks, Web servers... and frameworks to build Web UIs.
Web applications: Escher.jl

- Escher is a Web application framework
  - No need to use of HTML or anything: pure Julia
  - Based on the concept of tiles

- Predefined tiles:
  - Text (including Markdown and LaTeX)
  - Plots
  - Layouts (including tabs and pages)

- Main use case: provide a Web UI for a scientific application
- Similar to R’s Shiny

Install and run Escher’s server

- Escher comes with an integrated Web server

- Install Escher:
  ```
  julia> Pkg.add("Escher")
  ```

- Run the Web server:
  ```
  julia> using Escher
  julia> include(Pkg.dir("Escher", "src", "cli", "serve.jl"))
  julia> cd(Pkg.dir("Escher", "examples"))
  julia> escher_server()
  ```
  - Here: started from within the examples
  - Example: [http://127.0.0.1:5555/user-guide](http://127.0.0.1:5555/user-guide)

- Note: for Julia 0.5, you must check out the last version:
  ```
  julia> Pkg.checkout("Escher")
  ```
Quite large community in optimisation. Multiple modelling layers, some optimisation solvers written in Julia (Optim.jl, Pajarito.jl), links to most existing solvers.
Transition:
Quite specific topic, yes. But example of one selling point of Julia: macros. Look at the @ signs in the code!
Without these macros, the code makes little sense (x >= 0 when x has not yet been defined!?). However, with the macros, Julia does not directly evaluate the code: rather, JuMP rewrites it.
Can a generic mechanism be close to a specific compiler? AMPL: dedicated programming language for optimisation, with specifically optimised compiler; it ought to be very fast.
Python has no macros, so Pyomo can only rely on function calls. And this is very slow.
Data science

Julia is also made for data treatment and machine learning, with packages inspired by R and Python.
Data frames: DataFrames.jl

- R has the data frame type: an array with named columns
  \[
  df = DataFrame(N=1:3, colour=['"b", "w", "b"])
  \]

- Easy to retrieve information in each dimension:
  \[
  df[:, :colour]
  df[1, :]
  \]

- The package has good support in the ecosystem
  - Easy to plot with Plots.jl: Just install StatPlots.jl, it just works
  - Understood by machine learning packages, etc.
Another example of DSL embedded within Julia, which makes queries really simple.
JuliaML: set of comprehensive packages containing many loss and penalty functions, data transformations, plotting, etc.
ScikitLearn: port of the Python library
For scientific computations... and big data (to name a few), parallel is needed: must solve very large problems, deal with enormous quantities of data. Multiple paradigms so far: multithreading (cores of a machine), message passing (multiple machines), accelerators (GPUs). All three are currently supported within Julia.
Message passing

- Multiple machines (or processes) communicate over the network
  - For scientific computing: like MPI
  - For big data: like Hadoop (close to message passing)

- The Julia way?
  - Similar to MPI... but useable
  - Only one side manages the communication
Note: can also be used with clusters, of course. Example of Slurm script:

```
#!/bin/bash
#SBATCH --job-name="juliaTest"
#SBATCH --output="juliaTest.%j.%N.out"
#SBATCH --partition=compute
#SBATCH --nodes=8
#SBATCH --export=ALL
#SBATCH --ntasks-per-node=24
#SBATCH -t 01:00:00
export SLURM_NODEFILE=`generate_pbs_nodefile`
./julia --machinefile $SLURM_NODEFILE test.jl
```
Message passing: reductions

- Hadoop uses the map-reduce paradigm
- Julia has it too!

- Example: flip a coin multiple times and count heads

```julia
nheads = @parallel (+) for i in 1:500
    Int(rand(Bool))
end
```
Multithreading

- New (and experimental) with Julia 0.5: multithreading
- Current API (not set in stone):
  - `@Threads.threads before a loop`
  - As simple as MATLAB’s parfor or OpenMP!

- Add the environment variable `JULIA_NUM_THREADS` before starting Julia

Should be finalised with Julia 1.0.
Still experimental API, though.

Multithreading

```ruby
array = zeros(20)
@Threads.threads for i in 1:20
    array[i] = Threads.threadid()
end
```
High-end CPUs: up to 22 cores, with a price similar to a high-end GPU (for example, http://wccftech.com/intel-xeon-e5-2699a-v4-skylake-ep-2017-launch/). Architecture differences: GPU cores are grouped in streaming multiprocessors/compute units. All cores within this group perform the same instruction on different data.

Operations rewriting? A*x+b: not performed as c=A*b then d=c+b, but directly as A*b+c (using the corresponding kernel).
GPU computing

- Installation:
  - First install the ArrayFire library:
  - Then install the Julia wrapper:
    ```
    Pkg.add("ArrayFire")
    ```
  - Load it:
    ```
    using ArrayFire
    ```
GPU computing

• Ensure the OpenCL backend is used (or CUDA, or CPU):
  ```julia
  setBackend(AF_BACKEND_OPENCL)
  ```

• Send an array on the GPU:
  ```julia
  a_cpu = rand(Float32, 10, 10);
  a_gpu = AFArray(a_cpu);
  b_gpu = AFArray(rand(Float32, 10, 10));
  ```

• Then work on it as any Julia array:
  ```julia
  c_gpu = a_gpu + b_gpu;
  ```

• Finally, retrieve the results:
  ```julia
  c_cpu = Array(c_gpu);
  ```
Concluding remarks

Here: mainly libraries around Julia (except for parallel programming). The goal is to keep the core language sleek, and to rely on packages for functionalities.

Ask the audience: What do you think of Julia?
And so... shall I use Julia?

- First drawback of Julia: no completely stable version yet
  - Syntax can still change (but not a lot)
  - Also for packages: nothing is really 100% stable

- Quite young: appeared in 2012
  - 0.5 in September 2016 (original plans: June 2016)
  - 0.6 in January 2017 (original plans: September 2016), 1.0 just after

- ... but likely to survive!
  - Enterprise backing the project: JuliaComputing
  - 7 books about Julia (5 in 2016)

- Not ready for production... yet

Julia 0.6 feature freeze: end of 2016. Unlikely to be on time.