Introduction to Julia Programming Language

Jian Tao

jtao@tamu.edu

Fall 2018 HPRC Short Course

09/21/2018

Julia - What and Why?

Julia is a high-level general-purpose dynamic programming language primarily designed for high-performance numerical analysis and computational science.

- Born in MIT's Computer Science and Artificial Intelligence Lab in 2009
- Combined the best features of Ruby, MatLab, C, Python, R, and others
- First release in 2012
- Latest stable release v 1.0 in Aug 2018
- https://julialang.org/
- customized for "greedy, unreasonable, demanding programmers".

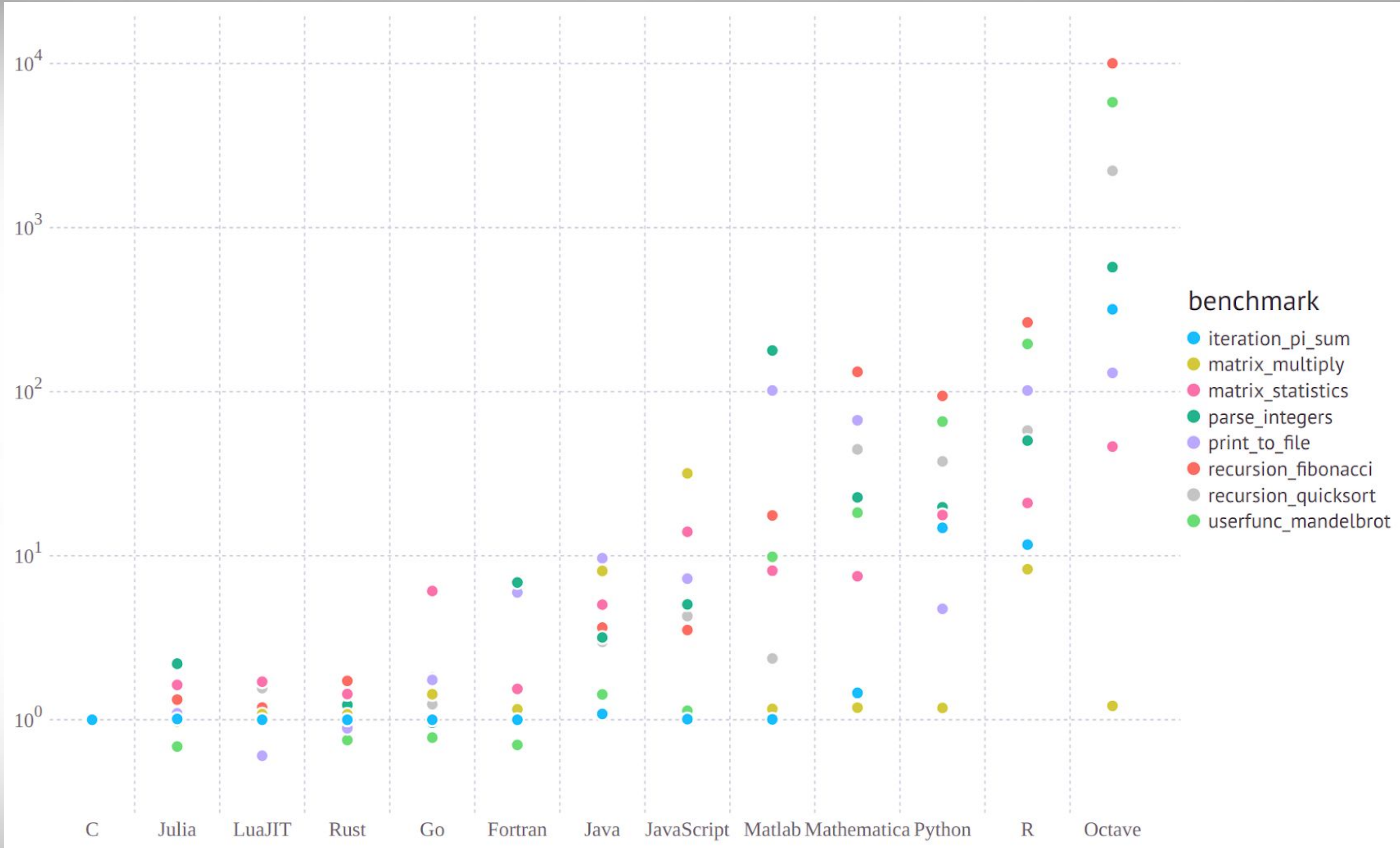


Image Credit: Julialang.org

Julia is a free and open source project, with

- more than 700 active open source contributors,
- 1,900 registered packages,
- 41,000 GitHub stars,
- 2 million downloads,
- used at more than 700 universities and research institutions,
- used at companies such as Aviva, BlackRock, Capital One, and Netflix.

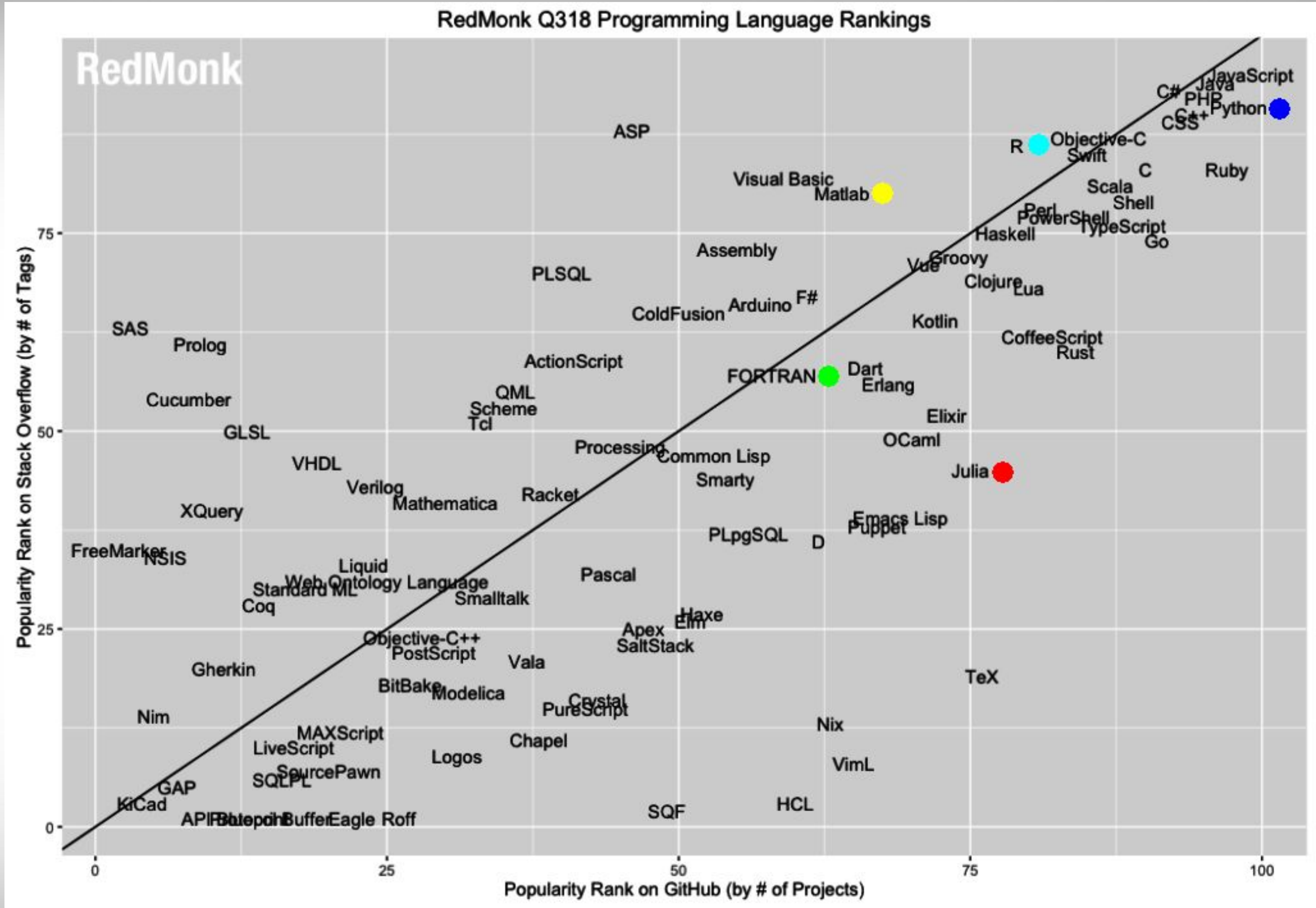


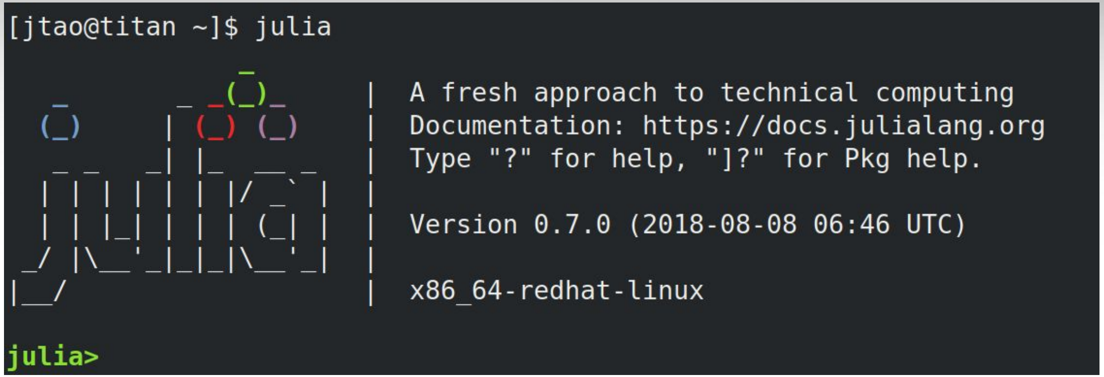
Image Credit: RedMonk (https://redmonk.com/sogrady/2018/08/10/language-rankings-6-18/)

Major features of **Julia:**

- **Fast**: designed for high performance,
- **General**: supporting different programming patterns,
- **Dynamic**: dynamically-typed with good support for interactive use,
- **Technical**: efficient numerical computing with a math-friendly syntax,
- **Optionally typed**: a rich language of descriptive data types,
- **Composable**: Julia's packages naturally work well together.

"Julia is as programmable as Python while it is as fast as Fortran for number crunching. It is like Python on steroids."
--an anonymous Julia user on the first impression of Julia.

Julia REPL



- Julia comes with a full-featured interactive command-line REPL (read-eval-print loop) built into the Julia executable.
- In addition to allowing quick and easy evaluation of Julia statements, it has a searchable history, tab-completion, many helpful keybindings, and dedicated help and shell modes.

Julia - Quickstart

The julia program starts the interactive **REPL**. You will be immediately switched to the **shell mode** if you type a **semicolon**. A **question mark** will switch you to the **help mode**. The **<TAB>** key can help with autocompletion.

```
julia> versioninfo()
julia> VERSION
```

Special symbols can be typed with the **escape symbol and <TAB>**

```
julia> \sqrt <TAB>
julia> for i ∈ 1:10 println(i) end  #\in <TAB>
```

Julia REPL Keybindings

Keybinding	Descrition
^D	Exit (when buffer is empty)
^C	Interrupt or cancel
^L	Clear console screen
Return/Enter, ^J	New line, executing if it is complete
? or ;	Enter help or shell mode (when at start of a line)
^R, ^S	Incremental history search

Juno IDE

- Juno is an Integrated Development Environment (IDE) for the Julia language.
- Juno is built on Atom, a text editor provided by Github.

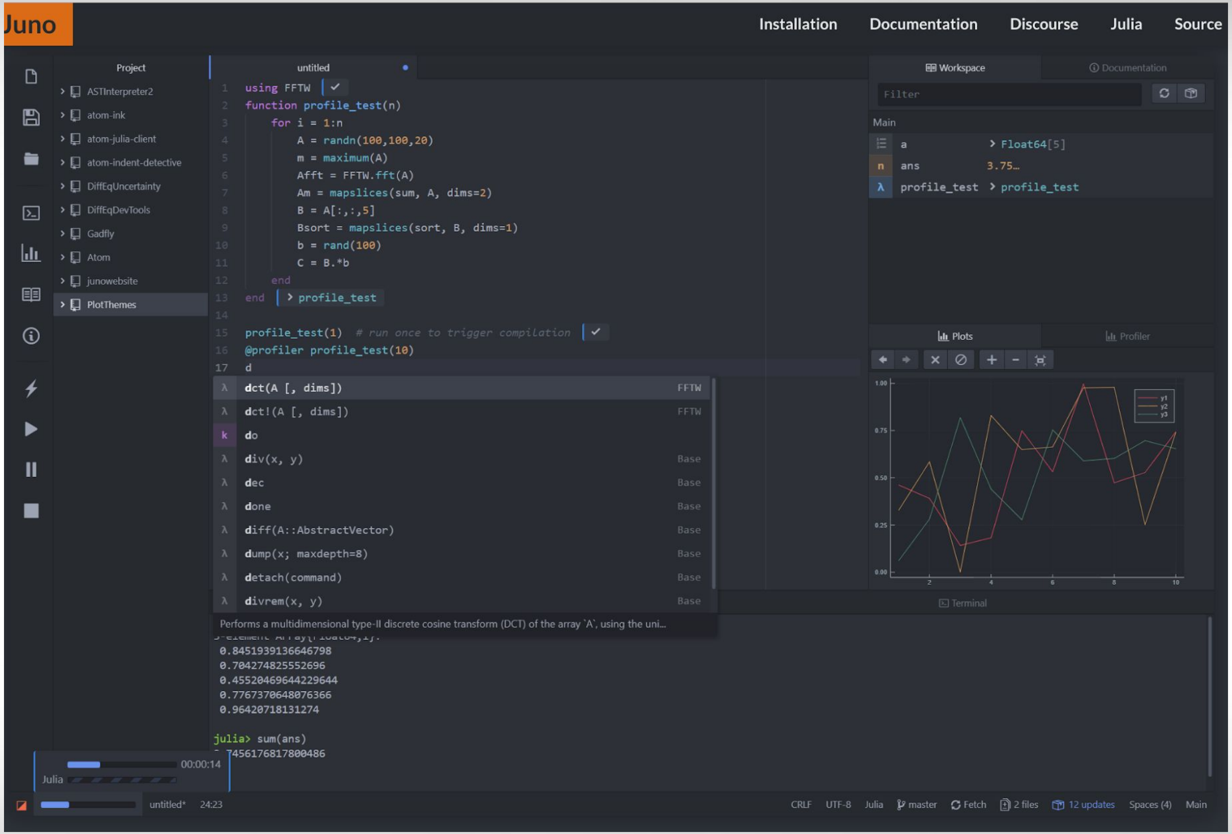


Image Credit: Juno (http://junolab.org/)

Jupyter Notebook

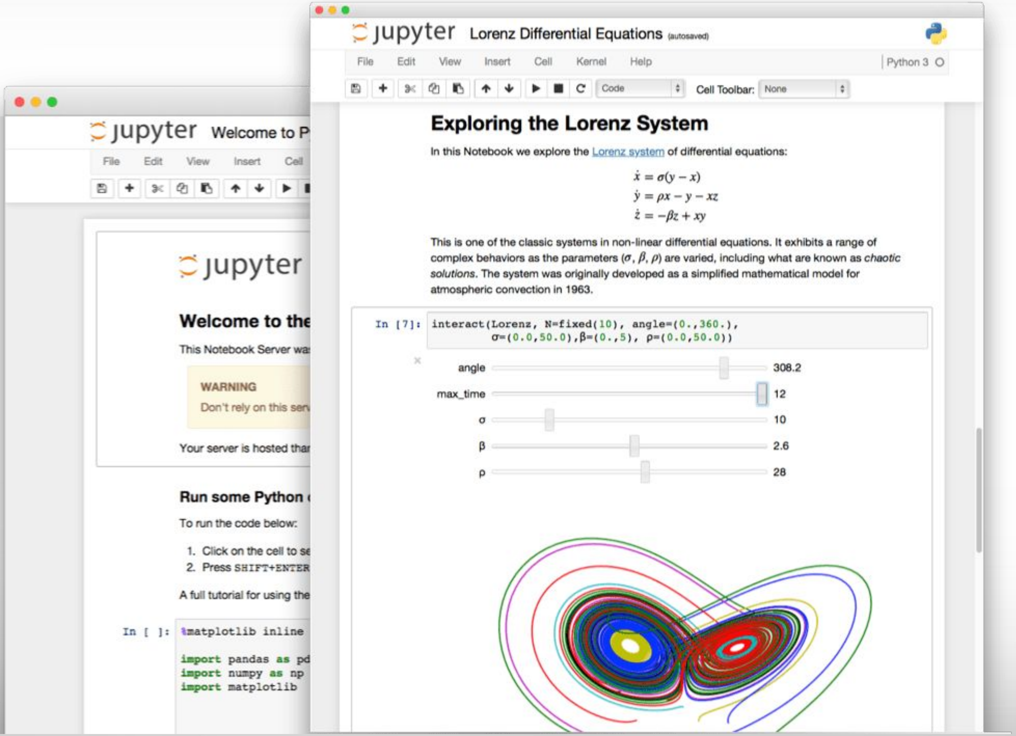


Image Credit: Jupyter (http://jupyter.org/)

Julia as an Advanced Calculator

Arithmetic Operators

`+`	Addition (also unary plus)
`-`	Subtraction (also unary minus)
`*`	multiplication
`/`	division
`\`	inverse division
`%`	mod
`^`	to the power of

More about Arithmetic Operators

1. The **order of operations** follows the math rules.
2. The **updating version** of the operators is formed by placing a = immediately after the operator. For instance, **`x+=3`** is equivalent to **`x=x+3`**.
3. **Unicode** could be defined as operator.
4. **A "dot" operation** is automatically defined to perform the operation element-by-element on arrays in every binary operation.
5. **Numeric Literal Coefficients**: Julia allows variables to be immediately preceded by a numeric literal, implying multiplication.

Arithmetic Expressions

Some examples:

```
julia> 10/5*2
julia> 5*2^3+4\2
julia> -2^4
julia> 8^1/3
julia> pi*e
julia> x=1; x+=3.1
julia> x=[1,2]; x.^=-2
```

Relational Operators

```
==       True, if it is equal
!=,≠     True, if not equal to
<        less than
>        greater than
<=,≤     less than or equal to
>=,≥     greater than or equal to
```

Boolean and Bitwise Operators

`&&`	Logical and
`||`	Logical or
`!`	Not
`⊻`, `xor()`	Exclusive OR
`|`	Bitwise OR
`~`	Negate
`&`	Bitwise And
`>>`	Right shift
`<<`	Left shift

NaN and Inf

NaN is a not-a-number value of type Float64.

Inf is positive infinity of type Float64.

-Inf is negative infinity of type Float64.

- **Inf** is equal to itself and greater than everything else except **NaN**.
- **-Inf** is equal to itself and less then everything else except **NaN**.
- NaN is not equal to, not less than, and not greater than anything, including itself.

```
julia> NaN == NaN   #false

julia> NaN != NaN
true

julia> NaN < NaN
false

julia> NaN > NaN
false

julia> isequal(NaN, NaN)
true

julia> isnan(1/0)
false
```

Variables

The basic types of Julia include **float**, **int**, **char, string**, and **bool**. A global variable can not be deleted, but its content could be cleared with the keyword **nothing.**

```
julia> b = true; typeof(b)
julia> varinfo()
julia> x = "Hi"; x > "He"        # x='Hi' is wrong. why?
julia> y = 10
julia> z = complex(1, y)
julia> println(b, x, y, z)
julia> b = nothing; show(b)
```

Naming Rules for Variables

- Variable names must begin with a letter or underscore

```
julia> 4c = 12
```

- Names can include any combinations of letters, numbers, underscores, and exclamation symbol. Some unicode characters could be used as well

```
julia> c_4 = 12; δ = 2
```

- Maximum length for a variable name is not limited
- Julia is case sensitive. The variable name A is different than the variable name a.

Displaying Variables

We can display a variable (i.e., show its value) by simply typing the name of the variable at the command prompt (leaving off the semicolon).

We can also use **`print`** or **`println`** (print plus a new line) to display variables.

```
julia> print("The value of x is:"); print(x)
julia> println("The value of x is:"); print(x)
```

Exercise

Create two variables: `a = 4` and `b = 17.2`

Now use Julia to perform the following set of calculations:

$(b+5.4)^{1/3}$ $b^2-4b+5a$

`a>b and a>1.0`   `a!=b`

Basic Syntax for Statements (I)

1. Comments start with '**#**'
2. Compound expressions with **begin** blocks and (;) chains

```
julia>  z = begin
           x = 1
           y = 2
           x + y
        end
julia>  z = (x = 1; y = 2; x + y)
```

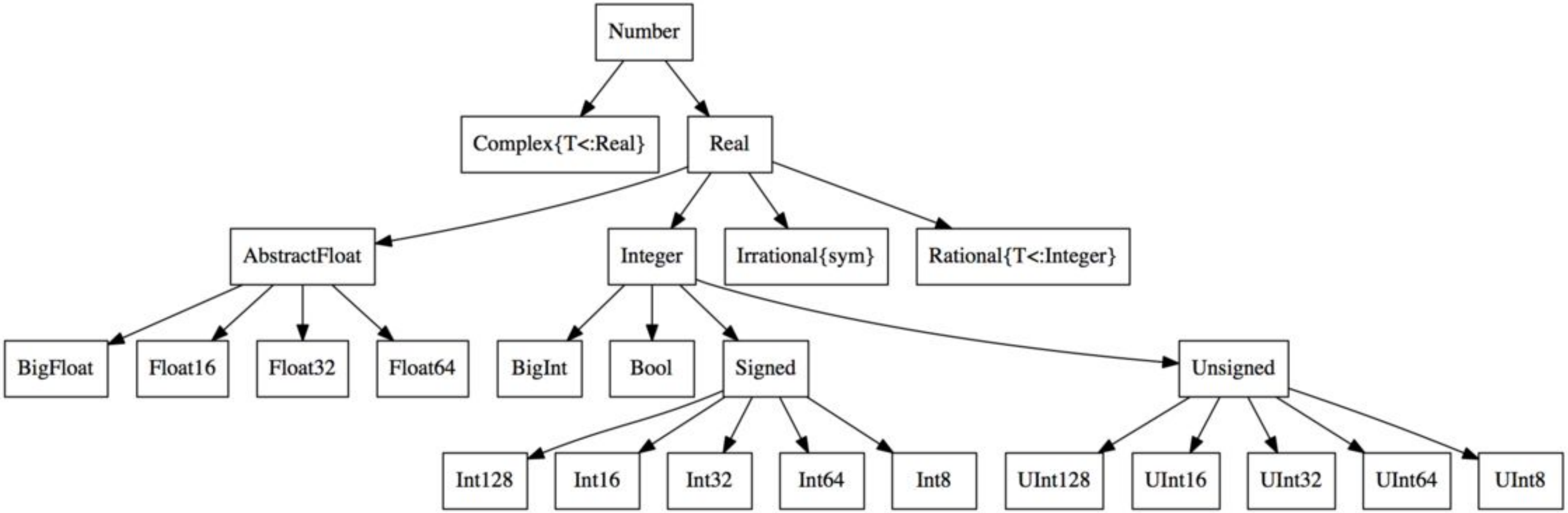
Basic Syntax for Statements (II)

The statements could be freely arranged with an optional ';' if a new line is used to separate statements.

```
julia> begin x = 1; y = 2; x + y end

julia> (x = 1;
        y = 2;
        x + y)
```

Numerical Data Types



Integer Data Types

Type	Signed?	Number of bits	Smallest value	Largest value
Int8	✓	8	-2^7	2^7 - 1
UInt8		8	0	2^8 - 1
Int16	✓	16	-2^15	2^15 - 1
UInt16		16	0	2^16 - 1
Int32	✓	32	-2^31	2^31 - 1
UInt32		32	0	2^32 - 1
Int64	✓	64	-2^63	2^63 - 1
UInt64		64	0	2^64 - 1
Int128	✓	128	-2^127	2^127 - 1
UInt128		128	0	2^128 - 1
Bool	N/A	8	false (0)	true (1)

Handling Big Integers

An overflow happens when a number goes beyond the representable range of a given type. Juliat provides **BigInt** type to handle big integers.

```
julia> x = typemax(Int64)
julia> x + 1
julia> x + 1 == typemin(Int64)
julia> x = big(typemax(Int64))^100
```

Floating Point Data Types

Type	Precision	Number of bits	Range
Float16	half	16	-65504 to -6.1035e-05 6.1035e-05 to 65504
Float32	single	32	−3.402823E38 to −1.401298E-45 1.401298E-45 to 3.402823E38
Float64	double	64	-1.79769313486232E308 to -4.94065645841247E-324 4.94065645841247E-324 to 1.79769313486232E308

- Additionally, full support for **Complex** and **Rational Numbers** is built on top of these primitive numeric types.
- All numeric types interoperate naturally without explicit casting thanks to a user-extensible **type promotion system**.

Handling Floating-point Types (I)

Perform each of the following calculations in your head.

```
julia> a = 4/3
julia> b = a - 1
julia> c = 3*b
julia> e = 1 - c
```

What does Julia get?

Handling Floating-point Types (II)

What does Julia get?

```
julia> a = 4/3     #1.3333333333333333

julia> b = a - 1  #0.33333333333333326
julia> c = 3*b     #0.9999999999999998
julia> e = 1 - c  #2.220446049250313e-16
```

It is impossible to perfectly represent all real numbers using a finite string of 1's and 0's.

Handling Floating-point Types (III)

Now try the following with BigFloat

```
julia> a = big(4)/3
julia> b = a - 1
julia> c = 3*b
julia> e = 1 - c #-1.7272337110188...e-77
```

Next, set the precision and repeat the above

```
julia> setprecision(4096)
```

BigFloat variables can store floating point data with arbitrary precision with a performance cost.

Complex and Rational Numbers

The global constant **im** is bound to the complex number **i**, representing the principal square root of **-1**.

```
julia> 2(1 - 1im)

julia> sqrt(complex(-1, 0))
```

Note that `3/4im == 3/(4*im) == -(3/4*im)`, since a literal coefficient binds more tightly than division. `3/(4*im)!=(3/4*im)`

Julia has a **rational number** type to represent exact ratios of integers. Rationals are constructed using the `//` operator, e.g., `9//27`

Some Useful Math Functions (I)

Rounding and division functions

Function	Descrition
round(x)	round x to the nearest integer
floor(x)	round x towards -Inf
ceil(x)	round x towards +Inf
trunc(x)	round x towards zero
div(x,y)	truncated division; quotient rounded towards zero
fld(x,y)	floored division; quotient rounded towards -Inf
cld(x,y)	ceiling division; quotient rounded towards +Inf
rem(x,y)	remainder; satisfies x == div(x,y)*y + rem(x,y); sign matches x
gcd(x,y...)	greatest positive common divisor of x, y,...
lcm(x,y...)	least positive common multiple of x, y,...

Sign and absolute value functions

Function	Descrition
abs(x)	a positive value with the magnitude of x
abs2(x)	the squared magnitude of x
sign(x)	indicates the sign of x, returning -1, 0, or +1
signbit(x)	indicates whether the sign bit is on (true) or off (false)
copysign(x,y)	a value with the magnitude of x and the sign of y
flipsign(x,y)	a value with the magnitude of x and the sign of x*y

Chars and Strings

Julia has a first-class type representing a single character, called **Char.**

Single quotes are & double quotes are used different in Julia.

```
julia> a = 'H'   #a is a character object
julia> b = "H"   #a is a string with length 1
```

Strings and Chars can be easily manipulated with built-in functions.

```
julia> c = string('s') * string('d')
julia> length(c); d = c^10*"4"; split(d,"s")
```

Handling Strings (I)

1. The built-in type used for strings in Julia is **String**. This supports the full range of Unicode characters via the UTF-8 encoding.
2. Strings are **immutable.**
3. A **Char** value represents a single character.
4. One can do comparisons and a limited amount of arithmetic with Char.
5. All indexing in Julia is **1-based**: the first element of any integer-indexed object is found at index 1.

```
julia> str = "Hello, world!"
julia> c = str[1]       #c = 'H'
julia> c = str[end]     #c = '!'
julia> c = str[2:8]     #c = "ello, w"
```

Handling Strings (II)

Interpolation: Julia allows interpolation into string literals using **$**, as in Perl. To include a literal **$** in a string literal, escape it with a backslash:

```
julia> "1 + 2 = $(1 + 2)"  #"1 + 2 = 3"
julia> print("\$100 dollars!\n")
```

Triple-Quoted String Literals: no need to escape for special symbols and trailing whitespace is left unaltered.

Handling Strings (III)

Julia comes with a collection of tools to handle strings.

```
julia> str="Julia"
julia> occursin("lia", str)
julia> z = repeat(str, 10)
julia> firstindex(str)
julia> lastindex(str)
julia> length(str)
```

Julia also supports Perl-compatible regular expressions (regexes).

```
julia> ismatch(r"^\s*(?:#|$)", "# a comment")
```

Help

- For help on a specific function or macro, type **?** followed by its name, and press enter. This only works if you know the name of the function you want help with. With **^S** and **^R** you can also do historical search.

```
Julia> ?cos
```

- Type `?help` to get more information about help

```
Julia> ?help
```

Functions

Definition of Functions

Two equivalent ways to define a function

```
julia> function func(x,y)
             return x + y, x
         end
```

```
julia> ∑(x,y) = x + y, x
```

Operators are functions

```
julia> +(1,2); plusfunc=+
Julia> plusfunc(2,3)
```

Recommended style for function definition: **append ! to names of functions that modify their arguments**

Functions with Optional Arguments

You can define functions with optional arguments with default values.

```
julia> function point(x, y, z=0)
         println("$x, $y, $z")
       end
julia> point(1,2); point(1,2,3)
```

Keywords and Positional Arguments

Keywords can be used to label arguments. Use a **semicolon** after the function's unlabelled arguments, and follow it with one or more **keyword=value** pairs

```
julia> function func(a, b, c="one"; d="two")
        println("$a, $b, $c, $d")
       end
julia> func(1,2); func(d="four", 1, 2, "three")
```

Anonymous Functions

As functions in Julia are first-class objects, they can be created anonymously without a name.

```
julia> x -> 2x - 1
julia> function (x)
          2x - 1
       end
```

An anonymous function is primarily used to feed in other functions.

```
julia> map((x,y,z) -> x + y + z,
           [1,2,3], [4, 5, 6], [7, 8, 9])
```

"Dotted" Function

Dot syntax can be used to vectorize functions, i.e., applying functions **elementwise** to arrays.

```
julia> func(a, b) = a * b
julia> func(1, 2)
julia> func.([1,2], 3)
julia> sin.(func.([1,2],[3,4]))
```

Function of Function

Julia functions can be treated the same as other Julia objects. You can return a function within a function.

```
julia> function my_exp_func(x)
          f = function (y) return y^x end
          return f
       end
julia> squarer=my_exp_func(2); quader=my_exp_func(3)
julia> squarer(3)
julia> quader(3)
```

Data Structures: Tuples, Arrays, Sets, and Dictionaries

Tuples

A tuple is an ordered sequence of elements. Tuples are good for small fixed-length collections. Tuples are **immutable**.

```
julia> t = (1, 2, 3)
julia> t = ((1, 2), (3, 4))
julia> t[1][2]
```

Arrays

An array is an ordered collection of elements. In Julia, arrays are used for lists, vectors, tables, and matrices. Arrays are **mutable**.

```
julia> a = [1, 2, 3]          # column vecor
julia> b = [1 2 3]            # row vector
julia> c = [1 2 3; 4 5 6]     # 2x3 vector
julia> d = [n^2 for n in 1:5]
julia> f = zeros(2,3); g = rand(2,3)
julia> h = ones(2,3); j = fill("A",9)
julia> k = reshape(rand(5,6),10,3)
julia> [a a]                  # hcat
julia> [b;b]                  # vcat
```

Array & Matrix Operations

Many Julia operators and functions can be used preceded with a dot. These versions are the same as their non-dotted versions, and work on the arrays element by element.

```
julia> b = [1 2 3; 4 5 7; 7 8 9]
julia> b .+ 10          # each element + 10
julia> sin.(b)          # sin function
julia> b'               # transpose (transpose(b))
julia> inv(b)           # inverse
julia> b * b            # matrix multiplication
julia> b .* b           # element-wise multiplication
julia> b .^ 2           # element-wise square
```

Sets

- Sets are mainly used to eliminate repeated numbers in a sequence/list.
- It is also used to perform some standard set operations.
- A could be created with the Set constructor function

Examples:

```
julia> months=Set(["Nov","Dec","Dec"])
julia> typeof(months)
julia> push!(months,"Sept")
julia> pop!(months,"Sept")
julia> in("Dec", months)
julia> m=Set(["Dec","Mar","Feb"])
julia> union(m,months)
julia> intersect(m,months)
julia> setdiff(m,months)
```

Dictionaries

- **Dictionaries** are mappings between keys and items stored in the dictionaries.
- Alternatively one can think of dictionaries as sets in which something stored against every element of the set.
- To define a dictionary, use `Dict()`

Examples:

```
julia> m=Dict("Oct"=>"October",
              "Nov"=>"November",
              "Dec"=>"December")
julia> m["Oct"]
julia> get(m, "Jan", "N/A")
julia> haskey(m, "Jan")
julia> m["Jan"]="January"
julia> delete!(m, "Jan")
julia> keys(m)
julia> values(m)
julia> map(uppercase, collect(keys(m)))
```

Conditional Statements & Loops

Controlling Blocks

Julia has the following constructs

- **ternary** expressions
- **Boolean switching** expressions
- **if elseif else end** - conditional evaluation
- **for end** - iterative evaluation
- **while end** - iterative conditional evaluation
- **try catch error throw** exception handling

Ternary and Boolean Expressions

A ternary expression can be constructed with the ternary operator **"?"** and **":"**,

```
julia> x = 1
julia> x > 0 ? sin(x)  :  cos(x)
```

You can combine the boolean condition and any expression using **&&** or ||,

```
julia> isodd(42) && println("That's even!")
```

Conditional Statements

Execute statements if condition is true.

There is no "**switch**" and "**case**" statement in Julia.

There is an "**ifelse**" statement.

```
julia> a = 8
julia> if a>10
           println("a > 10")
       elseif a<10
           println("a < 10")
       else
           println("a = 10")
       end
```

```
julia> s = ifelse(false, "hello", "goodbye") * " world"
```

Loop Control Statements - *for*

for statements help repeatedly execute a block of code for a certain number of iterations. Loop variables are local.

```
julia> for i in 0:1:10
           if i % 3 == 0
               continue
           end
           println(i)
       end
julia> for l in "julia"
              print(l, "-^-")
       end
```

Other Usage of *for* Loops

Array comprehension:

```
julia> [n for n in 1:10]
```

Array enumeration:

```
julia> [i for i in enumerate(rand(3))]
```

Generator expressions:

```
julia> sum(x for x in 1:10)
```

Nested loop:

```
for x in 1:10, y in 1:10
    @show (x, y)
    if y % 3 == 0
        break
    end
end
```

Loop Control Statements - *while*

while statements repeatedly execute a block of code as long as a condition is satisfied.

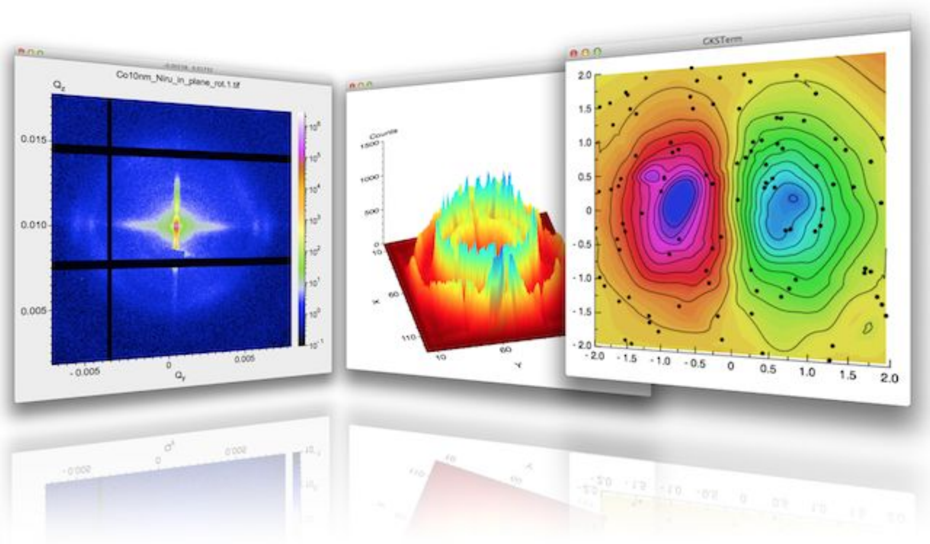
```
julia> n = 1
julia> s = 0
julia> while n <= 100
           s = s + n
           n = n + 1
       end
julia> println(s)
```

Exception Handling Blocks

try ... catch construction checks for errors and handles them gracefully,

```
julia> s = "test"
julia> try
           s[1] = "p"
       catch
           println("caught an error: $e")
           println("continue with execution!")
       end
```

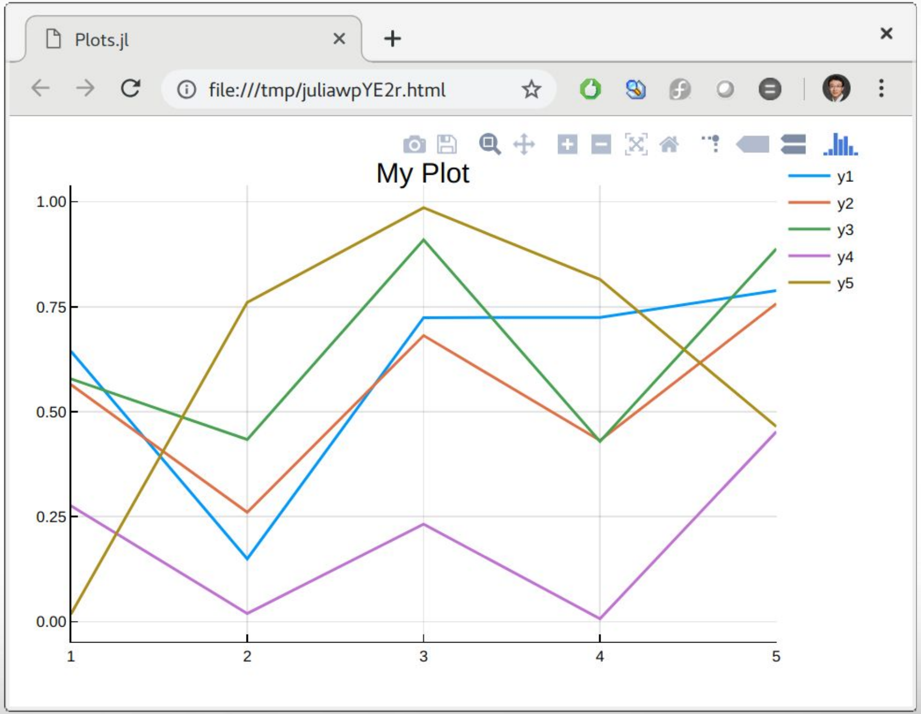
Plots with Julia



Plotly Julia Library

Plotly creates leading open source software for Web-based data visualization and analytical apps. Plotly Julia Library makes interactive, publication-quality graphs online.

```
julia> using Plots
julia> plotly()
julia> plot(rand(5,5), linewidth=2, title="My Plot")
```



GR Framework

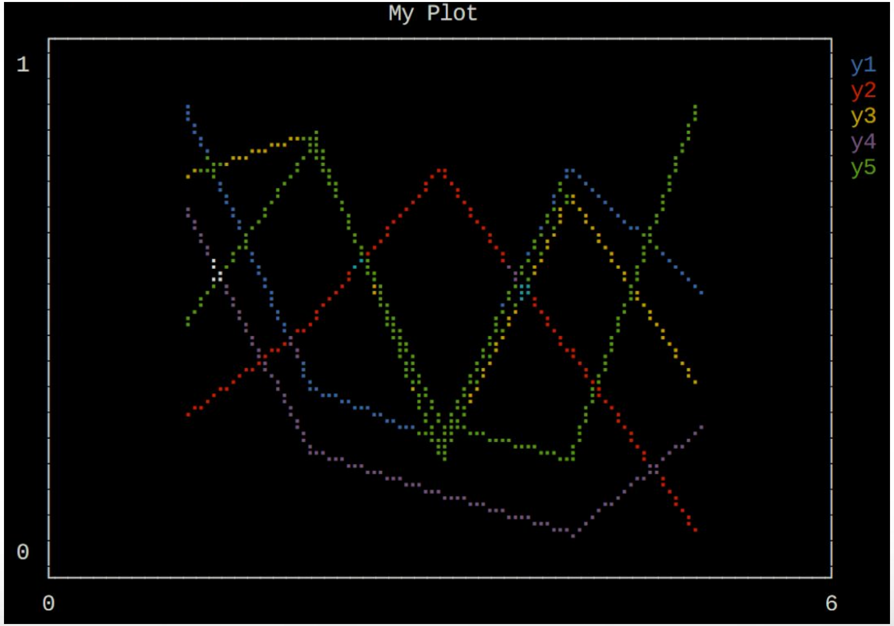
[GR framework] is a universal framework for cross-platform visualization applications.

```
julia> using Plots
julia> gr()
julia> plot(rand(5,5), linewidth=4, title="My Plot", size=(1024,1024))
```

UnicodePlots

UnicodePlots is simple and lightweight and it plots directly in your terminal.

```
julia> using Plots
julia> unicodeplots()
julia> plot(rand(5,5),
linewidth=2, title="My
Plot")
```



Online Resources

Official Julia Document

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

Julia Online Tutorials

https://julialang.org/learning/

Introducing Julia (Wikibooks.org)

https://en.wikibooks.org/wiki/Introducing_Julia

MATLAB–Python–Julia cheatsheet

https://cheatsheets.quantecon.org/

Acknowledgements

- The slides are created based on the materials from Julia official website and the Wikibook *Introducing Julia* at wikibooks.org.
- Supports from Texas A&M Engineering Experiment Station (TEES) and High Performance Research Computing (HPRC).

Appendix

Modules and Packages

Julia code is organized into **files**, **modules**, and **packages**. Files containing Julia code use the **.jl** file extension.

```
module MyModule
    ...
end
```

Julia manages its packages the package **Pkg**

```
julia> Pkg.add("MyPackage")
julia> Pkg.status()
julia> Pkg.update()
julia> Pkg.rm("MyPackage")
```

ASCII Code

When you press a key on your computer keyboard, the key that you press is translated to a binary code.

```
A = 1000001       (Decimal = 65)
a = 1100001       (Decimal = 97)
0 = 0110000       (Decimal = 48)
```

ASCII Code

ASCII stands for **A**merican **S**tandard **C**ode for **I**nformation **I**nterchange

Dec	Hex	Char	Dec	Hex	Char	Dec	Hex	Char	Dec	Hex	Char
0	00	Null	32	20	Space	64	40	@	96	60	`
1	01	Start of heading	33	21	!	65	41	A	97	61	a
2	02	Start of text	34	22	"	66	42	B	98	62	b
3	03	End of text	35	23	#	67	43	C	99	63	c
4	04	End of transmit	36	24	$	68	44	D	100	64	d
5	05	Enquiry	37	25	%	69	45	E	101	65	e
6	06	Acknowledge	38	26	&	70	46	F	102	66	f
7	07	Audible bell	39	27	'	71	47	G	103	67	g
8	08	Backspace	40	28	(	72	48	H	104	68	h
9	09	Horizontal tab	41	29	)	73	49	I	105	69	i
10	0A	Line feed	42	2A	*	74	4A	J	106	6A	j
11	0B	Vertical tab	43	2B	+	75	4B	K	107	6B	k
12	0C	Form feed	44	2C	,	76	4C	L	108	6C	l
13	0D	Carriage return	45	2D	-	77	4D	M	109	6D	m
14	0E	Shift out	46	2E	.	78	4E	N	110	6E	n
15	0F	Shift in	47	2F	/	79	4F	O	111	6F	o
16	10	Data link escape	48	30	0	80	50	P	112	70	p
17	11	Device control 1	49	31	1	81	51	Q	113	71	q
18	12	Device control 2	50	32	2	82	52	R	114	72	r
19	13	Device control 3	51	33	3	83	53	S	115	73	s
20	14	Device control 4	52	34	4	84	54	T	116	74	t
21	15	Neg. acknowledge	53	35	5	85	55	U	117	75	u
22	16	Synchronous idle	54	36	6	86	56	V	118	76	v
23	17	End trans. block	55	37	7	87	57	W	119	77	w
24	18	Cancel	56	38	8	88	58	X	120	78	x
25	19	End of medium	57	39	9	89	59	Y	121	79	y
26	1A	Substitution	58	3A	:	90	5A	Z	122	7A	z
27	1B	Escape	59	3B	;	91	5B	[	123	7B	{
28	1C	File separator	60	3C	<	92	5C	\	124	7C	|
29	1D	Group separator	61	3D	=	93	5D	]	125	7D	}
30	1E	Record separator	62	3E	>	94	5E	^	126	7E	~
31	1F	Unit separator	63	3F	?	95	5F	_	127	7F	□

Terminology

A **bit** is short for **bi**nary digi**t.** It has only two possible values: On (1) or Off (0).

A **byte** is simply a string of 8 bits.

A **kilobyte** (KB) is 1,024 (2^10) bytes.

A **megabyte** (MB) is 1,024 KB or 1,024^2 bytes.

A **gigabyte** (GB) is 1,024 MB or 1,024^3 bytes.

How Computers Store Variables

Computers store all data (numbers, letters, instructions, …) as strings of 1s and 0s (bits).

A **bit** is short for **bi**nary digi**t.** It has only two possible values: On (1) or Off (0).