

# Introduction to Julia Programming Language

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Spring 2024 HPRC Short Course

4/9/2024



TEXAS A&M UNIVERSITY  
School of Performance,  
Visualization & Fine Arts



High Performance  
Research Computing  
DIVISION OF RESEARCH



TEXAS A&M  
Institute of  
Data Science

# Introduction to Julia

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

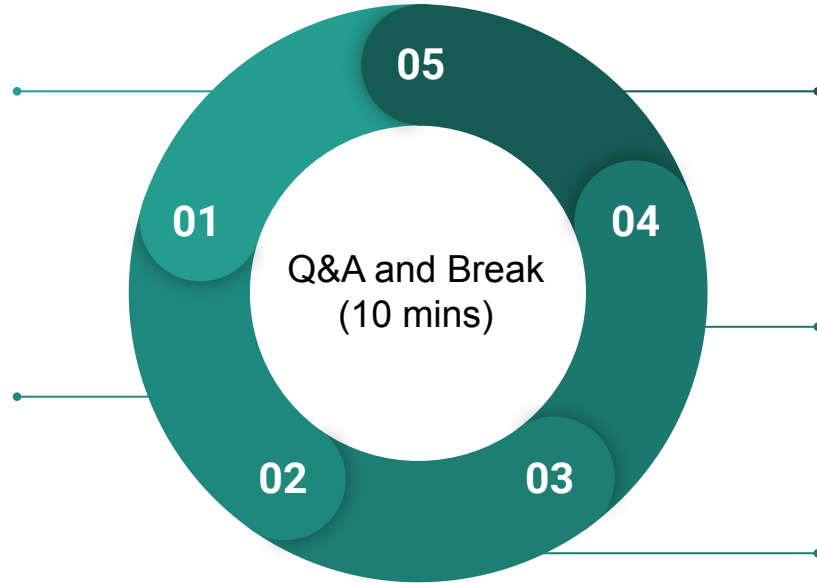
**Part II. Julia - What and Why? (~20 mins)**

**Q&A and Break (10 mins)**

**Part V. Plotting with Julia (~10 mins)**

**Part IV. Basics of Julia (~60 mins)**

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

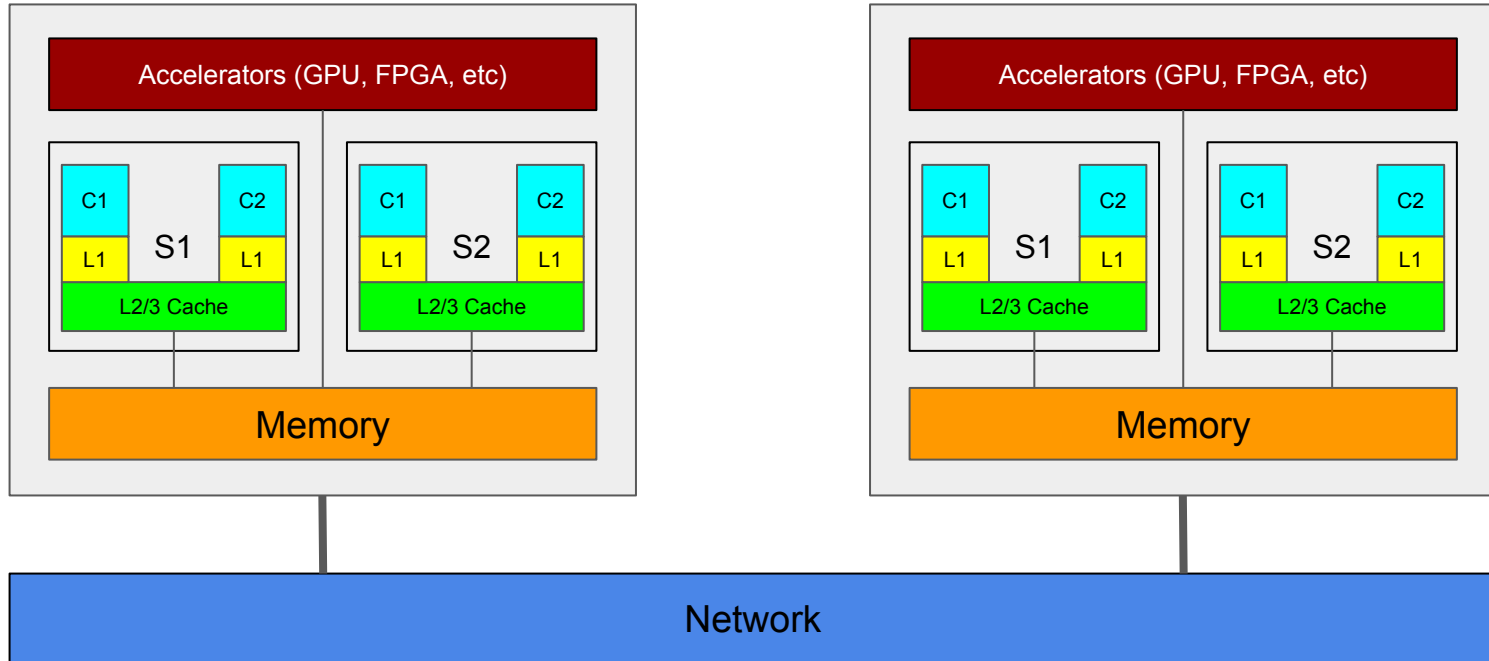


# Part I. Getting Started with ACES



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

# Common HPC System



**Programming Models:** MPI + (CUDA, OpenCL, OpenMP, OpenACC, etc.)

# NSF ACES

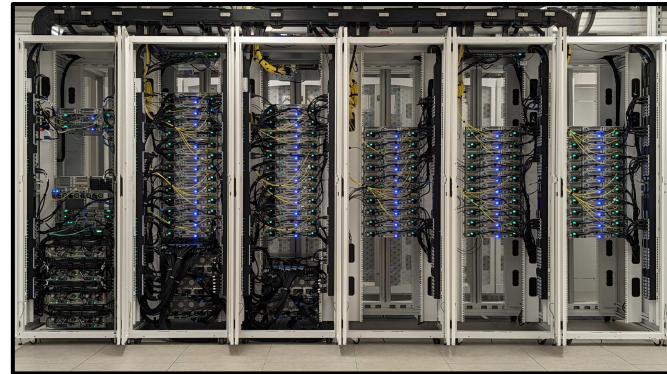
## Accelerating Computing for Emerging Sciences

### 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



Component	Description
CPU-centric computing with variable memory requirements	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
Composable infrastructure	Reconfigurable infrastructure that allows up to 20 PCIe cards (GPU, FPGA, VE, etc.) per compute node
Data transfer nodes	100 Gbps network adapter

# ACES Accelerators

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

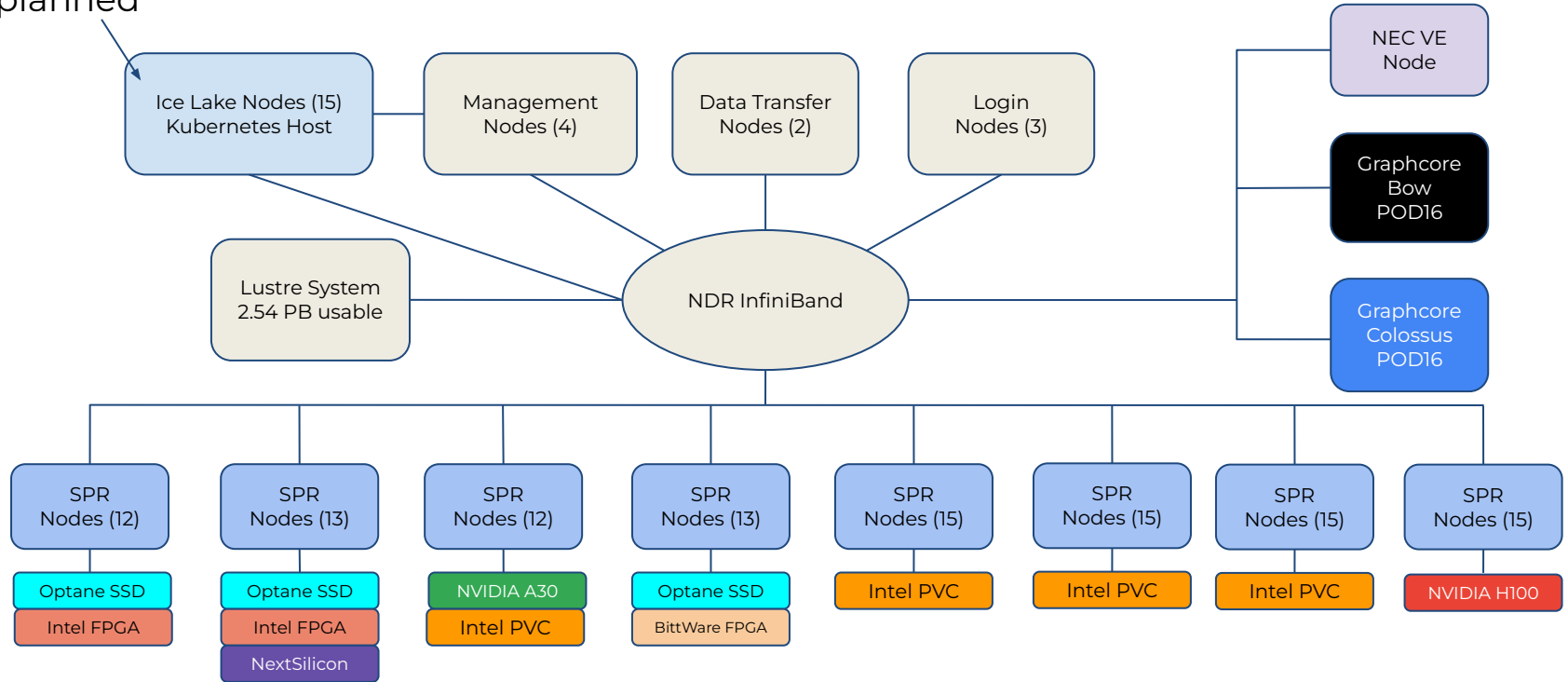


# Research Workflows - Accelerators

Hardware Profile	Applications Supported	
NEC Vector Engines	<ul style="list-style-type: none"> <li>AI/ML (Statistical Machine Learning, Data Frame)</li> <li>Chemistry (VASP, Quantum ESPRESSO)</li> <li>Earth Sciences</li> <li>NumPy Acceleration</li> </ul>	<ul style="list-style-type: none"> <li>Oil &amp; Gas (Seismic Imaging, Reservoir Simulation)</li> <li>Plasma Simulation</li> <li>Weather/Climate Simulation</li> </ul>
Graphcore IPUs	<ul style="list-style-type: none"> <li>Graph Data</li> <li>LSTM Neural Networks</li> </ul>	<ul style="list-style-type: none"> <li>Markov Chain Monte Carlo</li> <li>Natural Language Processing (Deep Learning)</li> </ul>
Intel/Bittware FPGA	<ul style="list-style-type: none"> <li>AI Models for Embedded Use Cases</li> <li>Big Data</li> <li>CXL Memory Interface</li> <li>Deep Learning Inference</li> <li>Genomics</li> </ul>	<ul style="list-style-type: none"> <li>MD Codes</li> <li>Microcontroller Emulation for Autonomy Simulations</li> <li>Streaming Data Analysis</li> </ul>
Intel Optane SSDs	<ul style="list-style-type: none"> <li>Bioinformatics</li> <li>Computational Fluid Dynamics (OpenFOAM)</li> </ul>	<ul style="list-style-type: none"> <li>MD Codes</li> <li>R</li> <li>WRF</li> </ul>
NextSilicon	<ul style="list-style-type: none"> <li>Biosciences (BLAST)</li> <li>Computational Fluid Dynamics (OpenFOAM)</li> <li>Cosmology (HACC)</li> <li>Graph Search (Pathfinder)</li> </ul>	<ul style="list-style-type: none"> <li>Molecular Dynamics (NAMD, AMBER, LAMMPS)</li> <li>Quantum ChromoDynamics (MILC)</li> <li>Weather/Environment modeling (WRF)</li> </ul>

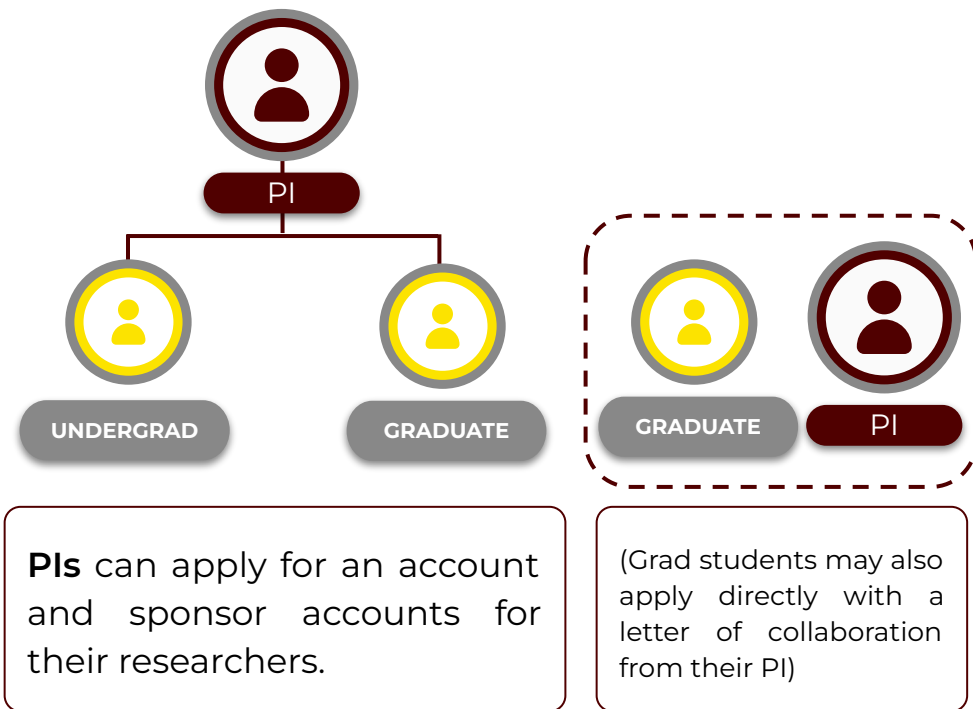
# ACES Configuration - Feb 2024

planned



# Getting on ACES

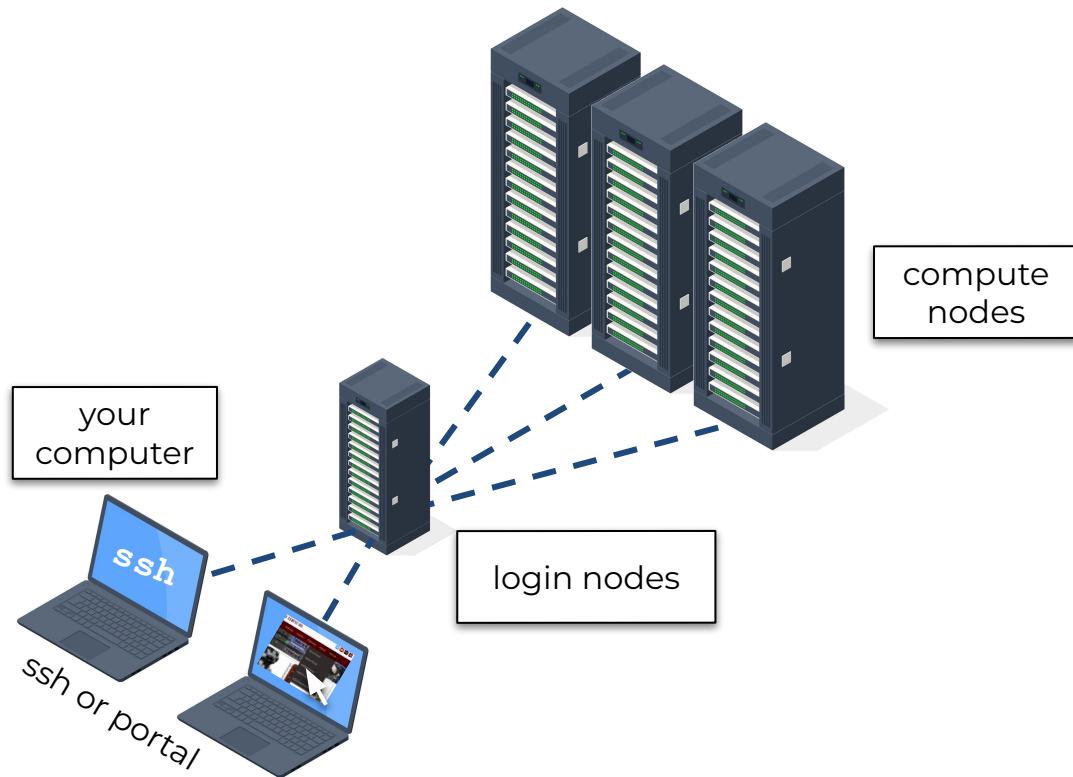
- You must have an [ACCESS](#) account!
- Application for ACES is available through ACCESS: <https://allocations.access-ci.org>
- Email us at [help@hprc.tamu.edu](mailto:help@hprc.tamu.edu) for questions, comments, and concerns.



# 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](https://hprc.tamu.edu), Portal dropdown menu



TEXAS A&M HIGH PERFORMANCE RESEARCH COMPUTING



Home User Services Resources Research Policies Events Training About Portal

- Terra Portal
- Grace Portal
- FASTER Portal
- FASTER Portal (ACCESS)
- ACES Portal (ACCESS)
- Launch Portal (ACCESS)

## Events

- Courses
- Seminars
- User Meetings
- Workshops
- THECB Micro-credential Courses

## Quick Links

New User Information

## COURSES

Last Updated: February 12, 2024

Every semester, Texas A&M High Performance Research Computing (HPRC) offers a variety of training in topics for beginning, intermediate, and advanced researchers. The semesters start with hour long **primer** courses that provide the foundational material that is prerequisite to ALL other short courses. These, along with courses on the clusters and schedulers form the core of the training. These courses are delivered in an interactive style through a live login session. In general, slides and other supplemental materials are available on each course page.

# Accessing ACES via the HPRC Portal (ACCESS)

Log-in using your ACCESS credentials.

The screenshot shows the ACCESS portal interface. At the top left is the ACCESS logo, and at the top right is the 'Powered By CILogon' logo. A teal header bar contains the text 'Consent to Attribute Release' with a dropdown arrow. Below this is a white box with the text: 'TAMU FASTER ACCESS\_OOD requests access to the following information. If you do not approve this request, do not proceed.' followed by a bulleted list: 'Your CILogon user identifier', 'Your name', 'Your email address', and 'Your username and affiliation from your identity provider'. Below the consent box is a teal header bar with the text 'Select an Identity Provider'. Underneath is a dropdown menu showing 'ACCESS CI (XSEDE)' with a question mark icon. Below the dropdown is a checkbox labeled 'Remember this selection' and a teal 'Log On' button. At the bottom of the selection box, it says 'By selecting "Log On", you agree to the [privacy policy](#).' At the very bottom of the page, there is a footer with small text: 'For questions about this site, please see [FAQs](#) or send email to [help@cilogon.org](mailto:help@cilogon.org). Know your responsibilities using the CILogon Services. See [acknow/isp/privac](#) for support for this site.'

The screenshot shows the ACCESS portal login page. At the top left is the ACCESS logo, and at the top right is the CILogon logo. The main heading is 'Login to CILogon'. Below this are two input fields: 'ACCESS Username' and 'ACCESS Password'. There is a checkbox labeled 'Don't Remember Login' and a teal 'Login' button. To the right of the login form is the CILogon logo and the text 'CILogon facilitates secure access to CyberInfrastructure (CI)'. Below this are several links: 'If you had an XSEDE account, please enter your XSEDE username and password for ACCESS login', 'Register for an ACCESS Account', 'Forgot your password?', and 'Need Help?'. At the bottom of the page, there is a footer with the text 'Click Here for Assistance'.

This is a close-up of the 'Select an Identity Provider' dropdown menu. The dropdown is highlighted with a yellow border and shows the option 'ACCESS CI (XSEDE)' with a question mark icon to its right.

Select the Identity Provider appropriate for your account.

# Shell Access via the Portal

ACES OnDemand Portal Files Jobs Clusters Interactive Apps Affinity Groups Dashboard

>\_aces Shell Access

Get a shell terminal right in your browser

# ACES

ACCELERATING COMPUTING FOR EMERGING SCIENCES

```
Host: login.aces Theme: Default
Warning: Permanently added 'login.aces,10.71.1.13' (ECDSA) to the list of known hosts.
*****
This computer system and the data herein are available only for authorized
purposes by authorized users. Use for any other purpose is prohibited and may
result in disciplinary actions or criminal prosecution against the user. Usage
may be subject to security testing and monitoring. There is no expectation of
privacy on this system except as otherwise provided by applicable privacy laws.
Refer to University SAP 29.01.03.M0.02 Acceptable Use for more information.
*****

Last login: Mon Feb 12 13:11:13 2024 from 10.71.1.6

=====
Texas A&M University High Performance Research Computing

Website: https://hprc.tamu.edu
Consulting: help@hprc.tamu.edu (preferred) or (979) 845-0219
ACES Documentation: https://hprc.tamu.edu/kb/User-Guides/ACES
FASTER Documentation: https://hprc.tamu.edu/kb/User-Guides/FASTER
Grace Documentation: https://hprc.tamu.edu/kb/User-Guides/Grace
Terra Documentation: https://hprc.tamu.edu/kb/User-Guides/Terra
YouTube Channel: https://www.youtube.com/texasamhprc
=====

*****
==== 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 ***

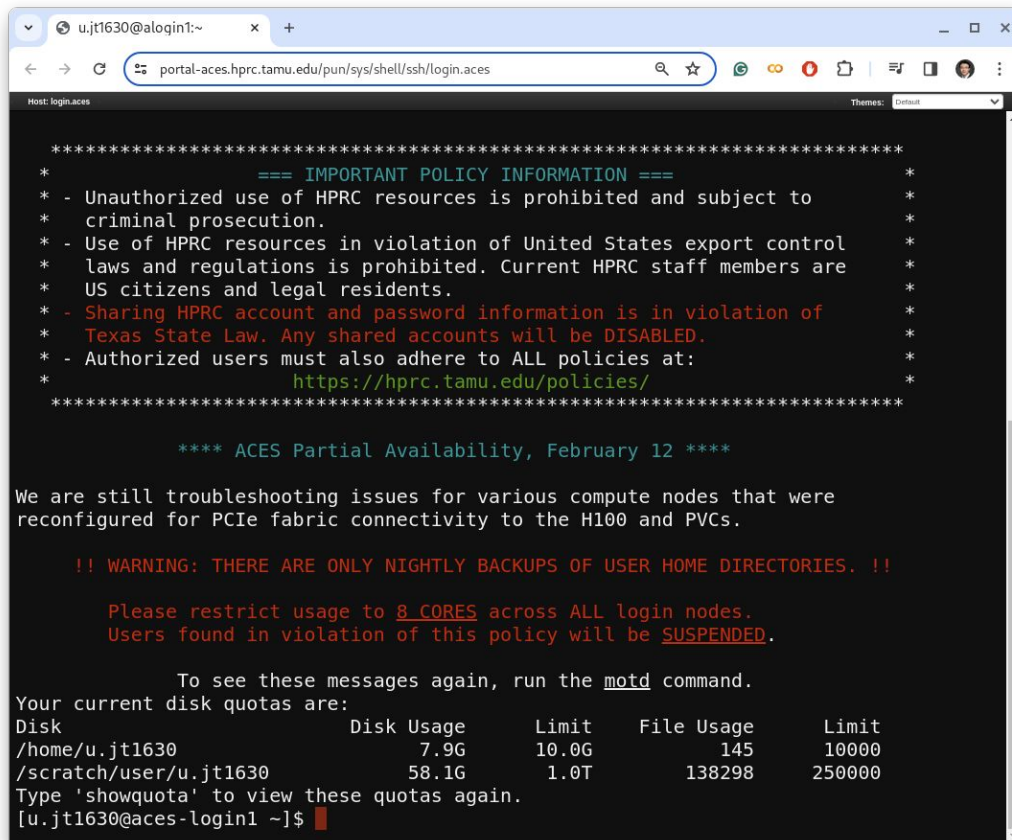
We are still troubleshooting issues for various compute nodes that were
reconfigured for PCIe fabric connectivity to the H100 and PVCs.

!! 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:
Disk          Disk Usage    Limit  File Usage    Limit
/home/u..jw123527  169M          499      10000
/scratch/user/u..jw123527  28.1G        1.0T    102472  250000
Type 'showquota' to view these quotas again.
[u..jw123527@aces-login3 ~]$ !
```

# ACES Shell Access - Shell



```
u.jt1630@alogin1:~
portal-aces.hprc.tamu.edu/pun/sys/shell/ssh/login.aces

Host: login.aces
Themes: Default

*****
*                               *
*      === 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. *
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* https://hprc.tamu.edu/policies/ *
*****

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Users found in violation of this policy will be SUSPENDED.

To see these messages again, run the motd command.
Your current disk quotas are:
Disk          Disk Usage      Limit   File Usage      Limit
/home/u.jt1630      7.9G           10.0G    145             10000
/scratch/user/u.jt1630  58.1G         1.0T     138298          250000
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
```

```
...
```

## Step 2. Load the module

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

## Step 3. Start Julia REPL

```
$ julia
```

```
[u.jt1630@aces-login1 ~]$ julia
Documentation: https://docs.julialang.org
Type "?" for help, "]" for Pkg help.
Version 1.10.2 (2024-03-01)
Official https://julialang.org/ release

julia> |
```

You can also use the [web-based interface](#) to find software modules available on HPRC systems.

# Using Your Own Julia Installation

## Step 1. Find the version to be installed at [Download Julia](#)

Current stable release: v1.10.2 (March 1, 2024)

Checksums for this release are available in both [SHA256](#) and [MD5](#) formats.

Platform	64-bit	32-bit
Windows <a href="#">[help]</a>	installer, portable	installer, portable
macOS x86 (Intel or Rosetta) <a href="#">[help]</a>	.dmg, .tar.gz	
macOS (Apple Silicon) <a href="#">[help]</a>	.dmg, .tar.gz	
Generic Linux on x86 <a href="#">[help]</a>	glibc (GPG) musl <sup>[1]</sup> (GPG)	glibc (GPG)
Generic Linux on ARM <a href="#">[help]</a>	AArch64 (GPG)	
Generic FreeBSD on x86 <a href="#">[help]</a>	.tar.gz (GPG)	

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

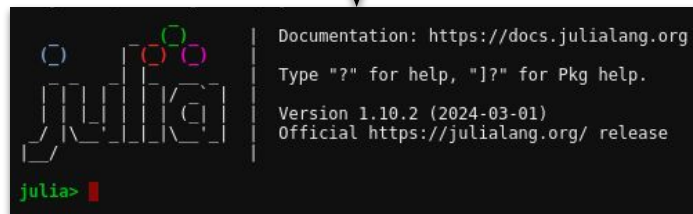
```
$curl -fsSL https://install.julialang.org | sh
```

## 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
```



```
Documentation: https://docs.julialang.org
Type "?" for help, "!" for Pkg help.
Version 1.10.2 (2024-03-01)
Official https://julialang.org/ release

julia> |
```

# 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

```
$ cd $SCRATCH
```

- Files for this course are located at

```
/scratch/training/julia_examples.tgz
```

Make a copy in your personal scratch directory

```
$ cp /scratch/training/julia/julia_examples.tgz $SCRATCH/
```

- Extract the files

```
$ tar -zxvf julia_examples.tgz
```

- Enter this directory (your local copy)

```
$ cd julia_examples
```

```
$ julia helloworld.jl
```

# Load Julia Module, Compile, and Run


```
[u.jt1630@aces-login1 julia_examples]$ module load Julia/1.10.2-linux-x86_64
[u.jt1630@aces-login1 julia_examples]$ ml

Currently Loaded Modules:
  1) Julia/1.10.2-linux-x86_64

[u.jt1630@aces-login1 julia_examples]$ julia helloworld.jl
hello world!
[u.jt1630@aces-login1 julia_examples]$ julia

Documentation: https://docs.julialang.org
Type "?" for help, "!" for Pkg help.

Version 1.10.2 (2024-03-01)
Official https://julialang.org/ release



julia> versioninfo()
Julia Version 1.10.2
Commit bd47eca2c8a (2024-03-01 10:14 UTC)
Build Info:
  Official https://julialang.org/ release
Platform Info:
  OS: Linux (x86_64-linux-gnu)
  CPU: 96 × Intel(R) Xeon(R) Platinum 8468
  WORD_SIZE: 64
  LIBM: libopenlibm
  LLVM: libLLVM-15.0.7 (ORCJIT, sapphirerapids)
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 = :

julia> █
```

# 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>**, 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

Keybinding	Description
<code>^d</code>	Exit (when buffer is empty)
<code>^c</code>	Interrupt or cancel
<code>^l</code>	Clear console screen
Return/Enter, <code>^j</code>	New line, executing if it is complete
<code>?</code> or <code>;</code>	Enter help or shell mode (when at start of a line)
<code>^R</code> , <code>^S</code>	Incremental history search
<code>]</code>	Enter Pkg REPL
Backspace or <code>^c</code>	Quit Pkg REPL

**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/>
- customized for "greedy, unreasonable, demanding programmers".
- [Julia Computing](#) established in 2015 to provide commercial support.

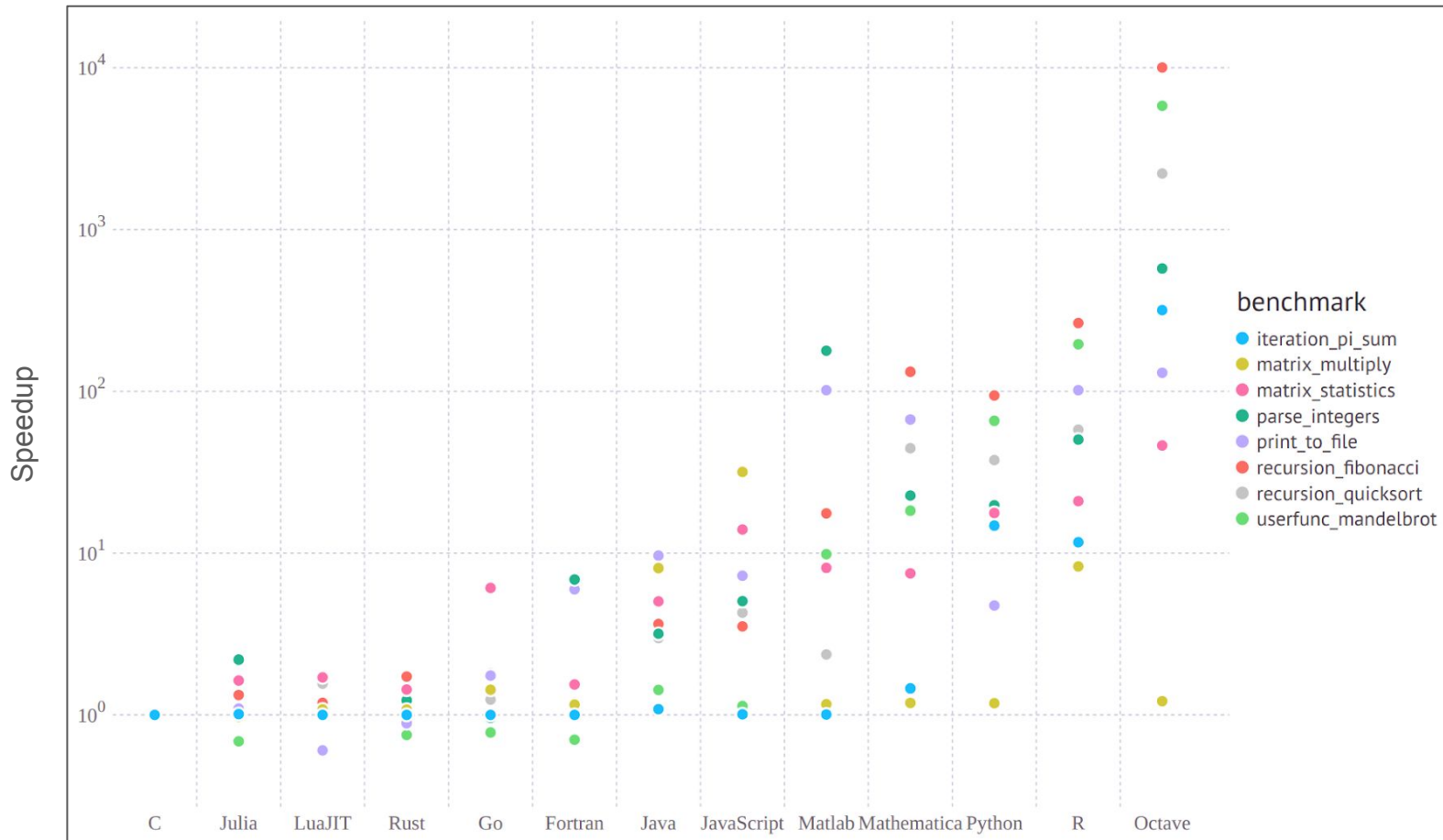


Image Credit: [Julia Micro-Benchmarks](https://www.julia-lang.org/en/learn/microbenchmarks)

# RedMonk Q124 Programming Language Rankings

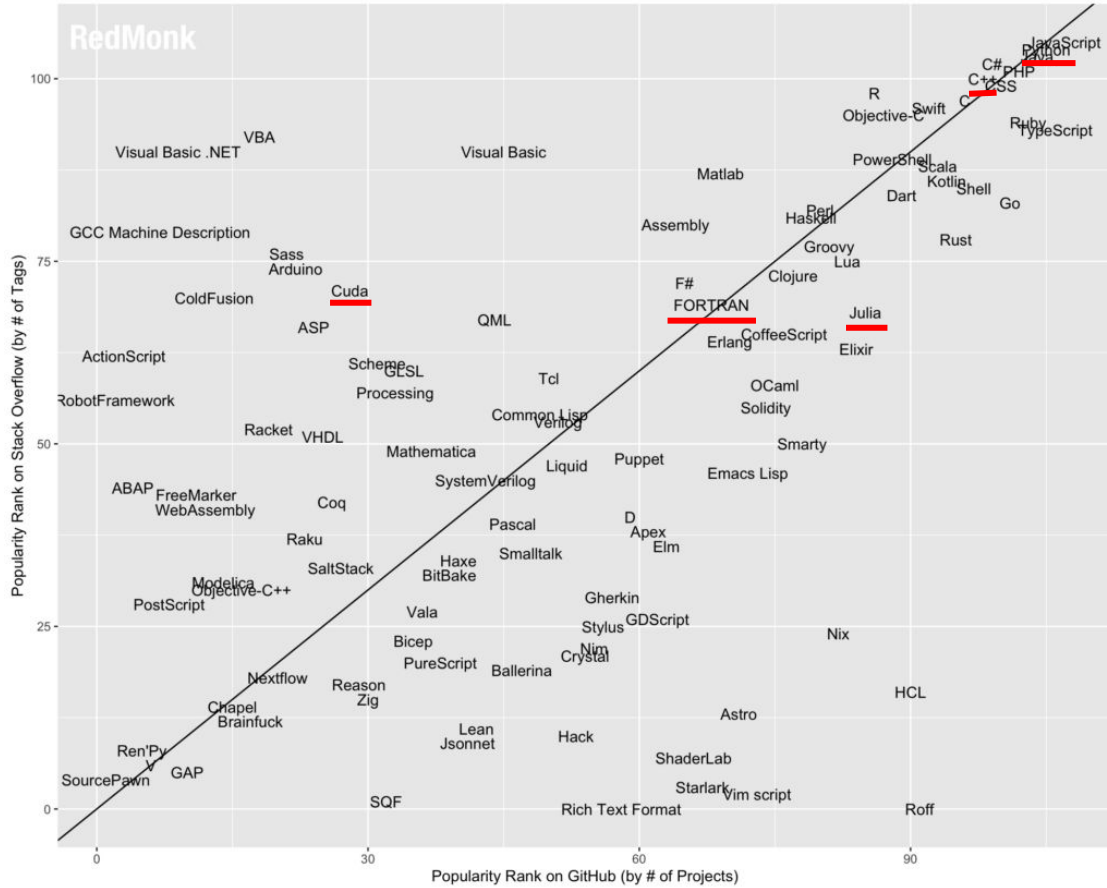


Image Credit: RedMonk ([The RedMonk Programming Language Rankings: January 2024 – tecosystems](https://www.redmonk.com/blog/redmonk-programming-language-rankings-january-2024/))



## 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.

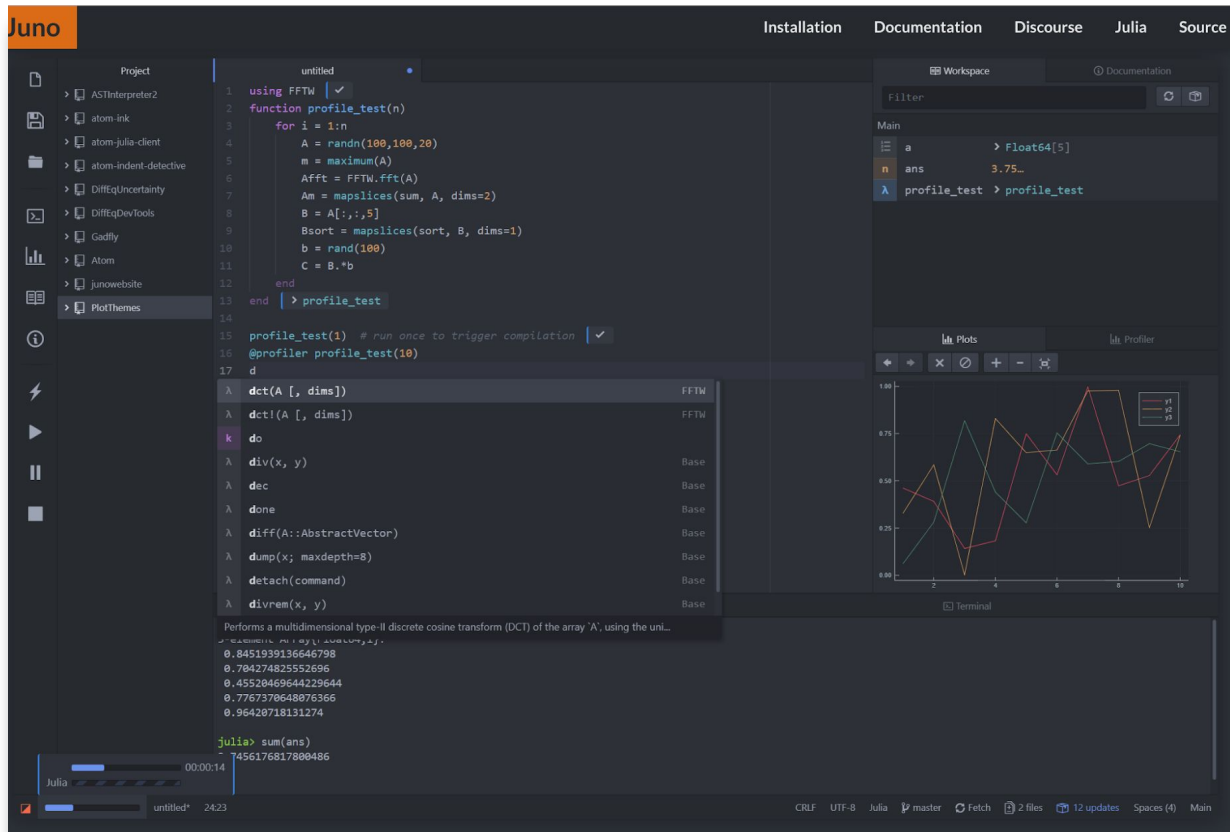


Image Credit: Juno (<http://junolab.org/>)

# Jupyter Notebook

The image displays two overlapping Jupyter Notebook windows. The background window shows the 'Welcome to Jupyter' page with instructions on how to run Python code. The foreground window is titled 'Lorenz Differential Equations' and contains text about the Lorenz system, its equations, and an interactive plot of the Lorenz attractor with sliders for parameters.

**Exploring the Lorenz System**

In this Notebook we explore the [Lorenz system](#) of differential equations:

$$\begin{aligned}\dot{x} &= \sigma(y - x) \\ \dot{y} &= \rho x - y - xz \\ \dot{z} &= -\beta z + xy\end{aligned}$$

This is one of the classic systems in non-linear differential equations. It exhibits a range of complex behaviors as the parameters  $(\sigma, \beta, \rho)$  are varied, including what are known as *chaotic solutions*. The system was originally developed as a simplified mathematical model for atmospheric convection in 1963.

In [7]: `interact(Lorenz, N=fixed(10), angle=(0.,360.),  
sigma=(0.0,50.0),beta=(0.,5), rho=(0.0,50.0))`

angle 308.2  
max\_time 12  
sigma 10  
beta 2.6  
rho 28

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

# Julia REPL

```
[u.jt1630@aces-login2 ~]$ julia
Documentation: https://docs.julialang.org
Type "?" for help, "]" for Pkg help.
Version 1.9.3 (2023-08-24)
Official https://julialang.org/ release

julia> |
```

A screenshot of a terminal window showing the Julia REPL interface. The terminal prompt is [u.jt1630@aces-login2 ~]\$ julia. Below the prompt, the Julia logo is displayed in a stylized, colorful font. To the right of the logo, the following text is shown: Documentation: https://docs.julialang.org, Type "?" for help, "]" for Pkg help., Version 1.9.3 (2023-08-24), and Official https://julialang.org/ release. At the bottom left, the prompt julia> is visible with a red cursor.

- 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

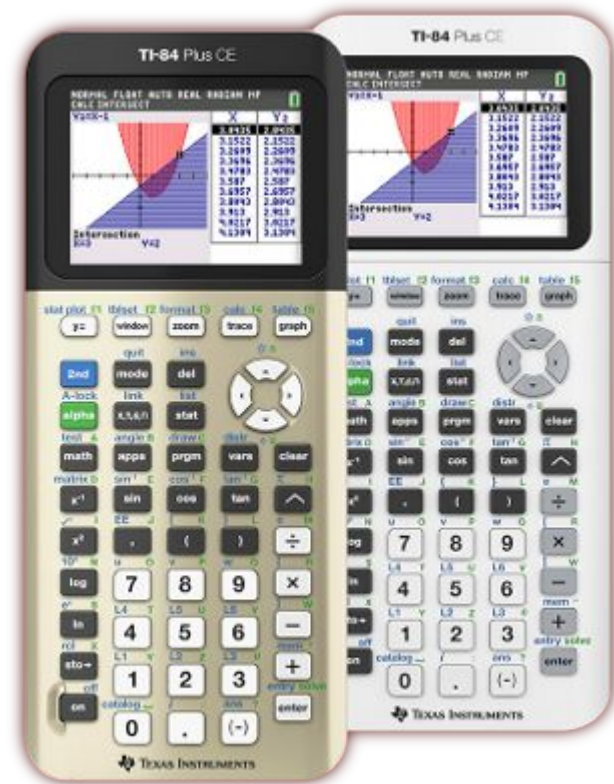


Image Credit: <http://www.ti.com/>



# Arithmetic Operators

<code>+</code>	Addition (also unary plus)
<code>-</code>	Subtraction (also unary minus)
<code>*</code>	multiplication
<code>/</code>	division
<code>\</code>	inverse division
<code>%</code>	mod
<code>^</code>	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

<code>==</code>	True, if it is equal
<code>!=, ≠</code>	True, if not equal to <code>#\ne &lt;TAB&gt;</code>
<code>&lt;</code>	less than
<code>&gt;</code>	greater than
<code>&lt;=, ≤</code>	less than or equal to <code>#\le &lt;TAB&gt;</code>
<code>&gt;=, ≥</code>	greater than or equal to <code>#\ge &lt;TAB&gt;</code>

*\* try `≠(4,5)`, what does this mean? How about `!=(4,5)`*

# Boolean and Bitwise Operators

<code>&amp;&amp;</code>	Logical and
<code>  </code>	Logical or
<code>!</code>	Not
<code>xor()</code>	Exclusive OR
<code> </code>	Bitwise OR
<code>~</code>	Negate
<code>&amp;</code>	Bitwise And
<code>&gt;&gt;</code>	Right shift
<code>&lt;&lt;</code>	Left shift

# NaN and Inf

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

```
julia> NaN == NaN #false
```

**Inf** is positive infinity of type Float64.

```
julia> NaN != NaN  
true
```

**-Inf** is negative infinity of type Float64.

```
julia> NaN < NaN  
false
```

```
julia> NaN > NaN  
false
```

```
julia> isequal(NaN, NaN)  
true
```

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

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

# 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:

$$(b+5.4)^{1/3}$$

$$a > b \ \&\& \ a > 1.0$$

$$b^2 - 4b + 5a$$

$$a \neq b$$

# 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)
```

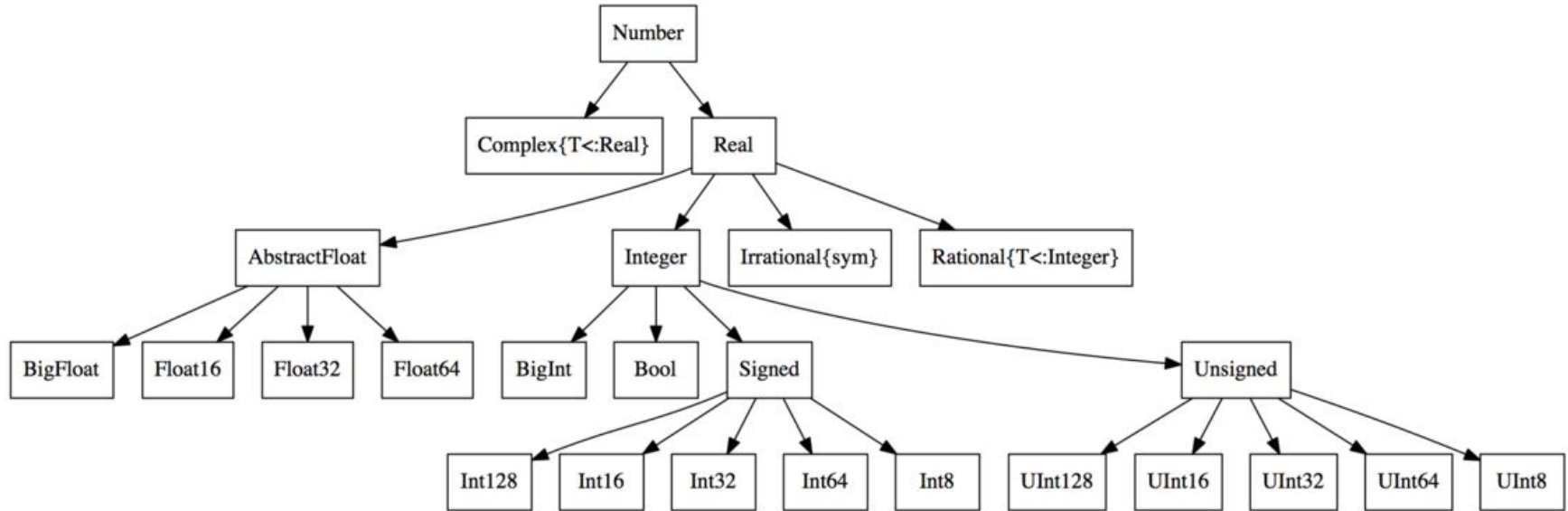
# Basic Syntax for Statements (II)

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. 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

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 #0.333333333333333326
```

```
julia> c = 3*b    #0.99999999999999998
```

```
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

## Rounding and division functions

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

## Sign and absolute value functions

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

\* *The built-in math functions in Julia are implemented in C([openlibm](#)).*

# 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> 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
```

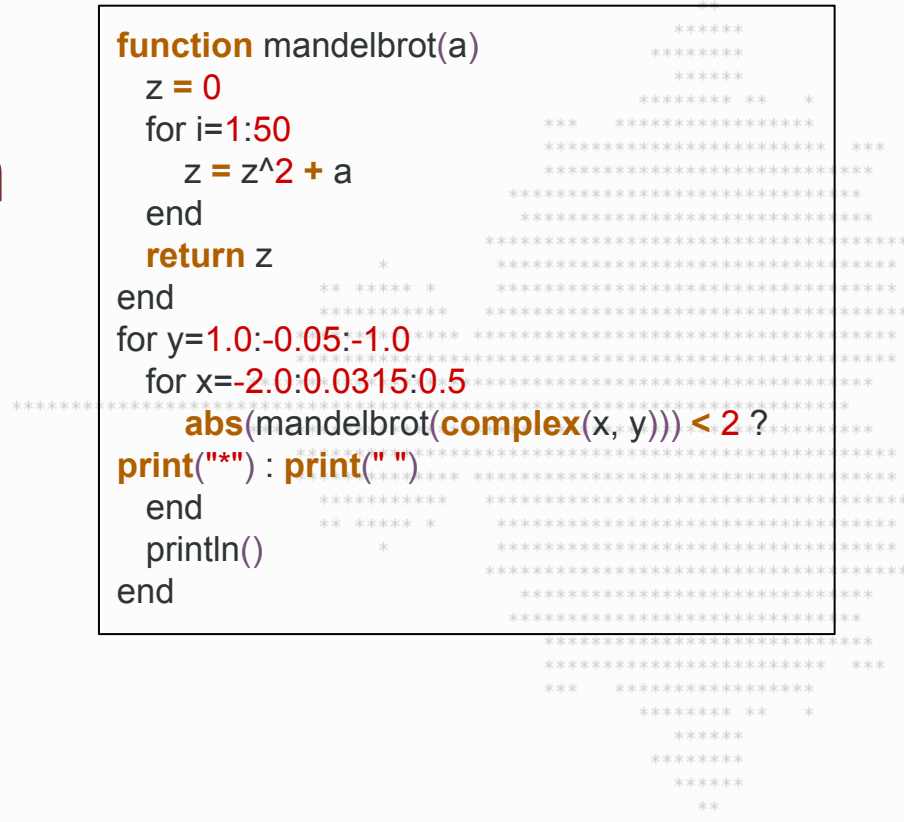
- Type `?help` to get more information about help

```
Julia> ?help
```

# Part IV. Basics of Julia

## 1. Functions - Building Blocks of Julia

```
function mandelbrot(a)
    z = 0
    for i=1:50
        z = z^2 + a
    end
    return z
end
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> function func(x,y)
    return x + y, x
end
```

```
julia> Σ(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

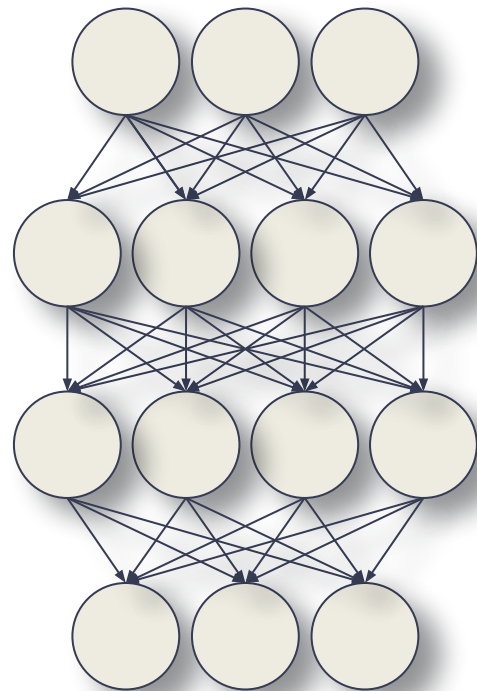
Julia functions can be treated the same as other Julia objects. You can return a function within a function.

```
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)
```

# 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> 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
```

# 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 is 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

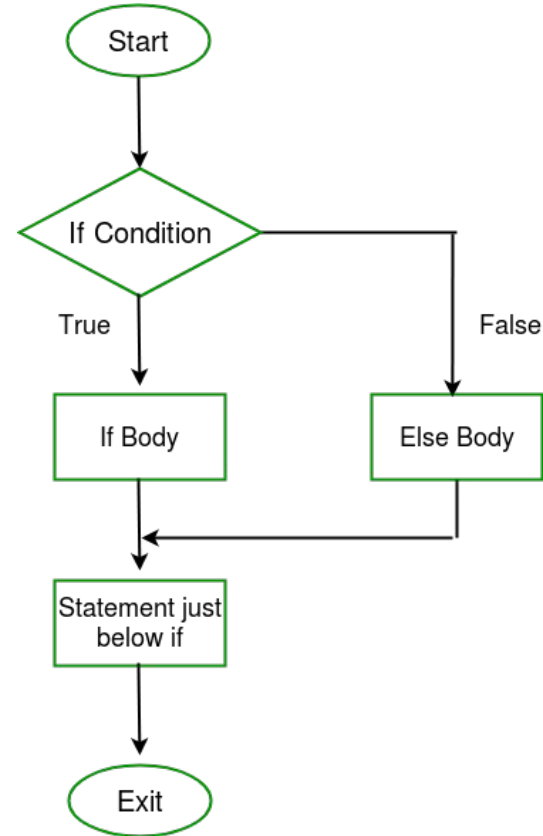


Image Credit: <https://www.geeksforgeeks.org>



# 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 ":",

```
julia> x = 1
```

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

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

```
julia> isodd(41) && 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> 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.

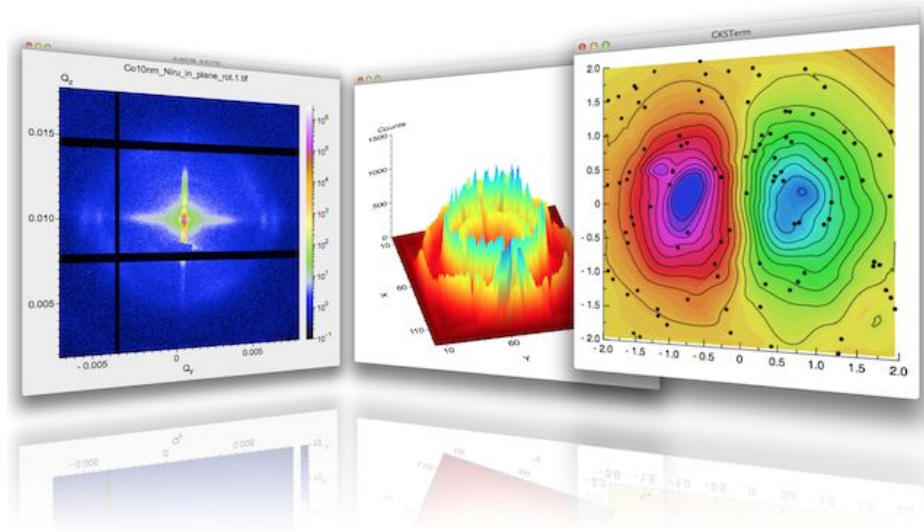
```
julia> n = 1
julia> s = 0
julia> while n <= 100
            s = s + n
            n = n + 1
        end
julia> println(s)
```

# Exception Handling Blocks

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

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

# Part V. Plotting with Julia

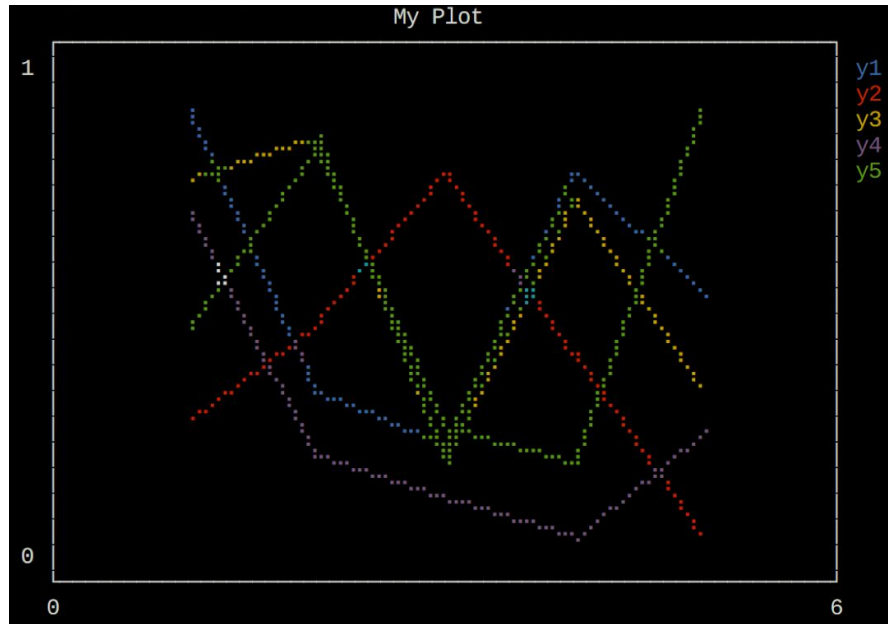




# UnicodePlots

[UnicodePlots](#) is simple and lightweight and it plots directly in your terminal (*might not work with web-based shell*).

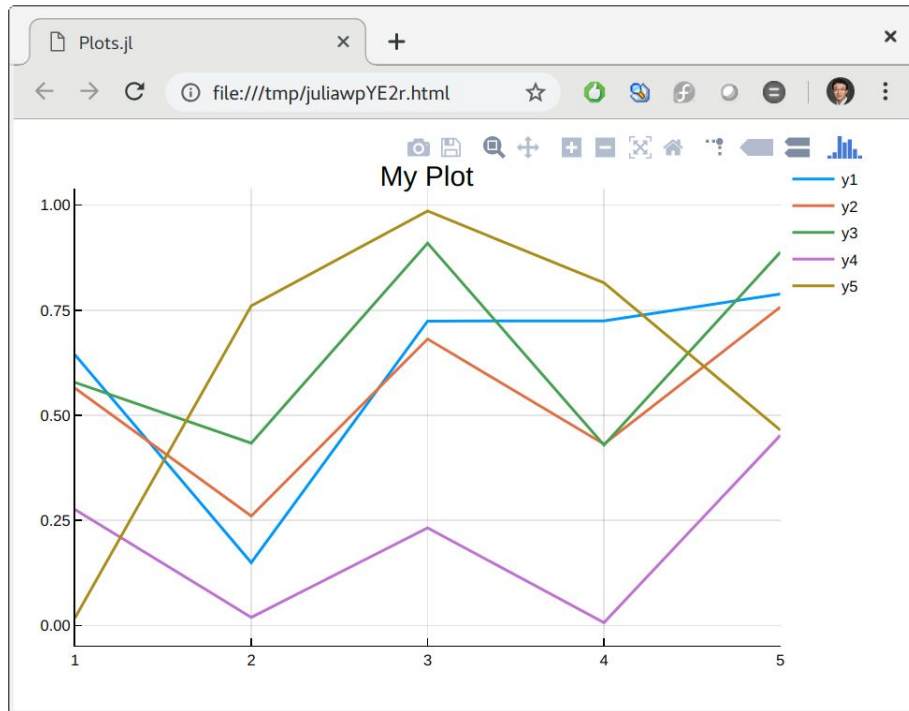
```
julia> using Plots
julia> unicodeplots()
julia> plot(rand(5,5),
linewidth=2, title="My
Plot")
```



# 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 (not working with web-based shell).

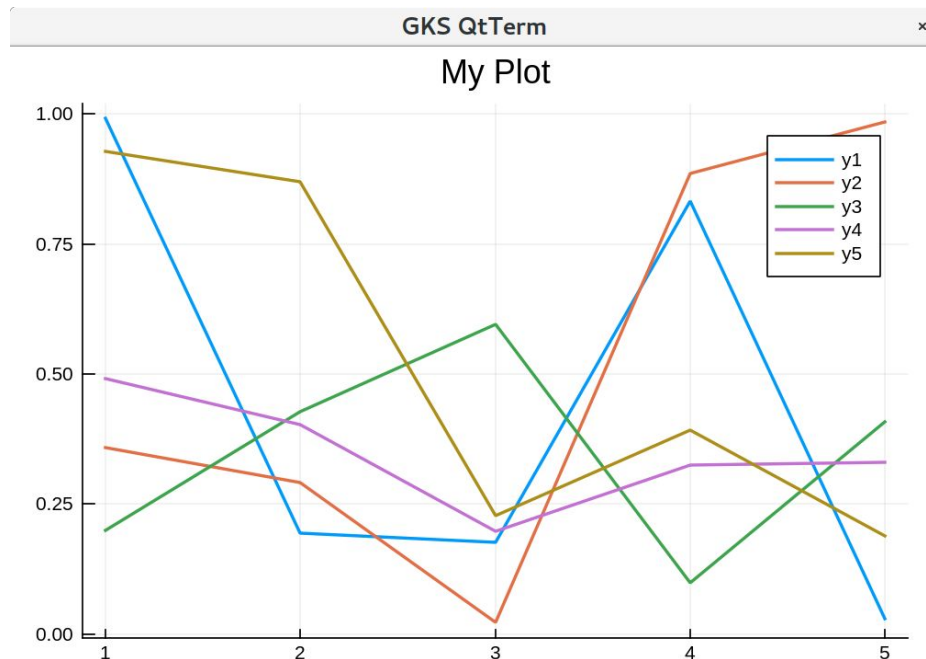
```
julia> using Plots
julia> plotly()
julia> plot(rand(5,5),
linewidth=2, title="My
Plot")
```



# GR Framework

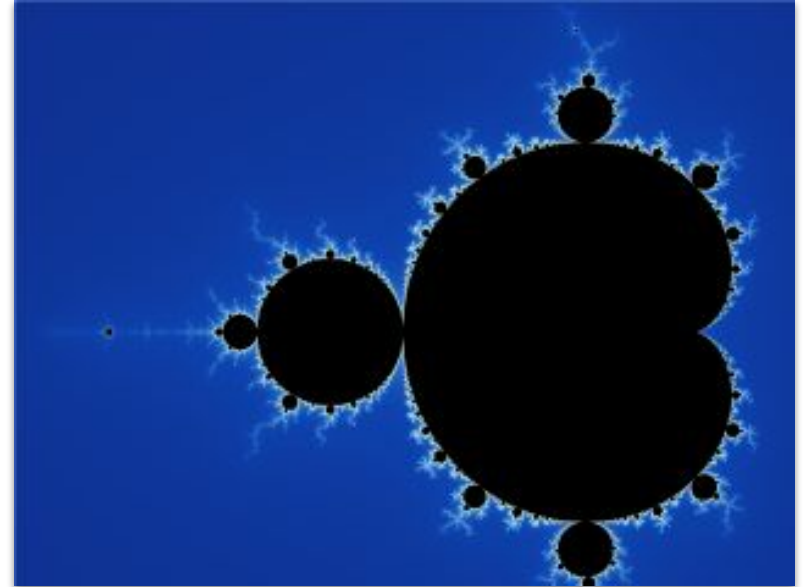
[GR framework](#) is a universal framework for cross-platform visualization applications (not working with web-based shell).

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



# 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  $z_0=0$ .
- Mandelbrot set is the set of values of  $c$  when  $z_n$  remains bounded for a relatively large  $n$ .



# Mandelbrot - Julia Version

```
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)

[https://en.wikibooks.org/wiki/Introducing\\_Julia](https://en.wikibooks.org/wiki/Introducing_Julia)

MATLAB–Python–Julia cheatsheet

<https://cheatsheets.quantecon.org/>

The Fast Track to Julia

<https://juliadocs.github.io/Julia-Cheat-Sheet/>

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- Support from [NSF OAC Award #2112356](#) - Category II: ACES - Accelerating Computing for Emerging Sciences



# Appendix

# 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

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

Julia manages its packages with **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  
American Standard  
Code for Information  
Interchange

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 **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.