Introduction to Julia Programming Language

Jian Tao
jtao@tamu.edu
Spring 2024 HPRC Short Course
4/9/2024
Introduction to Julia

Part I. Getting Started with ACES (~20 mins)

Part II. Julia - What and Why? (~20 mins)

Part III. Julia as an Advanced Calculator (~30 mins)

Part IV. Basics of Julia (~60 mins)

Part V. Plotting with Julia (~10 mins)

Q&A and Break (10 mins)
Part I. Getting Started with ACES

TAMU HPRC Short Course: [Getting Started with FASTER and ACES](#)
Common HPC System

Programming Models: MPI + (CUDA, OpenCL, OpenMP, OpenACC, etc.)
NSF ACES
Accelerating Computing for Emerging Sciences

Our Mission:
- NSF ACSS CI test-bed
- Offer an accelerator testbed for numerical simulations and **AI/ML workloads**
- Provide consulting, technical guidance, and training to researchers
- Collaborate on computational and data-enabled research.
ACES In Action
### ACES System Description

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU-centric computing with variable memory requirements</td>
<td>Dual Intel Sapphire Rapids 2.1 GHz 96 cores per node, 512 GB memory, 1.6 TB NVMe storage (PCIe 5.0), NVIDIA Mellanox NDR 200 Gbps InfiniBand</td>
</tr>
<tr>
<td>Composable infrastructure</td>
<td>Reconfigurable infrastructure that allows up to 20 PCIe cards (GPU, FPGA, VE, etc.) per compute node</td>
</tr>
<tr>
<td>Data transfer nodes</td>
<td>100 Gbps network adapter</td>
</tr>
</tbody>
</table>
## ACES Accelerators

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graphcore IPU</td>
<td>32</td>
<td>16 Colossus GC200 IPUs; 16 Bow IPUs. Each IPU group hosted with a CPU server as a POD16 on a 100 GbE RoCE fabric</td>
</tr>
<tr>
<td>Intel PAC D5005 FPGA</td>
<td>2</td>
<td>Accelerator with Intel Stratix 10 GX FPGA and 32 GB DDR4</td>
</tr>
<tr>
<td>BittWare IA-840F FPGA</td>
<td>2</td>
<td>Accelerator with Agilex AGF027 FPGA and 64 GB of DDR4</td>
</tr>
<tr>
<td>NextSilicon Coprocessor</td>
<td>2</td>
<td>Reconfigurable accelerator with an optimizer continuously evaluating application behavior.</td>
</tr>
<tr>
<td>NEC Vector Engine</td>
<td>8</td>
<td>Vector computing card (8 cores and HBM2 memory)</td>
</tr>
<tr>
<td>Intel Optane SSD</td>
<td>48</td>
<td>18 TB of Intel Optane SSDs addressable as memory w/ MemVerge Memory Machine.</td>
</tr>
<tr>
<td>NVIDIA H100 + A30</td>
<td>30 + 4</td>
<td>NVIDIA GPUs for HPC, DL Training, AI Inference</td>
</tr>
<tr>
<td>Intel GPU Max 1100 (PVC)</td>
<td>120</td>
<td>Intel GPUs for HPC, DL Training, AI Inference</td>
</tr>
</tbody>
</table>
## Research Workflows - Accelerators

<table>
<thead>
<tr>
<th>Hardware Profile</th>
<th>Applications Supported</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NEC Vector Engines</strong></td>
<td>• AI/ML (Statistical Machine Learning, Data Frame)</td>
</tr>
<tr>
<td></td>
<td>• Chemistry (VASP, Quantum ESPRESSO)</td>
</tr>
<tr>
<td></td>
<td>• Earth Sciences</td>
</tr>
<tr>
<td></td>
<td>• NumPy Acceleration</td>
</tr>
<tr>
<td></td>
<td>• Oil &amp; Gas (Seismic Imaging, Reservoir Simulation)</td>
</tr>
<tr>
<td></td>
<td>• Plasma Simulation</td>
</tr>
<tr>
<td></td>
<td>• Weather/Climate Simulation</td>
</tr>
<tr>
<td><strong>Graphcore IPUs</strong></td>
<td>• Graph Data</td>
</tr>
<tr>
<td></td>
<td>• LSTM Neural Networks</td>
</tr>
<tr>
<td></td>
<td>• Markov Chain Monte Carlo</td>
</tr>
<tr>
<td></td>
<td>• Natural Language Processing (Deep Learning)</td>
</tr>
<tr>
<td><strong>Intel/Bittware FPGA</strong></td>
<td>• AI Models for Embedded Use Cases</td>
</tr>
<tr>
<td></td>
<td>• Big Data</td>
</tr>
<tr>
<td></td>
<td>• CXL Memory Interface</td>
</tr>
<tr>
<td></td>
<td>• Deep Learning Inference</td>
</tr>
<tr>
<td></td>
<td>• Genomics</td>
</tr>
<tr>
<td></td>
<td>• MD Codes</td>
</tr>
<tr>
<td></td>
<td>• Microcontroller Emulation for Autonomy Simulations</td>
</tr>
<tr>
<td></td>
<td>• Streaming Data Analysis</td>
</tr>
<tr>
<td><strong>Intel Optane SSDs</strong></td>
<td>• Bioinformatics</td>
</tr>
<tr>
<td></td>
<td>• Computational Fluid Dynamics (OpenFOAM)</td>
</tr>
<tr>
<td></td>
<td>• MD Codes</td>
</tr>
<tr>
<td></td>
<td>• R</td>
</tr>
<tr>
<td></td>
<td>• WRF</td>
</tr>
<tr>
<td><strong>NextSilicon</strong></td>
<td>• Biosciences (BLAST)</td>
</tr>
<tr>
<td></td>
<td>• Computational Fluid Dynamics (OpenFOAM)</td>
</tr>
<tr>
<td></td>
<td>• Cosmology (HACC)</td>
</tr>
<tr>
<td></td>
<td>• Graph Search (Pathfinder)</td>
</tr>
<tr>
<td></td>
<td>• Molecular Dynamics (NAMD, AMBER, LAMMPS)</td>
</tr>
<tr>
<td></td>
<td>• Quantum ChromoDynamics (MILC)</td>
</tr>
<tr>
<td></td>
<td>• Weather/Environment modeling (WRF)</td>
</tr>
</tbody>
</table>
ACES Configuration - Feb 2024

Ice Lake Nodes (15) Kubernetes Host

Management Nodes (4)

Data Transfer Nodes (2)

Login Nodes (3)

Lustre System 2.54 PB usable

NDR InfiniBand

SPR Nodes (12)
Optane SSD
Intel FPGA

SPR Nodes (13)
Optane SSD
Intel FPGA

SPR Nodes (12)
NVIDIA A30
Intel PVC

SPR Nodes (13)
Optane SSD
BittWare FPGA

SPR Nodes (15)
Intel PVC

SPR Nodes (15)
Intel PVC

SPR Nodes (15)
Intel PVC

SPR Nodes (15)
NVIDIA H100

NEC VE Node

Graphcore Bow POD16

Graphcore Colossus POD16

planned

Ice Lake Nodes (15)

Kubernetes Host

Intel PVC

NextSilicon
Getting on ACES

- You must have an **ACCESS** account!
- Application for ACES is available through ACCESS: [https://allocations.access-ci.org](https://allocations.access-ci.org)
- Email us at [help@hprc.tamu.edu](mailto:help@hprc.tamu.edu) for questions, comments, and concerns.

**PIs** can apply for an account and sponsor accounts for their researchers.

(Grad students may also apply directly with a letter of collaboration from their PI)
Batch Computing on Clusters

Workflow on a cluster:

- Interact via **your own machine**
- Log in to the cluster’s **portal** (and/or the **login nodes**) and write instructions
- Send instructions to **compute nodes** to do the heavy-lifting
Accessing the HPRC Portal

- HPRC webpage: hprc.tamu.edu, Portal dropdown menu
Accessing ACES via the HPRC Portal (ACCESS)

Log-in using your ACCESS credentials.

Select the Identity Provider appropriate for your account.
Shell Access via the Portal

Get a shell terminal right in your browser
ACES Shell Access - Shell

HOST Login: ACES

= IMPORTANT POLICY INFORMATION =
- Unauthorized use of HPRC resources is prohibited and subject to
  criminal prosecution.
- Use of HPRC resources in violation of United States export control
  laws and regulations is prohibited. Current HPRC staff members are
  US citizens and legal residents.
- Sharing HPRC account and password information is in violation of
  Texas State Law. Any shared accounts will be DISABLED.
- Authorized users must also adhere to ALL policies at:
  https://hprc.tamu.edu/policies/

= ACES Partial Availability, February 12 =
We are still troubleshooting issues for various compute nodes that were
reconfigured for PCIe fabric connectivity to the H100 and PVCs.

!!! WARNING: THERE ARE ONLY NIGHTLY BACKUPS OF USER HOME DIRECTORIES. !!!

Please restrict usage to 8 CORES across ALL login nodes.
Users found in violation of this policy will be SUSPENDED.

To see these messages again, run the motd command.

Your current disk quotas are:

<table>
<thead>
<tr>
<th>Disk</th>
<th>Disk Usage</th>
<th>Limit</th>
<th>File Usage</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>/home/u.jt1630</td>
<td>7.9G</td>
<td>10.0G</td>
<td>145</td>
<td>10000</td>
</tr>
<tr>
<td>/scratch/user/u.jt1630</td>
<td>58.1G</td>
<td>1.0T</td>
<td>138298</td>
<td>250000</td>
</tr>
</tbody>
</table>

Type 'showquota' to view these quotas again.
[u.jt1630@aces-login1 ~]$
Using Pre-installed Julia Module

**Step 1. Find the module to be loaded**

```
$ module spider julia
...
Description:
Julia is a high-level, high-performance
dynamic programming language for numerical
computing
```

**Versions:**
- Julia/1.8.5-linux-x86_64
- Julia/1.9.3-linux-x86_64
- Julia/1.10.0-musl-x86_64
- Julia/1.10.2-linux-x86_64
...

You can also use the web-based interface to find software modules available on HPRC systems.

**Step 2. Load the module**

```
$ module load Julia/1.10.2-linux-x86_64
```

**Step 3. Start Julia REPL**

```
$ julia
```

[Image of Julia REPL console]

You can also use the [web-based interface](https://docs.julialang.org) to find software modules available on HPRC systems.
Using Your Own Julia Installation

**Step 1. Find the version to be installed** at [Download Julia](https://julialang.org)

Current stable release: v1.10.2 (March 1, 2024)
Checksums for this release are available in both SHA256 and MD5 formats.

<table>
<thead>
<tr>
<th>Platform</th>
<th>64-bit</th>
<th>32-bit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windows [help]</td>
<td>installer, portable</td>
<td>installer, portable</td>
</tr>
<tr>
<td>macOS x86 (Intel or Rosetta) [help]</td>
<td>.dmg, .tar.gz</td>
<td></td>
</tr>
<tr>
<td>macOS (Apple Silicon) [help]</td>
<td>.dmg, .tar.gz</td>
<td></td>
</tr>
<tr>
<td>Generic Linux on x86 [help]</td>
<td>glibc (GPG)</td>
<td>musl (GPG)</td>
</tr>
<tr>
<td>Generic Linux on ARM [help]</td>
<td>AArch64 (GPG)</td>
<td></td>
</tr>
<tr>
<td>Generic FreeBSD on x86 [help]</td>
<td>.tar.gz (GPG)</td>
<td></td>
</tr>
</tbody>
</table>

* You can install the latest Julia version (v1.10.2 March 1, 2024) directly by running this in your terminal:

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

**Step 2. Download & Unzip**

```
$ cd $SCRATCH
$ wget https://.../julia-1.10.2-linux-x86_64.tar.gz
$ tar -zxvf julia-1.10.2-linux-x86_64.tar.gz
```

**Step 3. Start Julia REPL**

```
$ module purge
$ cd $SCRATCH/julia-1.10.2/bin; ./julia
```

[julia REPL interface]

Documentation: [https://docs.julialang.org](https://docs.julialang.org)
Type "?” for help, "!” for Pkg help.
Version 1.10.2 (2024-03-01)
Official [https://julialang.org/](https://julialang.org/) release
Install Julia Packages

# export Julia Depot path (default to ~/.julia)
$export JULIA_DEPOT_PATH=$SCRATCH/.julia

# start Julia
$julia

# type ']' to open Pkg REPL
# press backspace or ^C to quit Pkg REPL.
julia>]
(@v1.9) pkg> add Plots UnicodePlots Plotly
Commands to Copy Examples

- Navigate to your personal scratch directory
  
  ```bash
  $ cd $SCRATCH
  ```

- Files for this course are located at
  
  `/scratch/training/julia_examples.tgz`

  Make a copy in your personal scratch directory
  
  ```bash
  $ cp /scratch/training/julia/julia_examples.tgz $SCRATCH/
  ```

- Extract the files
  
  ```bash
  $ tar -zxvf julia_examples.tgz
  ```

- Enter this directory (your local copy)
  
  ```bash
  $ cd julia_examples
  $ julia helloworld.jl
  ```
Load Julia Module, Compile, and Run

```
[u.jt1530@aces-login1 julia_examples]$ module load Julia/1.10.2-linux-x86_64
[u.jt1530@aces-login1 julia_examples]$ ml
Currently Loaded Modules:
  1) Julia/1.10.2-linux-x86_64

[u.jt1530@aces-login1 julia_examples]$ julia helloworld.jl
hello world!
[u.jt1530@aces-login1 julia_examples]$ julia

```

```
 julia> versioninfo()
Julia Version 1.10.2
Commit bd47e2ca2c8a (2024-03-01 10:14 UTC)
Build Info:
  Official https://julialang.org/ release
Platform Info:
  OS: Linux (x86_64-linux-gnu)
  CPU: 96 x Intel(R) Xeon(R) Platinum 8480
  WORD_SIZE: 64
  LIBM: libopenlibm
  LLVM: libLLVM-15.0.7 (ORCJIT, saphirerapid)
  Threads: 1 default, 0 interactive, 1 GC (on 96 virtual cores)
Environment:
  LD_LIBRARY_PATH = /sw/eb/sw/Julia/1.10.2-linux-x86_64/lib
  JULIA_DEPOT_PATH = :

```

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>`**, but they might not show properly on the web-based terminal.

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

<table>
<thead>
<tr>
<th>Keybinding</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>^d</td>
<td>Exit (when buffer is empty)</td>
</tr>
<tr>
<td>^c</td>
<td>Interrupt or cancel</td>
</tr>
<tr>
<td>^l</td>
<td>Clear console screen</td>
</tr>
<tr>
<td>Return/Enter, ^J</td>
<td>New line, executing if it is complete</td>
</tr>
<tr>
<td>? or ;</td>
<td>Enter help or shell mode (when at start of a line)</td>
</tr>
<tr>
<td>^R, ^S</td>
<td>Incremental history search</td>
</tr>
<tr>
<td>]</td>
<td>Enter Pkg REPL</td>
</tr>
<tr>
<td>Backspace or ^c</td>
<td>Quit Pkg REPL</td>
</tr>
</tbody>
</table>
Part II.
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 v1.10.2 as of Mar 31, 2024
- [https://julialang.org/](https://julialang.org/)
- customized for "greedy, unreasonable, demanding programmers".
- [Julia Computing](https://julia.com/) established in 2015 to provide commercial support.
Image Credit: [Julia Micro-Benchmarks](https://example.com)
Image Credit: RedMonk (The RedMonk Programming Language Rankings: January 2024 – tecosystems)
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.

Mostly importantly, for many of us, **Julia** seems to be the language of choice for **Scientific Machine Learning**.
Juno IDE

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

Image Credit: Jupyter (http://jupyter.org/)
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.
Part III.
Julia as an Advanced Calculator

Image Credit: http://www.ti.com/
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 \euler <TAB>
julia> x=1; x+=3.1
julia> x=[1,2]; x = x.^(-2)
Relational Operators

== True, if it is equal
!=, ≠ True, if not equal to \ne <TAB>
< less than
greater than
\le <TAB>
greater than or equal to \ge <TAB>

* try ≠(4,5), what does this mean? How about !=(4,5)
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
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. Unicode can be used as variable names!

```
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)
julia> 🏈=2; 🏃=1                 # \\:football:  <TAB> \\:runner:  <TAB>
```
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:

\[
\frac{(b+5.4)^{1/3}}{} \quad \frac{b^2-4b+5a}{b^2-4b+5a} \quad \frac{a>b \land a>1.0}{a>b \land a>1.0} \quad \frac{a!=b}{a!=b}
\]
Basic Syntax for Statements (I)

1. Comments start with '#'

2. Compound expressions with `begin` blocks and `(;)` chains

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

<table>
<thead>
<tr>
<th>Type</th>
<th>Signed?</th>
<th>Number of bits</th>
<th>Smallest value</th>
<th>Largest value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Int8</td>
<td>✓</td>
<td>8</td>
<td>-2^7</td>
<td>2^7 - 1</td>
</tr>
<tr>
<td>UInt8</td>
<td></td>
<td>8</td>
<td>0</td>
<td>2^8 - 1</td>
</tr>
<tr>
<td>Int16</td>
<td>✓</td>
<td>16</td>
<td>-2^15</td>
<td>2^15 - 1</td>
</tr>
<tr>
<td>UInt16</td>
<td></td>
<td>16</td>
<td>0</td>
<td>2^16 - 1</td>
</tr>
<tr>
<td>Int32</td>
<td>✓</td>
<td>32</td>
<td>-2^31</td>
<td>2^31 - 1</td>
</tr>
<tr>
<td>UInt32</td>
<td></td>
<td>32</td>
<td>0</td>
<td>2^32 - 1</td>
</tr>
<tr>
<td>Int64</td>
<td>✓</td>
<td>64</td>
<td>-2^63</td>
<td>2^63 - 1</td>
</tr>
<tr>
<td>UInt64</td>
<td></td>
<td>64</td>
<td>0</td>
<td>2^64 - 1</td>
</tr>
<tr>
<td>Int128</td>
<td>✓</td>
<td>128</td>
<td>-2^127</td>
<td>2^127 - 1</td>
</tr>
<tr>
<td>UInt128</td>
<td></td>
<td>128</td>
<td>0</td>
<td>2^128 - 1</td>
</tr>
<tr>
<td>Bool</td>
<td>N/A</td>
<td>8</td>
<td>false (0)</td>
<td>true (1)</td>
</tr>
</tbody>
</table>
Handling Big Integers

An overflow happens when a number goes beyond the representable range of a given type. Julia 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

<table>
<thead>
<tr>
<th>Type</th>
<th>Precision</th>
<th>Number of bits</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Float16</td>
<td>half</td>
<td>16</td>
<td>-65504 to -6.1035e-05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6.1035e-05 to 65504</td>
</tr>
<tr>
<td>Float32</td>
<td>single</td>
<td>32</td>
<td>-3.402823E38 to -1.401298E-45</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.401298E-45 to 3.402823E38</td>
</tr>
<tr>
<td>Float64</td>
<td>double</td>
<td>64</td>
<td>-1.79769313486232E308 to -4.94065645841247E-324</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.94065645841247E-324 to 1.79769313486232E308</td>
</tr>
</tbody>
</table>

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

```julia
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

## Rounding and division functions

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>round(x)</code></td>
<td>round $x$ to the nearest integer</td>
</tr>
<tr>
<td><code>floor(x)</code></td>
<td>round $x$ towards $-\infty$</td>
</tr>
<tr>
<td><code>ceil(x)</code></td>
<td>round $x$ towards $+\infty$</td>
</tr>
<tr>
<td><code>trunc(x)</code></td>
<td>round $x$ towards zero</td>
</tr>
<tr>
<td><code>div(x,y)</code></td>
<td>truncated division; quotient rounded towards zero</td>
</tr>
<tr>
<td><code>fld(x,y)</code></td>
<td>floored division; quotient rounded towards $-\infty$</td>
</tr>
<tr>
<td><code>cld(x,y)</code></td>
<td>ceiling division; quotient rounded towards $+\infty$</td>
</tr>
<tr>
<td><code>rem(x,y)</code></td>
<td>remainder; satisfies $x = \text{div}(x,y) \cdot y + \text{rem}(x,y)$; sign matches $x$</td>
</tr>
</tbody>
</table>

## Sign and absolute value functions

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>abs(x)</code></td>
<td>a positive value with the magnitude of $x$</td>
</tr>
<tr>
<td><code>abs2(x)</code></td>
<td>the squared magnitude of $x$</td>
</tr>
<tr>
<td><code>sign(x)</code></td>
<td>indicates the sign of $x$, returning -1, 0, or +1</td>
</tr>
<tr>
<td><code>signbit(x)</code></td>
<td>indicates whether the sign bit is on (true) or off (false)</td>
</tr>
<tr>
<td><code>copysign(x,y)</code></td>
<td>a value with the magnitude of $x$ and the sign of $y$</td>
</tr>
<tr>
<td><code>flipsign(x,y)</code></td>
<td>a value with the magnitude of $x$ and the sign of $x \cdot y$</td>
</tr>
</tbody>
</table>

*The built-in math functions in Julia are implemented in C([openlibm](https://openlibm.sgi.com/)).*
Char 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
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
julia> c = string('s') * string('d')
julia> length(c); d = c^10*"4"; split(d,"s")
```
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
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
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.
Julia comes with a collection of tools to handle strings.

```julia
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
julia> occursin(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
Part IV. Basics of Julia

1. Functions - Building Blocks of Julia

```julia
function mandelbrot(a)
    z = 0
    for i=1:50
        z = z^2 + a
    end
    return z
end

for y=1.0:-0.05:-1.0
    for x=-2.0:0.0315:0.5
        abs(mandelbrot(complex(x, y))) < 2 ?
            print("*")
            print(" ")
    end
    println()
end
```
Definition of Functions

Two equivalent ways to define a function

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

julia> Σ(x,y) = x + y, x
```

Operators are functions

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

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

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

squerer=my_exp_func(2); quader=my_exp_func(3)
squerer(3)
quader(3)
```
Part IV. Basics of Julia

2. 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
julia> a = [1, 2, 3]    # column vector
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
```
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
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
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)))
```
Part IV. Basics of Julia

3. Conditional Statements & Loops

Image Credit: https://www.geeksforgeeks.org
Controlling Blocks

Julia has the following controlling 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 ":",

\[ \text{julia}\geq x = 1 \]
\[ \text{julia}\geq x > 0 \ ? \ \sin(x) : \ \cos(x) \]

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

\[ \text{julia}\geq \text{isodd}(41) \ \&\& \ \text{println}("That's odd!") \]
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
julia> for i in 0:1:10
    if i % 3 == 0
        continue
    end
    println(i)
end
julia> for l in "julia"
    print(l, "-^-")
end
```
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
julia> s = "test"
julia> try
   s[1] = "p"
catch err
   println("caught an error: $err")
   println("continue with execution!")
end
```
Part V. Plotting with Julia
UnicodePlots is simple and lightweight and it plots directly in your terminal (*might not work with web-based shell*).

```julia
julia> using Plots
julia> unicodeplots()
julia> plot(rand(5,5),
linewidth=2, title="My Plot")
```
Plotly creates leading open source software for Web-based data visualization and analytical apps. Plotly Julia Library makes interactive, publication-quality graphs online (not working with web-based shell).

```julia
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 (not working with web-based shell).

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

![My Plot](image)
Fractal

- Fractal refers to geometric shapes containing detailed structure at arbitrarily small scales.
- Fractals appear similar at various scales.

Credit: Fractal - Wikipedia
Benoit Mandelbrot Set

\[ z_{n+1} = z_n^2 + c \]

- \( z \) and \( c \) are complex numbers.
- Starting with \( z_0 = 0 \).
- Mendelbrot set is the set of values of \( c \) when \( z_n \) remains bounded for a relatively large \( n \).
function mandelbrot(a)
    z = 0
    for i=1:50
        z = z^2 + a
    end
    return z
end

for y=1.0:-0.05:-1.0
    for x=-2.0:0.0315:0.5
        abs(mandelbrot(complex(x, y))) < 2
        ? print("*") : print(" ") # in one line
    end
println()
end

The first published picture of the Mandelbrot set, by Robert W. Brooks and Peter Matelski in 1978, reproduced with the code to the left.
Online Resources

Official Julia Document
https://docs.julialang.org/en/v1/

Julia Online Tutorials
https://julialang.org/learning/

Introducing Julia (Wikibooks.org)

MATLAB–Python–Julia cheatsheet
https://cheatsheets.quantecon.org/

The Fast Track to Julia
https://juliadocs.github.io/Julia-Cheat-Sheet/
Acknowledgments

- The slides are created based on the materials from Julia official website and the Wikibook Introducing Julia at wikibooks.org.
- Support from Texas A&M Engineering Experiment Station (TEES), Texas A&M Institute of Data Science (TAMIDS), and Texas A&M High Performance Research Computing (HPRC).
- Support from NSF OAC Award #2019129 - MRI: Acquisition of FASTER - Fostering Accelerated Sciences Transformation Education and Research
- Support from NSF OAC Award #2112356 - Category II: ACES - Accelerating Computing for Emerging Sciences
Modules and Packages

Julia code is organized into files, modules, and packages. Files containing Julia code use the .jl file extension. Modules can be defined as

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

Julia manages its packages with Pkg

```julia
julia> Pkg.add("MyPackage")
julia> Pkg.status()
julia> Pkg.update()
julia> Pkg.rm("MyPackage")
```
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 American Standard Code for Information Interchange.
Terminology

A **bit** is short for **binary digit**. 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.