

HPC User Environment 1

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HPC User Services

LSU HPC / LONI

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Louisiana State University

Baton Rouge

September 10, 2025

- **HPC User Environment 1**

1. An Intro to HPC
2. Accounts and allocations
3. Introduction to the cluster
4. Software environment (modules)

- **HPC User Environment 2**

1. Queuing system
2. How to run jobs

- **HPC User Environment 1**

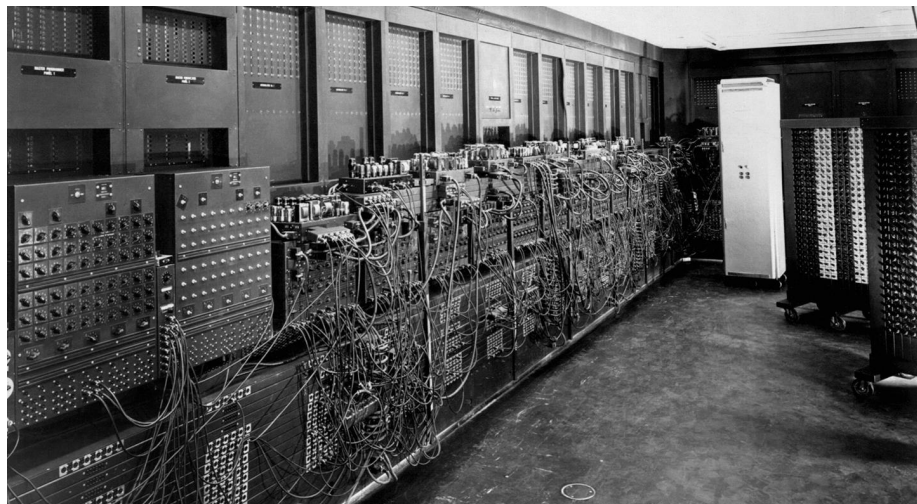
1. An Intro to HPC
 - 1) Why HPC?
 - 2) What is HPC?
 - 3) Our HPC
2. Getting started
 - 1) Accounts
 - 2) Allocation
3. Into the cluster
 - 1) Getting connected
 - 2) File system
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- **HPC User Environment 1**

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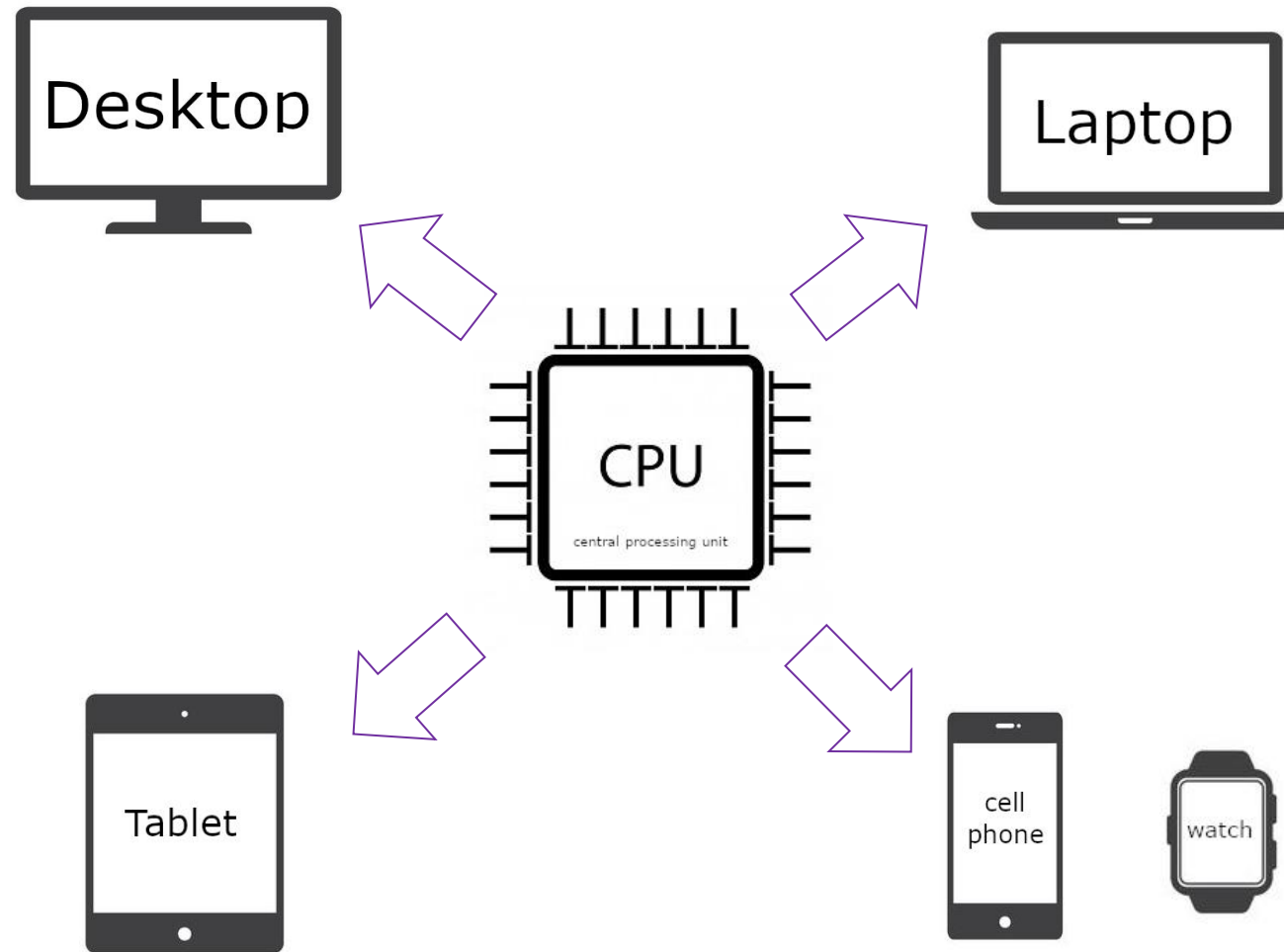
1) Why HPC?

- Everything **COMPUTER!**



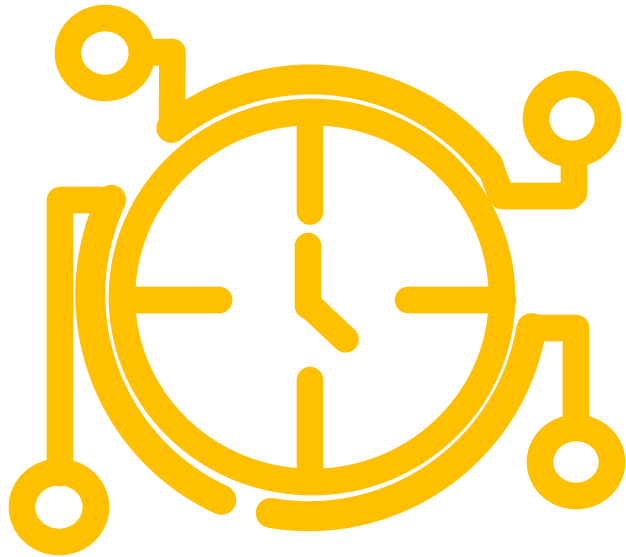
ENIAC, 1945

First all-vacuum tube supercomputer (18000 vacuum tubes), a decimal computer, hard-wired program with dials and switches.

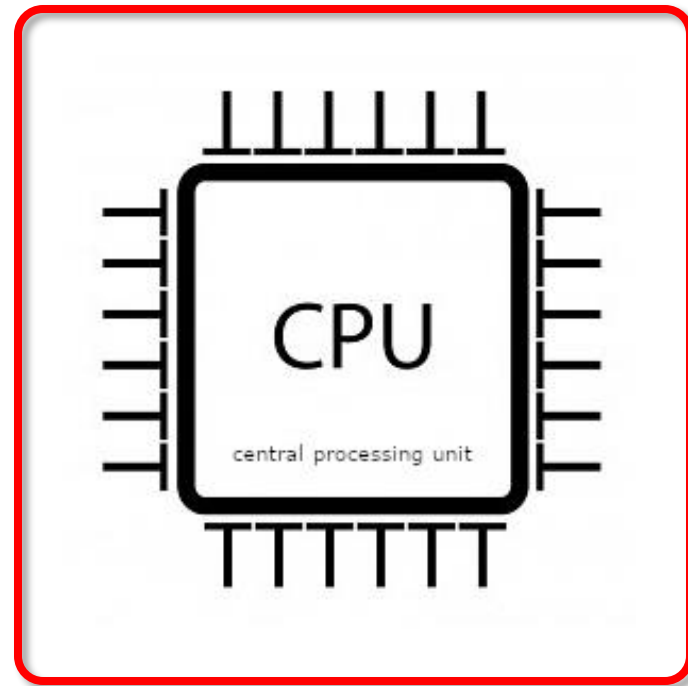


Moor's law – double transistors every two years

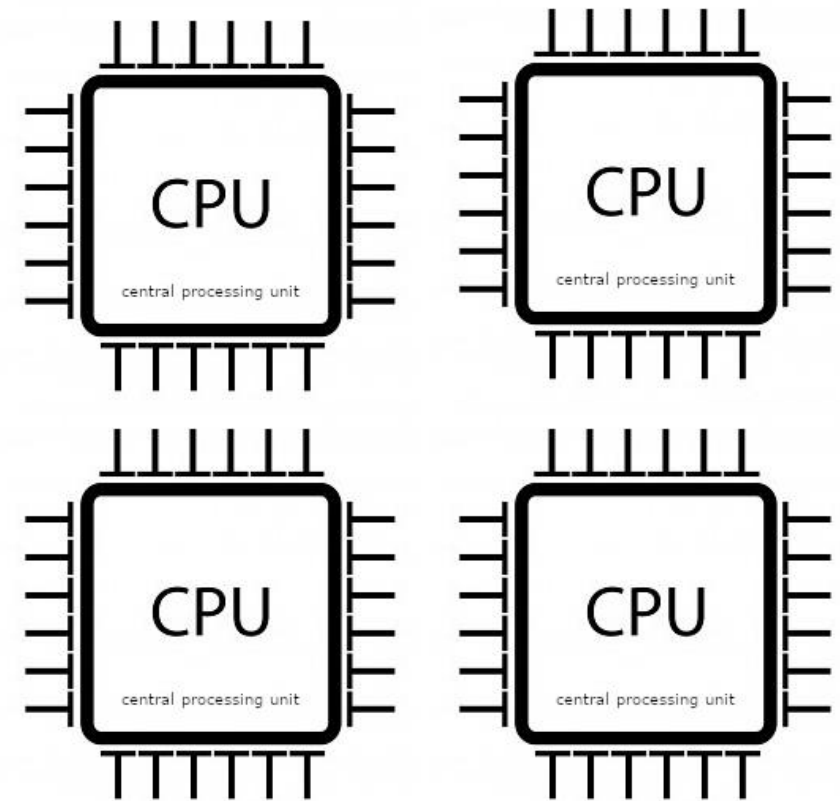
Transistor size – atom size



Clock speed? –
cycles per second

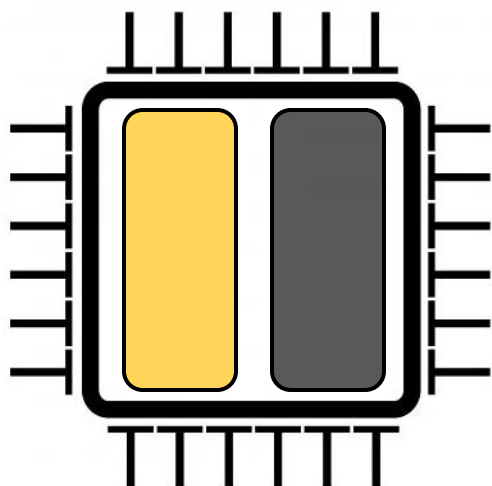


Intel® Core™ i7-1065G7 Processor
8M Cache, up to 3.90 GHz

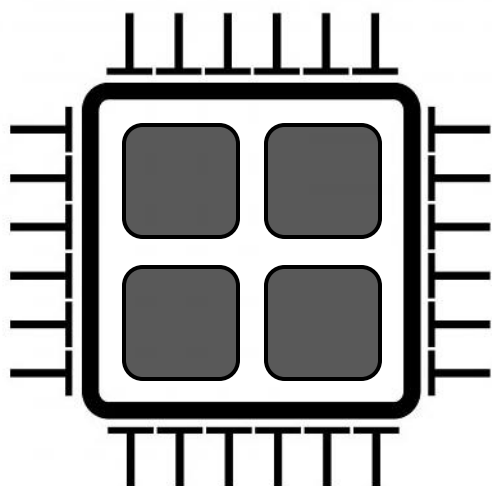


Parallel computing



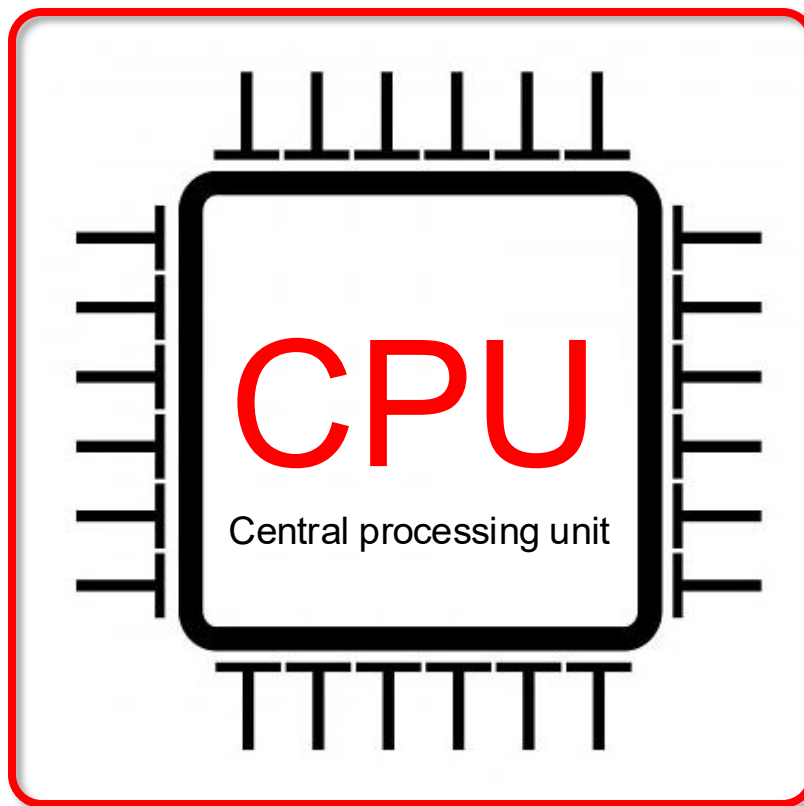


Dual-core CPU

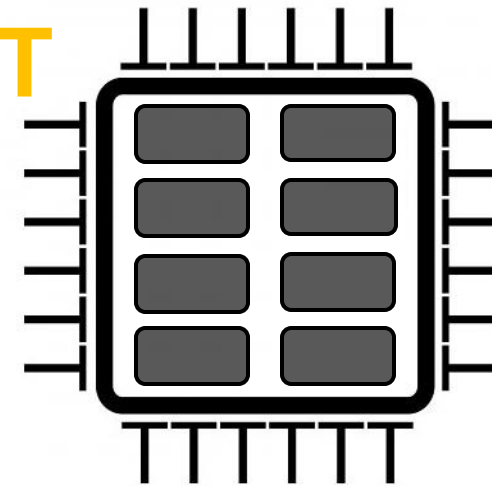


Quad-core CPU

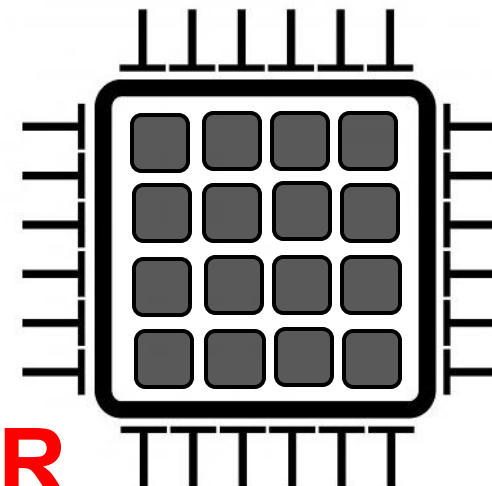
CORE = TASK UNIT



CPU = PROCESSOR



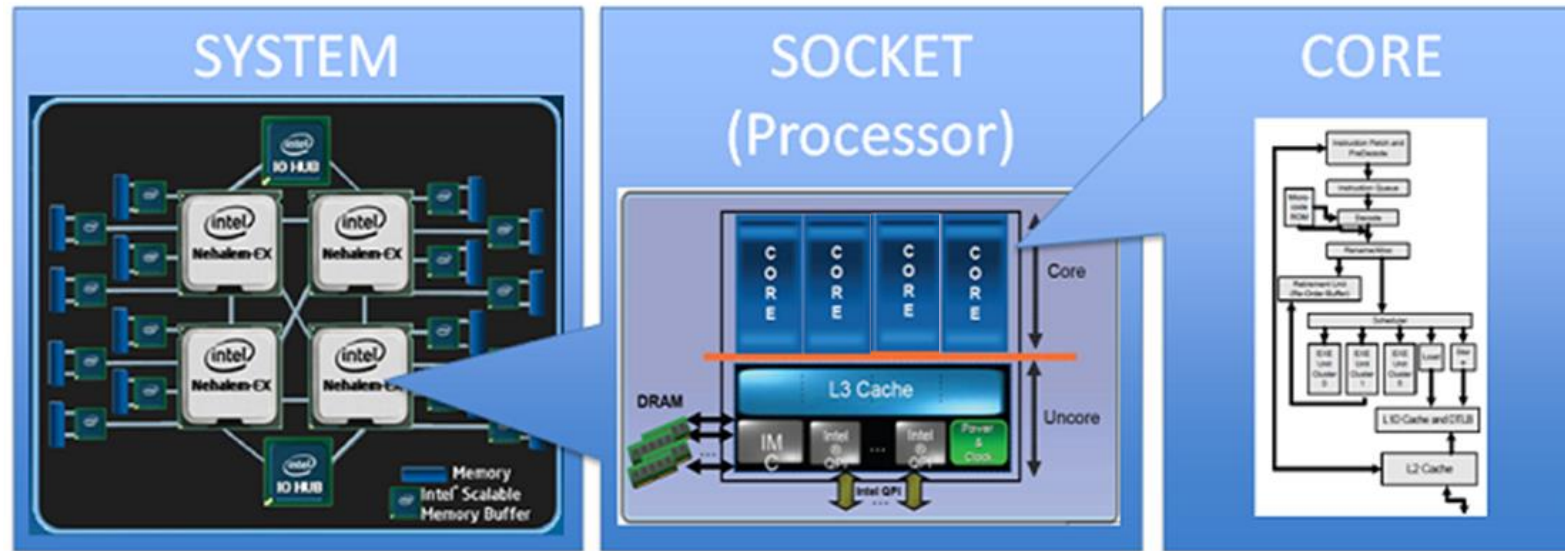
Octa-core CPU



Multiple-core CPU

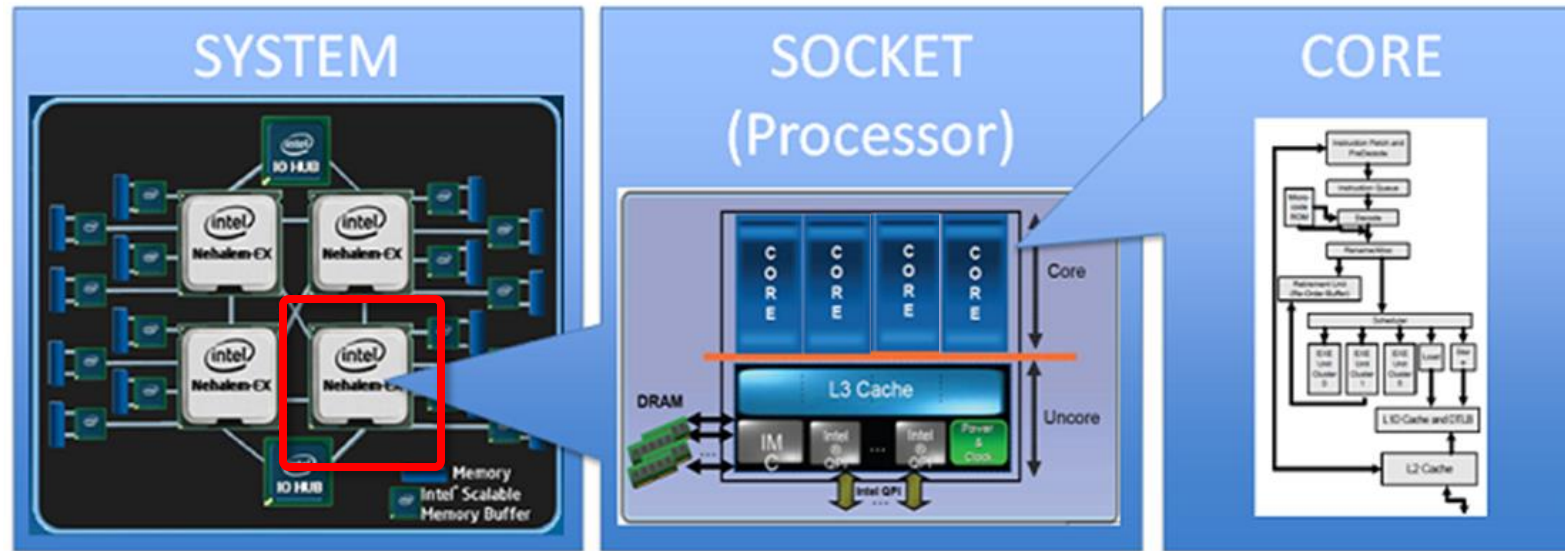
1) Why HPC?

- How many processors does this computer have?



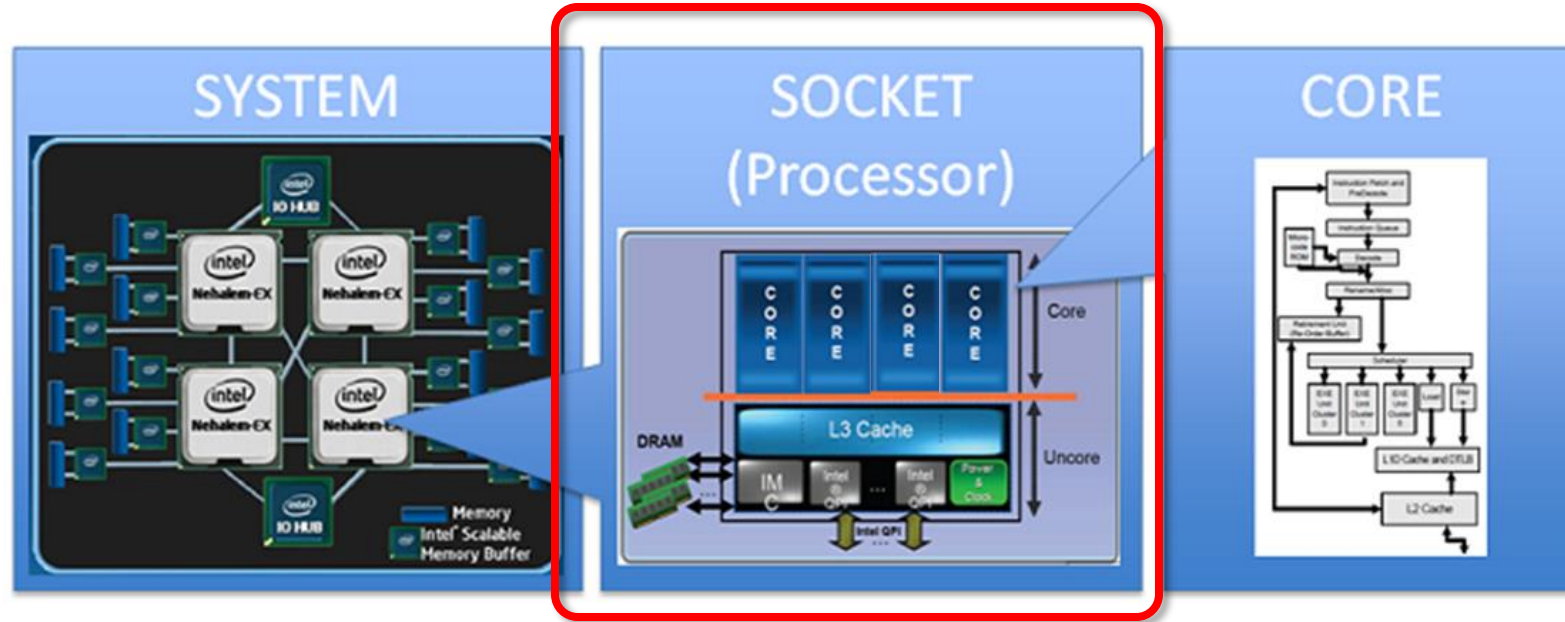
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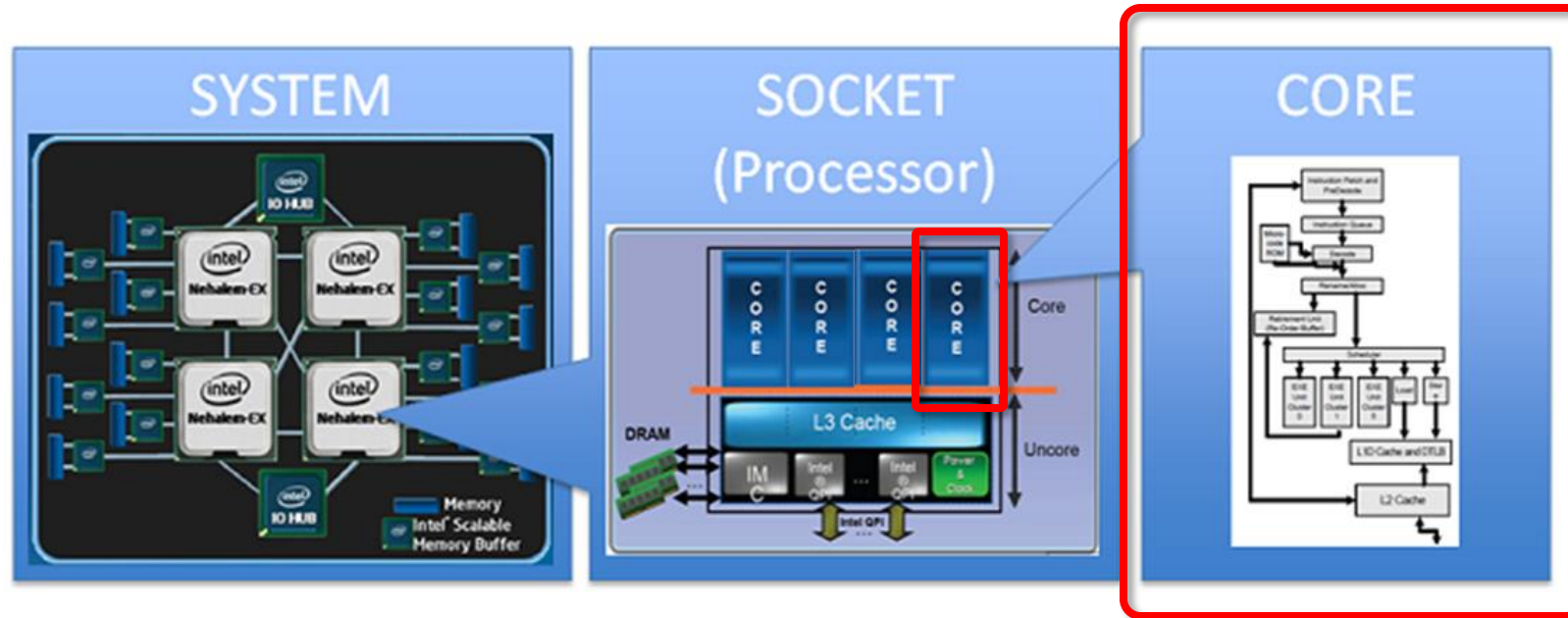
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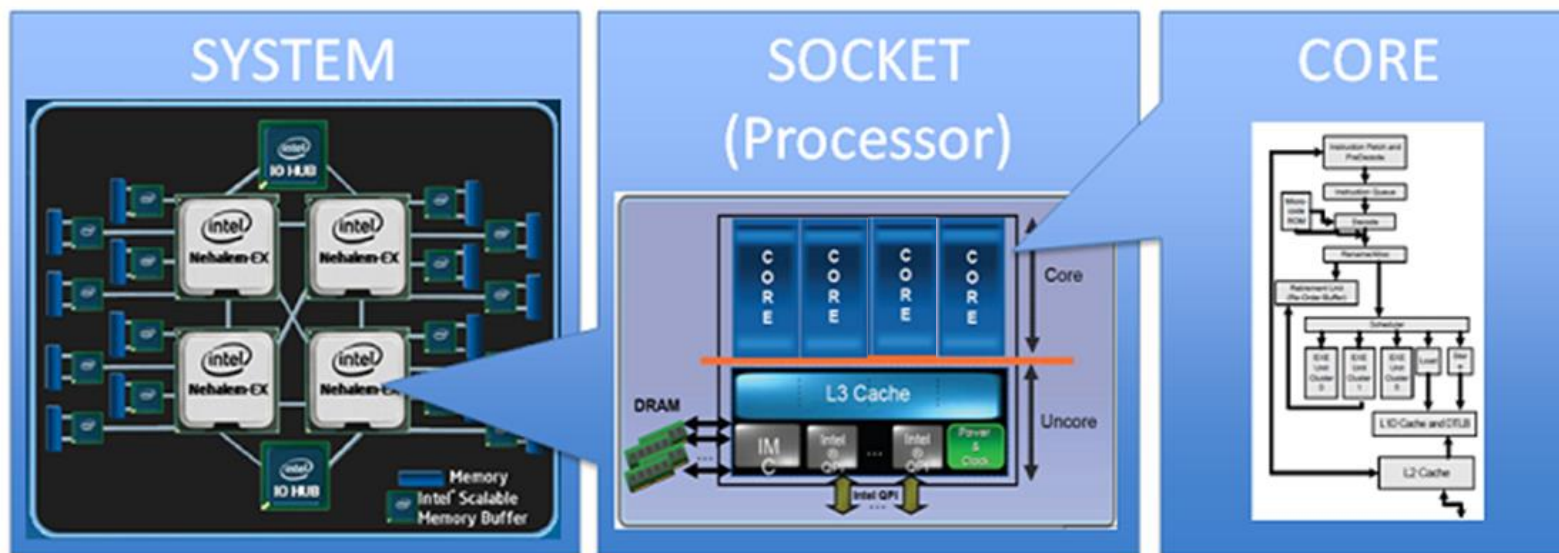
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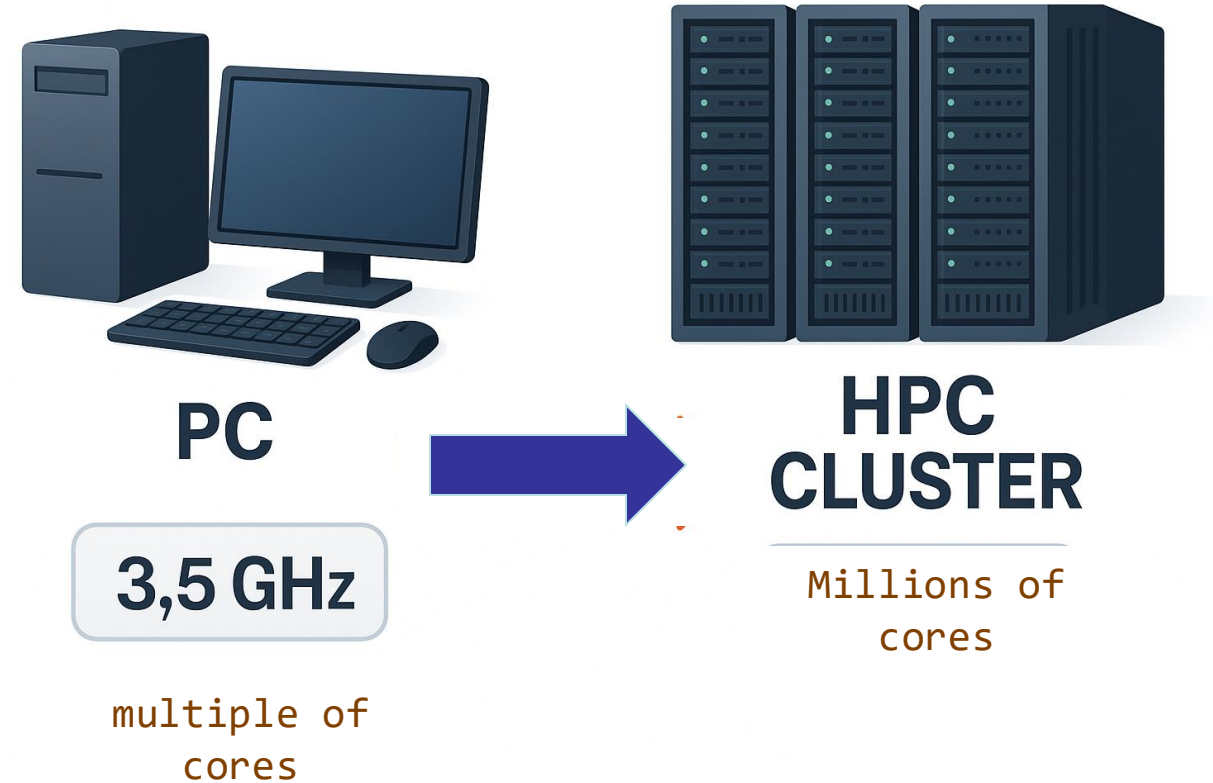


4 cores * 4 processors = **16** total cores

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2) What is HPC?

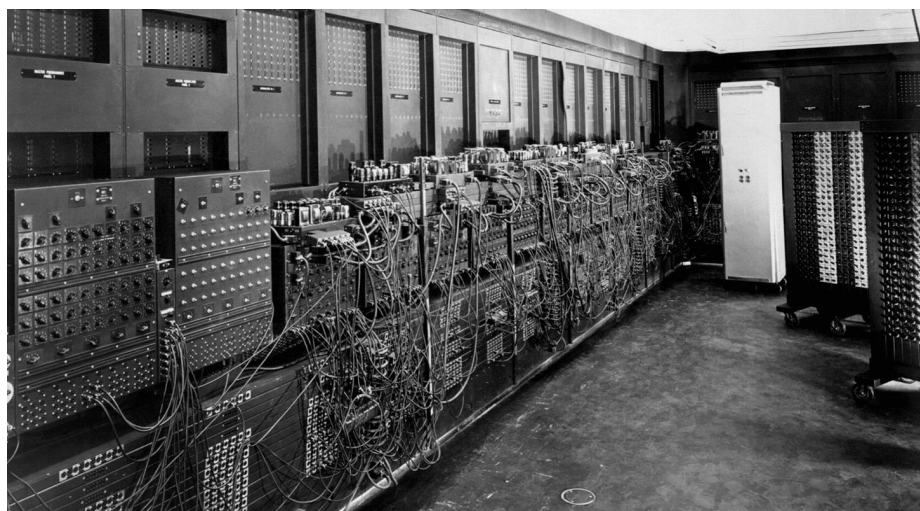
- **High Performance Computing (HPC):**
The ability to process data and perform complex calculations at high speeds using cutting-edge modern technology.
- **Supercomputer:**
The class of machines that ranks among the fastest in the world.
 - Rule of thumb: a supercomputer has millions of cores in comparison to a single PC.



How do we evaluate the performance of supercomputer?

2) What is HPC?

- Performance is measured in **Floating Point Operations Per Second (FLOPS)**



ENIAC FLOPS: **500**

$$FLOPS = \text{cores} \times \text{clock} \times \frac{FLOPs}{\text{cycle}}$$

↓ ↓ ↓ ↓

1267 GHz 18 4.4 GHz 16

1.27 TFLOPS

Computer performance

Name	FLOPS
yottaFLOPS	10 ²⁴
zettaFLOPS	10 ²¹
exaFLOPS	10 ¹⁸
petaFLOPS	10 ¹⁵
teraFLOPS	10 ¹²
gigaFLOPS	10 ⁹
megaFLOPS	10 ⁶
kiloFLOPS	10 ³

“The first teraflop desktop PC: Intel i97980XE (Sep 2017)”

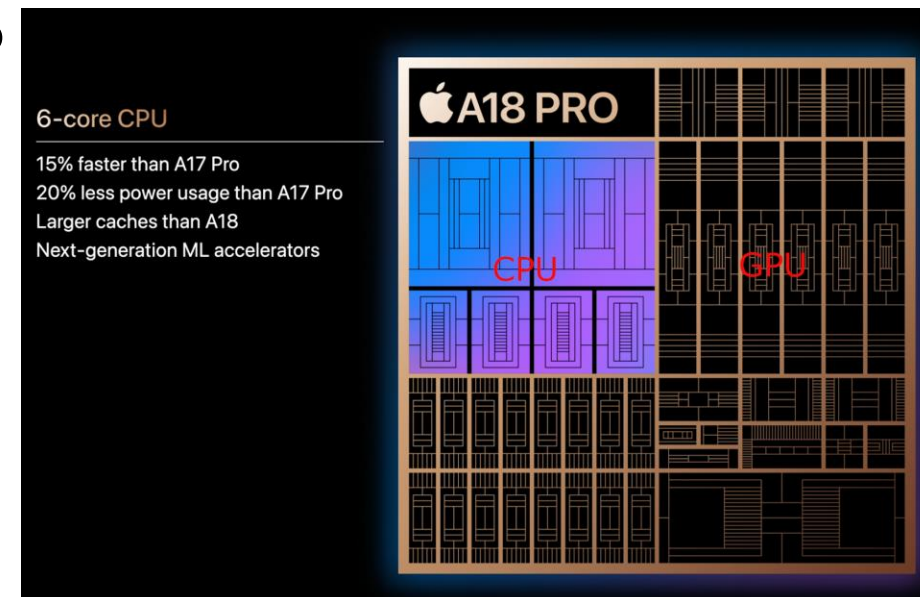
CPU clock rate: 4.4 GHz
CORE: 18 cores
FLOPs per cycle: 16



2) What is HPC?

- Your smartphone vs. supercomputer 24 and 30 years ago
 - **Apple A18 Pro** (Hexa-core, 4.04 GHz): ~**2.6 TFLOPS (FP32)**
(can perform 2.6 trillion 32-bit math operations per second)
 - #1 ASCI WHITE, SP POWER3 375 MHz: **7.3 (12.3) TFLOPS**
Total Cores: **8,192**, OS: **AIX**; Vendor: **IBM (2000)**
 - #1 **Fujitsu** 105MHz: **0.2 (0.4) TFLOPS**
Total Cores: **140**, OS: **UXP/V**; Vendor: **Fujitsu (1994)**

iPhone 16 Pro (2024)



CPU clock rate: 4.04 GHz
CORE: ARMv9.2, 6 cores
Transistors: 18 billion
Technology: 3 nm
OS system: iOS 18.5

2) What is HPC?



Rank	System	Cores	Rmax (PFlop/s)	Rpeak (PFlop/s)	Power (kW)
1	El Capitan - HPE Cray EX255a, AMD 4th Gen EPYC 24C 1.8GHz, AMD Instinct MI300A, Slingshot-11, TOSS, HPE DOE/NNSA/LLNL United States	11,039,616	1,742.00	2,746.38	29,581
2	Frontier - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE Cray OS, HPE DOE/SC/Oak Ridge National Laboratory United States	9,066,176	1,353.00	2,055.72	24,607
3	Aurora - HPE Cray EX - Intel Exascale Compute Blade, Xeon CPU Max 9470 52C 2.4GHz, Intel Data Center GPU Max, Slingshot-11, Intel DOE/SC/Argonne National Laboratory United States	9,264,128	1,012.00	1,980.01	38,698

Current (September 2025)

[1] Top 500 list, <https://top500.org/lists/top500/2024/06/>



2) What is HPC?



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2) What is HPC?



Rpeak = Number of CPUs x Cores per CPU x Clock Speed (Hz) x FLOPs per cycle

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2) What is HPC?



June 2019:

Rank	System	Cores	Rmax (PFlop/s)	Rpeak (PFlop/s)	Power (kW)
474	QB-2 - Dell C8220X Cluster, Intel Xeon E5-2680v2 10C 2.8GHz, Infiniband FDR, NVIDIA K20x, DELL EMC Louisiana Optical Network Initiative United States	23,040	1.05	1.47	500

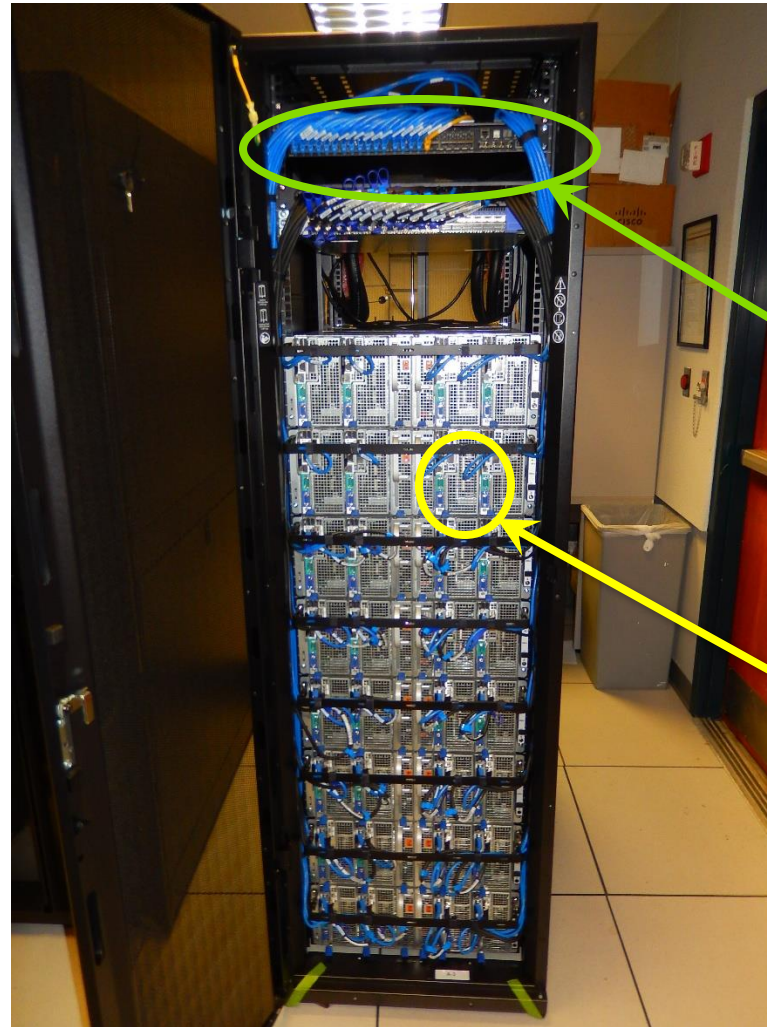
2) What is HPC?

- Inside a cluster:



2) What is HPC?

- Inside a rack:

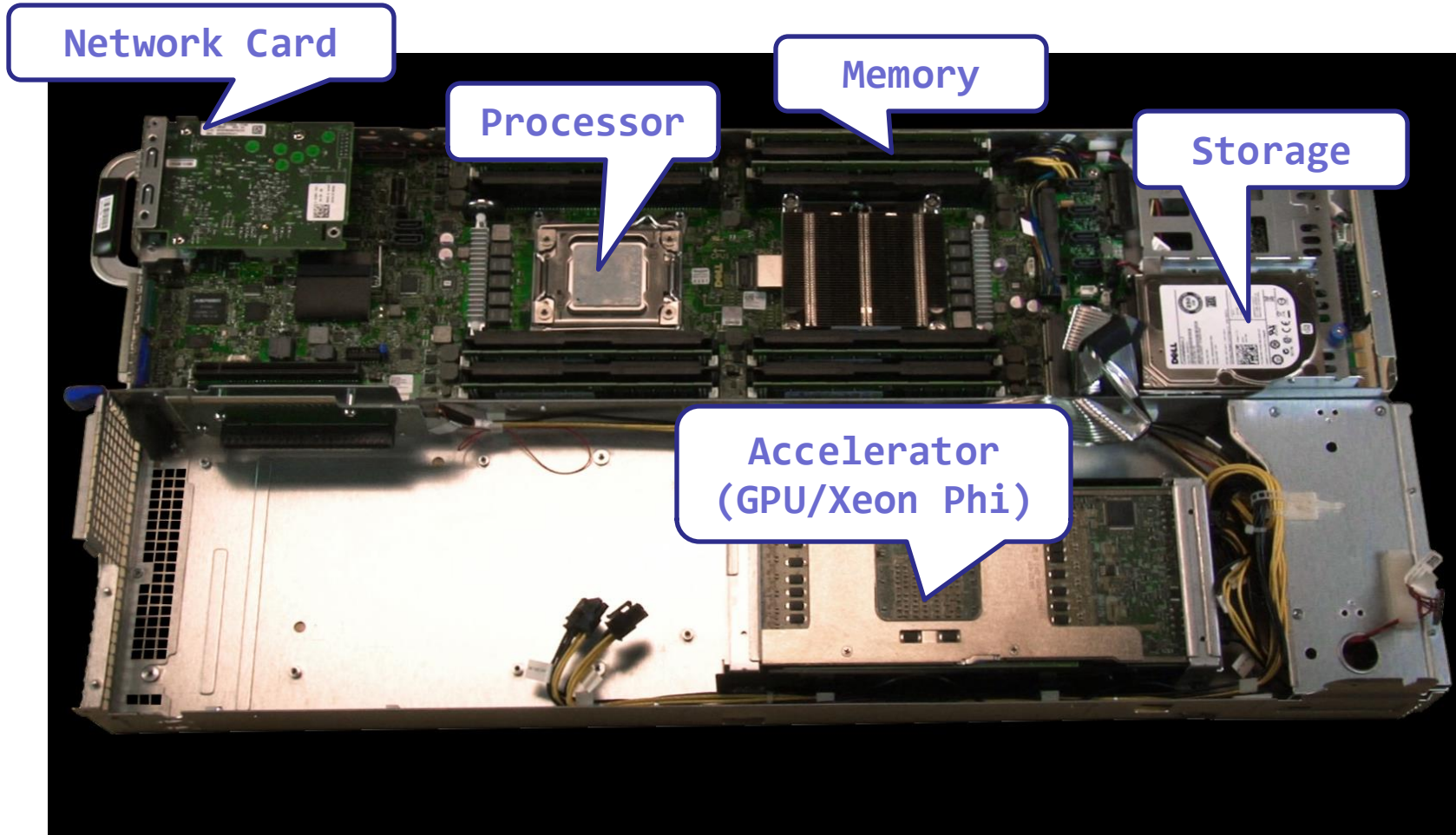


Interconnect:
Infiniband
Switch

Compute
Node

2) What is HPC?

- Inside a node:



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3) Our HPC

- i. University level: **LSU HPC**
- ii. State level: **LONI**
- iii. National level: **ACCESS**

Universities of
Louisiana State



Louisiana State
University Campus,
Baton Rouge, LA



Advancing
Innovation

Universities of the United States

i. **University level: LSU HPC**

- Available to **LSU (Baton Rouge campus) Faculty** and their **affiliates**
- Administered & supported by HPC@LSU



HPC HPC HPC HIGH PERFORMANCE COMPUTING

i. University level: **LSU HPC**

SuperMIC	
Hostname	smic.hpc.lsu.edu
Peak Performance/TFlops	1000
Compute nodes	360
Processor/node	2 10-core
Processor Speed	2.8 GHz
Processor Type	Intel Xeon 64bit
Nodes with Accelerators	360
Accelerator Type	Xeon Phi 7120P
OS	RHEL v8
Vendor	
Memory per node	64 GB
Detailed Cluster Description	
User Guide	
Available Software	

Deep Bayou	
Hostname	db1.lsu.edu
Peak Performance/TFlops	257
Compute nodes	13
Processor/node	2 24-core
Processor Speed	2.4 - 3.0 GHz
Processor Type	Intel Cascade Lake Xeon 64bit
Nodes with Accelerators	13
Accelerator Type	2 x NVIDIA Volta V100S
OS	RHEL v8
Vendor	Dell
Memory per node	192 GB
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SuperMike III	
Hostname	mike.hpc.lsu.edu
Peak Performance/TFlops	1,285
Compute nodes	183
Processor/node	2 32-core
Processor Speed	2.6GHz
Processor Type	Intel Xeon Ice Lake
Nodes with Accelerators	8
Accelerator Type	4 NVIDIA A100
OS	RHEL v8
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Memory per node	256/2048 GB
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OS	RHEL v8
Vendor	
Memory per node	64 GB
Detailed Cluster Description	
User Guide	
Available Software	

Deep Bayou	
Hostname	db1.lsu.edu
Peak Performance/TFlops	257
Compute nodes	13
Processor/node	2 24-core
Processor Speed	2.4 - 3.0 GHz
Processor Type	Intel Cascade Lake Xeon 64bit
Nodes with Accelerators	13
Accelerator Type	2 x NVIDIA Volta V100S
OS	RHEL v8
Vendor	Dell
Memory per node	192 GB
Detailed Cluster Description	
User Guide	
Available Software	

SuperMike III	
Hostname	mike.hpc.lsu.edu
Peak Performance/TFlops	1,285
Compute nodes	183
Processor/node	2 32-core
Processor Speed	2.6GHz
Processor Type	Intel Xeon Ice Lake
Nodes with Accelerators	8
Accelerator Type	4 NVIDIA A100
OS	RHEL v8
Vendor	Dell
Memory per node	256/2048 GB
Detailed Cluster Description	
User Guide	
Available Software	

[1] <http://www.hpc.lsu.edu/resources/hpc/index.php#lsuhpc>



ii. State level: **Louisiana Optical Network Infrastructure (LONI)**

- State-of-the-art fiber optic network
- Runs throughout Louisiana State, connects Louisiana and Mississippi State research universities.
- \$40M Optical Network, 10Gb Ethernet over fiber optics.
- Available to **LONI subscribers** and their **affiliates**
- Administered & supported by **HPC@LSU**



ii. State level: Louisiana Optical Network Infrastructure (LONI)



Louisiana State University
Louisiana Tech University
University of New Orleans
Southern University
Tulane University
University of Louisiana at Lafayette
Xavier University of Louisiana



ii. State level: Louisiana Optical Network Infrastructure (LONI)

QB3		QB4	
Hostname	qbc.loni.org	Hostname	qbd.loni.org
Peak Performance/TFlops	857	Peak Performance/TFlops	4,300
Compute nodes	202	Compute nodes	547
Processor/node	2 24-Core	Processor/node	2 32-Core
Processor Speed	2.4GHz	Processor Speed	2.6GHz
Processor Type	Intel Cascade Lake Xeon 64bit	Processor Type	Intel Xeon Platinum 8358 64bit
Nodes with Accelerators	8	Nodes with Accelerators	62
Accelerator Type	NVIDIA Volta V100	Accelerator Type	NVIDIA Ampere A100 80GB
OS	RHEL v8	OS	RHEL v8
Vendor	Dell	Vendor	Dell
Memory per node	192 GB	Memory per node	256/512/2048 GB
Location	Information Systems Building, Baton Rouge	Location	Information Systems Building, Baton Rouge
Detailed Cluster Description		Detailed Cluster Description	
User Guide		User Guide	
Available Software		Available Software	

[1] <http://www.hpc.lsu.edu/resources/hpc/index.php#loni>



iii. **National level: Advanced Cyberinfrastructure Coordination Ecosystem: Services & Support (ACCESS)**

- NSF funded
- <https://access-ci.org/>



Advancing
Innovation

- **Summary**

	LSU HPC	LONI HPC
Available to...	LSU faculty & affiliates	LONI subscribers & affiliates
Clusters	SuperMIC Deep Bayou SuperMike III	QB3 QB4

Questions?

- **HPC User Environment 1**

1. Intro to HPC
 - 1) Why HPC?
 - 2) What is HPC?
 - 3) Our HPC
2. Getting started
 - 1) Accounts
 - 2) Allocation
3. Intro the cluster
 - 1) Getting connected
 - 2) File system
4. Software environment
 - 1) Preinstalled (modules)
 - 2) User installation

Two things are needed to run jobs on our clusters

1) Account

2) Allocation

- **HPC User Environment 1**

1. Intro to HPC
 - 1) Why HPC?
 - 2) What is HPC?
 - 3) Our HPC
2. Getting started
 - 1) Accounts
 - 2) Allocation
3. Intro the cluster
 - 1) What users see?
 - 2) Useful commands & tools
4. Software environment
 - 1) Preinstalled (modules)
 - 2) User installation

	LSU HPC	LONI HPC
Available to...	LSU faculty & affiliates	LONI subscribers & affiliates
Clusters	SuperMIC Deep Bayou SuperMike III	QB3 QB4

- LSU HPC & LONI: **distinct systems, distinct accounts**
- Having an account on one does **not** grant the user access to the other

i. Eligibility (LSU HPC)

LSU HPC	
Available to...	
Requirements	

i. Eligibility (LSU HPC)

LSU HPC	
Available to...	<ul style="list-style-type: none">✓ Faculty of LSU Baton Rouge campus✓ Research staff (postdocs, research associates, ...)✓ Students (graduate & undergraduate)✓ Research collaborators (LSU & non-LSU)✓ Other affiliates
Requirements	

i. Eligibility (LSU HPC)

LSU HPC	
Available to...	<ul style="list-style-type: none">✓ Faculty of LSU Baton Rouge campus✓ Research staff (postdocs, research associates, ...)✓ Students (graduate & undergraduate)✓ Research collaborators (LSU & non-LSU)✓ Other affiliates
Requirements	<ul style="list-style-type: none">• Institutional email (e.g., @lsu.edu)• Account sponsor / PI<ul style="list-style-type: none">✓ <u>Full-time faculty & certain research staff @ LSU Baton Rouge campus</u>× Students, postdocs, research associates (even @ LSU)× Outside collaborators× HPC staff

i. Eligibility (LSU HPC)

You are a ...	Your account sponsor

i. Eligibility (LSU HPC)

You are a ...	Your account sponsor
Full-time faculty @ LSU Baton Rouge campus	Yourself

i. Eligibility (LSU HPC)

You are a ...	Your account sponsor
Full-time faculty @ LSU Baton Rouge campus	Yourself
Graduate student @ LSU doing research	Your advisor

i. Eligibility (LSU HPC)

You are a ...	Your account sponsor
Full-time faculty @ LSU Baton Rouge campus	Yourself
Graduate student @ LSU doing research	Your advisor
Outside collaborator	Your LSU collaborator (full-time faculty)

i. Eligibility (LSU HPC)

You are a ...	Your account sponsor
Full-time faculty @ LSU Baton Rouge campus	Yourself
Graduate student @ LSU doing research	Your advisor
Outside collaborator	Your LSU collaborator (full-time faculty)
LSU student taking a course that requires HPC	Your instructor (full-time faculty)

i. Eligibility (LSU HPC)

You are a ...	Your account sponsor
Full-time faculty @ LSU Baton Rouge campus	Yourself
Graduate student @ LSU doing research	Your advisor
Outside collaborator	Your LSU collaborator (full-time faculty)
LSU student taking a course that requires HPC	Your instructor (full-time faculty)
REU student working @ LSU	Your LSU advisor (full-time faculty)

i. Eligibility (LONI)

LONI HPC	
Available to...	<ul style="list-style-type: none">✓ Faculty of LONI subscribers✓ Research staff (postdocs, research associates, ...)✓ Students (graduate & undergraduate)✓ Research collaborators (@ LONI subscribers / outside)✓ Other affiliates
Requirements	<ul style="list-style-type: none">• Institutional email (e.g., @uno.edu)• Account sponsor / PI<ul style="list-style-type: none">✓ <u>Full-time faculty & certain research staff @ LONI subscribers</u>× Students, postdocs, research associates (even @ LONI subscribers)× Outside collaborators× HPC staff

i. Eligibility (LONI)

You are a ...	Your account sponsor
Full-time faculty @ LONI subscribers	Yourself
Graduate student during research	Your advisor (faculty @ LONI subscribers)
Outside collaborator	Your collaborator (faculty @ LONI subscribers)
Student taking a course that requires HPC	Your instructor (faculty @ LONI subscribers)
REU student	Your advisor (faculty @ LONI subscribers)

i. Eligibility (Summary)

	LSU HPC	LONI HPC
Available to...	<ul style="list-style-type: none"> ✓ Faculty of LSU Baton Rouge campus ✓ Research staff (postdocs, research associates, ...) ✓ Students (graduate & undergraduate) ✓ Research collaborators (LSU & non-LSU) ✓ Other affiliates 	<ul style="list-style-type: none"> ✓ Faculty of LONI subscribers ✓ Research staff (postdocs, research associates, ...) ✓ Students (graduate & undergraduate) ✓ Research collaborators ✓ Other affiliates
Requirements	<ul style="list-style-type: none"> • Institutional email (e.g., @lsu.edu) • Account sponsor / PI <ul style="list-style-type: none"> ✓ <u>Full-time faculty & certain research staff @ LSU Baton Rouge campus</u> × Students, postdocs, research associates (even @ LSU) × Outside collaborators × HPC staff 	<ul style="list-style-type: none"> • Institutional email (e.g., @uno.edu) • Account sponsor / PI <ul style="list-style-type: none"> ✓ <u>Full-time faculty & certain research staff @ LONI subscribers</u> × Students, postdocs, research associates (even @ LONI subscribers) × Outside collaborators × HPC staff

i. Eligibility

Test1

❖ I can be granted an LSU HPC or LONI account if:

- a) I am using HPC resource for my research, the account will be sponsored by my advisor (PI)
- b) I am attending HPC training sessions, the account will be sponsored by the HPC staff
- c) I am taking a class that requires using HPC resource, the account will be sponsored by the course instructor
- d) a and b
- e) a and c
- f) All of the above

i. Eligibility

Test1

❖ I can be granted an LSU HPC or LONI account if:

- a) I am using HPC resource for my research, the account will be sponsored by my advisor (PI)
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- c) I am taking a class that requires using HPC resource, the account will be sponsored by the course instructor
- d) a and b
- e) a and c
- f) All of the above

i. Eligibility

Test2

❖ Who may be eligible for LSU HPC accounts? (Choose all that apply)

- a) Alice, a professor in Europe, who collaborates with Professor X @ LSU Baton Rouge campus and wishes to run simulations
- b) Bob, recently graduated from LSU and moved to New York for a postdoc position, but is still working with his PhD advisor Professor Y @ LSU Baton Rouge campus to finish their unfinished research
- c) Charlie, a current undergraduate student @ LSU Baton Rouge campus, who is taking an online Machine Learning course given by Professor Z @ Stanford, and needs practice on a GPU-enabled HPC system

i. Eligibility

Test2

❖ **Who may be eligible for LSU HPC accounts? (Choose all that apply)**

- a) Alice, a professor in Europe, who collaborates with Professor X @ LSU Baton Rouge campus and wishes to run simulations
- b) Bob, recently graduated from LSU and moved to New York for a postdoc position, but is still working with his PhD advisor Professor Y @ LSU Baton Rouge campus to finish their unfinished research
- c) Charlie, a current undergraduate student @ LSU Baton Rouge campus, who is taking an online Machine Learning course given by Professor Z @ Stanford, and needs practice on a GPU-enabled HPC system

ii. How to apply

	LSU HPC	LONI HPC
Portal	https://accounts.hpc.lsu.edu/login_request.php	https://allocations.loni.org/login_request.php

ii. How to apply

	LSU HPC	LONI HPC
Portal	https://accounts.hpc.lsu.edu/login_request.php	https://allocations.loni.org/login_request.php

[1] <http://www.hpc.lsu.edu/links.php>



ii. How to apply

	LSU HPC	LONI HPC
Portal	https://accounts.hpc.lsu.edu/login_request.php	https://allocations.loni.org/login_request.php
Steps	<p>a) Enter your institutional email and submit</p> <p>b) Check email and open the link (valid for 24 hrs)</p> <p>c) Fill the form (In Contact/Collaborator, enter your account sponsor's full name) and submit</p> <p>d) You will receive a notification when your account is activated once we have verified your credentials</p> <ul style="list-style-type: none">• Be patient. Do not reset your password if you cannot log in yet.	

iii. Manage your account

	LSU HPC	LONI HPC
Portal	https://accounts.hpc.lsu.edu	https://allocations.loni.org

iii. Manage your account

	LSU HPC	LONI HPC
Portal	https://accounts.hpc.lsu.edu	https://allocations.loni.org
Things to do	<ul style="list-style-type: none">• Change personal information, password, ...• Change default shell (bash / tcsh / ksh / csh / sh)• Request / manage / check allocation• Request / manage / check storage• ...	

iv. Reset password

	LSU HPC	LONI HPC
Portal	https://accounts.hpc.lsu.edu/user_reset.php	https://allocations.loni.org/user_reset.php

iv. Reset password

	LSU HPC	LONI HPC
Portal	https://accounts.hpc.lsu.edu/user_reset.php	https://allocations.loni.org/user_reset.php
Steps	<p>a) Enter your registered email and submit</p> <p>b) Check email and open the link (valid for 24 hrs)</p> <p>c) Enter your new password and submit</p> <p>d) You will receive a confirmation email once your new password is approved by our staff</p> <p>** IMPORTANT **</p> <ul style="list-style-type: none">Your new password is NOT available right away (wait until you receive confirmation of approval)Do NOT submit multiple times	

iv. Reset password

Case study

- **User:**
“I have been trying to access my accounts on QB3 via an SSH client, but the connection won't go through. I reset my passwords this weekend and the terminals keep giving me a ‘Password Authentication Failed’ error message.....”
- **User Services:**
“When you send a password reset request, it has to be manually processed for security reason before your new password becomes available.”

iv. Reset password

Password security

- Passwords should be changed as soon as your account is activated for added security.
- Password must be at least 12 and at most 32 characters long, must contain **3 of the 4 classes** of characters
 - Lowercase letters
 - Uppercase letters
 - Digits
 - Special characters (punctuation, spaces, etc.)
- Do not use a word or phrase from a dictionary
- Do not use a word that can be obviously tied to the user (*e.g.*, your name, user name, *etc.*)
- **Do NOT share your password to others, including your advisor!!!!**

- **HPC User Environment 1**

1. Intro to HPC
 - 1) Why HPC?
 - 2) What is HPC?
 - 3) Our HPC
2. **Getting started**
 - 1) Accounts
 - 2) Allocation
3. Intro the cluster
 - 1) Getting connected
 - 2) File system
4. Software environment
 - 1) Preinstalled (modules)
 - 2) User installation



i. What is **allocation**?

- A deposit of **service units (SU)** that users will be charged from to run jobs on our cluster
 - 1 SU = 1 core-hour
 - Example:
 - My allocation: 50,000 SU
 - Running a job: 24 core * 10 hours = 240 SU
 - Balance: 49,760 SU
 - Cannot run jobs after exhausted
- All LSU HPC & LONI clusters requires allocation to run jobs
- **Free** to users
- But not worthless! (**1 SU ≈ \$0.1**)

ii. Eligibility

You are a ...	To get allocation ...

ii. Eligibility

You are a ...	To get allocation ...
Account sponsor / PI*	Submit a request

* Full-time faculty & certain research staff @ LSU / LONI subscribers

ii. Eligibility

You are a ...	To get allocation ...
Account sponsor / PI*	Submit a request
Non-account sponsor / non-PI	Join your sponsor's allocation

* Full-time faculty & certain research staff @ LSU / LONI subscribers

iii. Request an allocation (if you are an account sponsor / PI)

	LSU HPC	LONI HPC
Portal	https://accounts.hpc.lsu.edu/allocations.php	https://allocations.loni.org/allocations.php

[1] <http://www.hpc.lsu.edu/links.php>



iii. Request an allocation (if you are an account sponsor / PI)

	LSU HPC	LONI HPC
Portal	https://accounts.hpc.lsu.edu/allocations.php	https://allocations.loni.org/allocations.php
Steps	<ol style="list-style-type: none">Log in using your accountClick on “New Allocation for [Cluster Name]”<ul style="list-style-type: none">SuperMIC & SuperMike III share allocationsQB3 and QB4 share allocationsDeep Bayou has separated allocationFill the form and submitYour request will be reviewed, and you will be notified if your allocation is approved	

iii. Request an allocation (if you are an account sponsor / PI)

Allocation types

Type	Size [SU]	Can be requested...	Decisions made on...	Activated on...	Limited to...

iii. Request an allocation (if you are an account sponsor / PI)

Allocation types

Type	Size [SU]	Can be requested...	Decisions made on...	Activated on...	Limited to...
Startup	150,000	Any time	Following request	Jan 1 Apr 1 Jul 1 Oct 1	2 active / PI

iii. Request an allocation (if you are an account sponsor / PI)

Allocation types

Type	Size [SU]	Can be requested...	Decisions made on...	Activated on...	Limited to...
Startup	150,000	Any time	Following request	Jan 1 Apr 1 Jul 1 Oct 1	2 active / PI
Research	> 150,000	> 1 month before decision date	Jan 1 Apr 1 Jul 1 Oct 1		[LSU HPC] 5,000,000 SU / allocation 9,000,000 SU / PI
					[LONI] 12,000,000 SU / allocation 24,000,000 SU / PI

iii. Request an allocation (if you are an account sponsor / PI)

Allocation types

Type	Size [SU]	Proposal					
		Technical merit	Software characteristics	Previous impact and outcome	External funding or LSU demand	# of pages	
Startup	150,000	(Not required)					
Research	A	>150,000 and ≤300,000	Required	Required	Optional	Optional	4
	B	>300,000 and ≤1,000,000	Required	Required	Required	Optional	5
	C	>1,000,000	Required	Required	Required	Required	6

iv. Join an allocation (if you are not an account sponsor / PI)

	LSU HPC	LONI HPC
Portal	https://accounts.hpc.lsu.edu/allocations.php	https://allocations.loni.org/allocations.php

iv. Join an allocation (if you are not an account sponsor / PI)

	LSU HPC	LONI HPC
Portal	https://accounts.hpc.lsu.edu/allocations.php	https://allocations.loni.org/allocations.php
Steps	<p>[Method 1: Join by request]</p> <ul style="list-style-type: none">a) Log in using your accountb) Click on “Join allocation”c) Search for your account sponsor / PI, and click "Join Projects"d) Find the desired allocation you wish to join, click “Join”e) Your account sponsor / PI will receive an email notification and approve your request <p>[Method 2: Ask your PI to add you]</p> <ul style="list-style-type: none">a) Ask your PI to log in using his/her accountb) Click on “Manage memberships”c) Find the desired allocation, click “Edit -> Add a User”d) Search for your account, click “Add to [Allocation name]”	

* HPC staff **CANNOT** add you to allocations! Must be approved by your PI!

iv. Join an allocation (if you are not an account sponsor / PI)

Case study

- **User:**
“Hi, my PI recently applied for an allocation on SuperMIC and was approved (see forwarded email below). However, I do not see that this allocation is available for my use in <https://accounts.hpc.lsu.edu/balances.php> . When will I be able to access the allocation?”
- **User Services:**
“You should either request to join your PI’s allocation through the user portal, or ask your PI to add you to the allocation”

- **Test**

- ❖ **What are the TWO things required to run jobs on our clusters?**

- a) An active myLSU account
- b) An active LSU HPC / LONI account
- c) An active LSU HPC / LONI allocation
- d) A valid payment method (credit card / bank account / check / cash ...) to pay for the services

- Test

- ❖ What are the TWO things required to run jobs on our clusters?

- a) An active myLSU account
- b) An active LSU HPC / LONI account
- c) An active LSU HPC / LONI allocation
- d) A valid payment method (credit card / bank account / check / cash ...) to pay for the services

- Login to one of the user portals (LSU HPC or LONI) with your HPC username and password. Update your email and phone number (for practice).
 - LSU HPC: <https://accounts.hpc.lsu.edu>
 - LONI: <https://allocations.loni.org>
- Download MobaXterm (if you are Windows user)
- Review commands in Linux and the vim editor

Cheat sheet of Commands in Linux

history	Command history
mkdir	Make a folder
ls	List a folder -a List all files including hidden -l Shows files with a long listing format
cd	Change directory
pwd	Show current directory
cp	Copy
rm	Remove files (CAREFUL!)
Up arrow (↑)	Move back in history
Tab	Fill in unique file name
Tab Tab	Press tab twice, show all available file names

Cheat sheet of vim editor

- vi (name of file)
- Commands in VI
 - i enter insert mode (-- INSERT -- shows in the bottom left corner)
 - esc exits insert mode, back to the command mode
 - dd -> deletes line
 - u -> Undo
 - Shift Z shift Z or :wq -> saves and exits VI
 - :q! -> exit without saving
 - :(some number) -> moves through file to row #
 - /(indicator) -> search
 - Use N to find Next
 - [(page up)] (page down)
- NO CAPS (for example :q! is not :Q!)

- **HPC User Environment 1**

1. Intro to HPC
 - 1) Why HPC?
 - 2) What is HPC?
 - 3) Our HPC
2. Getting started
 - 1) Accounts
 - 2) Allocation
3. Intro the cluster
 - 1) Getting connected
 - 2) File system
4. Software environment
 - 1) Preinstalled (modules)
 - 2) User installation

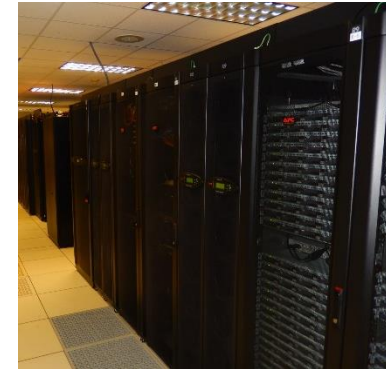
i. General architecture

Term	Definition

1) Getting connected

i. General architecture

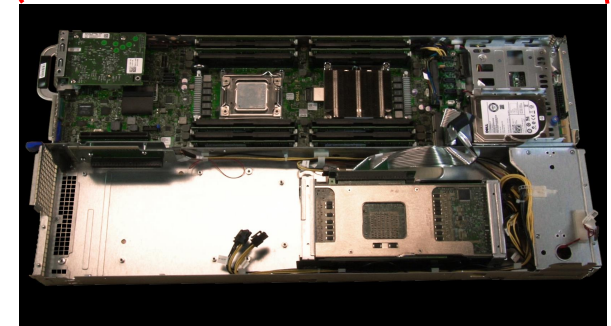
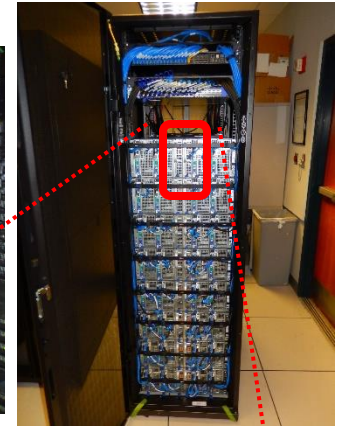
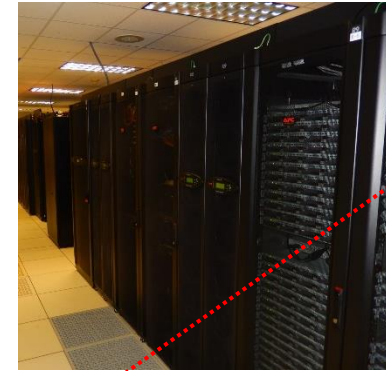
Term	Definition
Cluster	A set of connected computer nodes that work together. (<i>E.g., QB2</i>)



1) Getting connected

i. General architecture

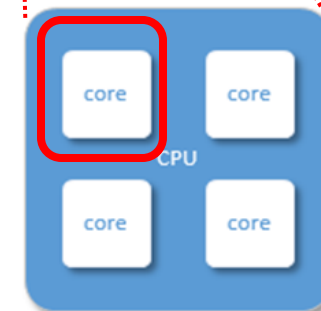
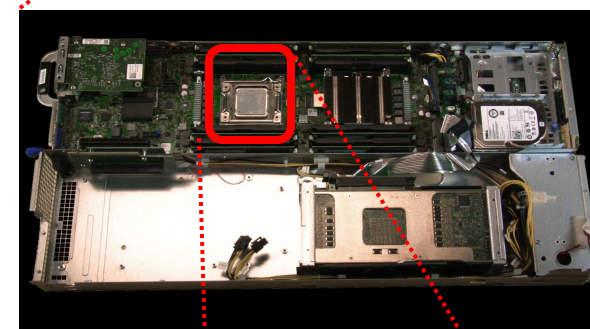
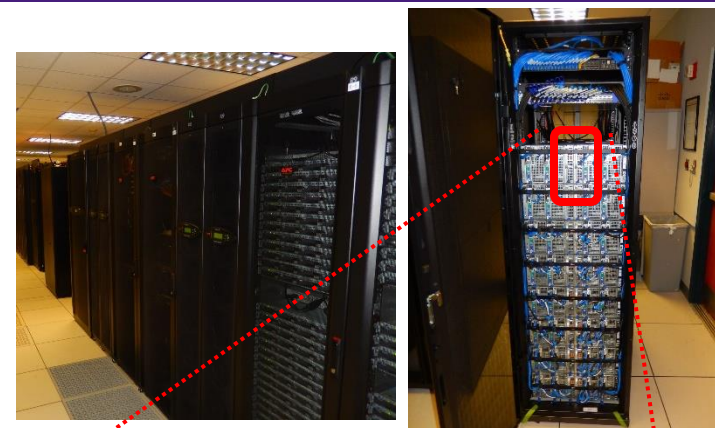
Term	Definition
Cluster	A set of connected computer nodes that work together. (<i>E.g.</i> , QB2)
Node	A single, named host machine in the cluster. (<i>E.g.</i> , qb010)



1) Getting connected

i. General architecture

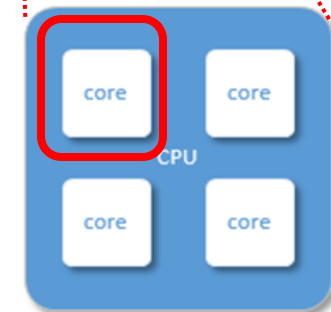
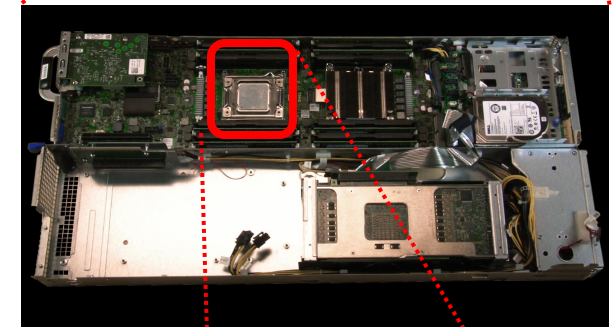
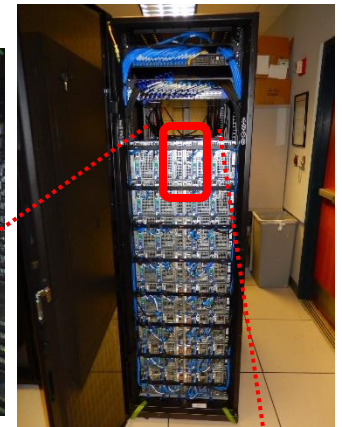
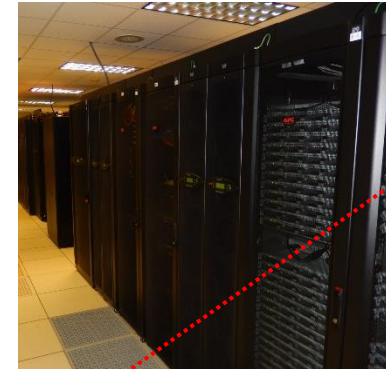
Term	Definition
Cluster	A set of connected computer nodes that work together. (E.g., QB2)
Node	A single, named host machine in the cluster. (E.g., qb010)
Core	The basic computation unit in a processor. (E.g. , QB2 has two 10-core processors → 20 cores)



1) Getting connected

i. General architecture

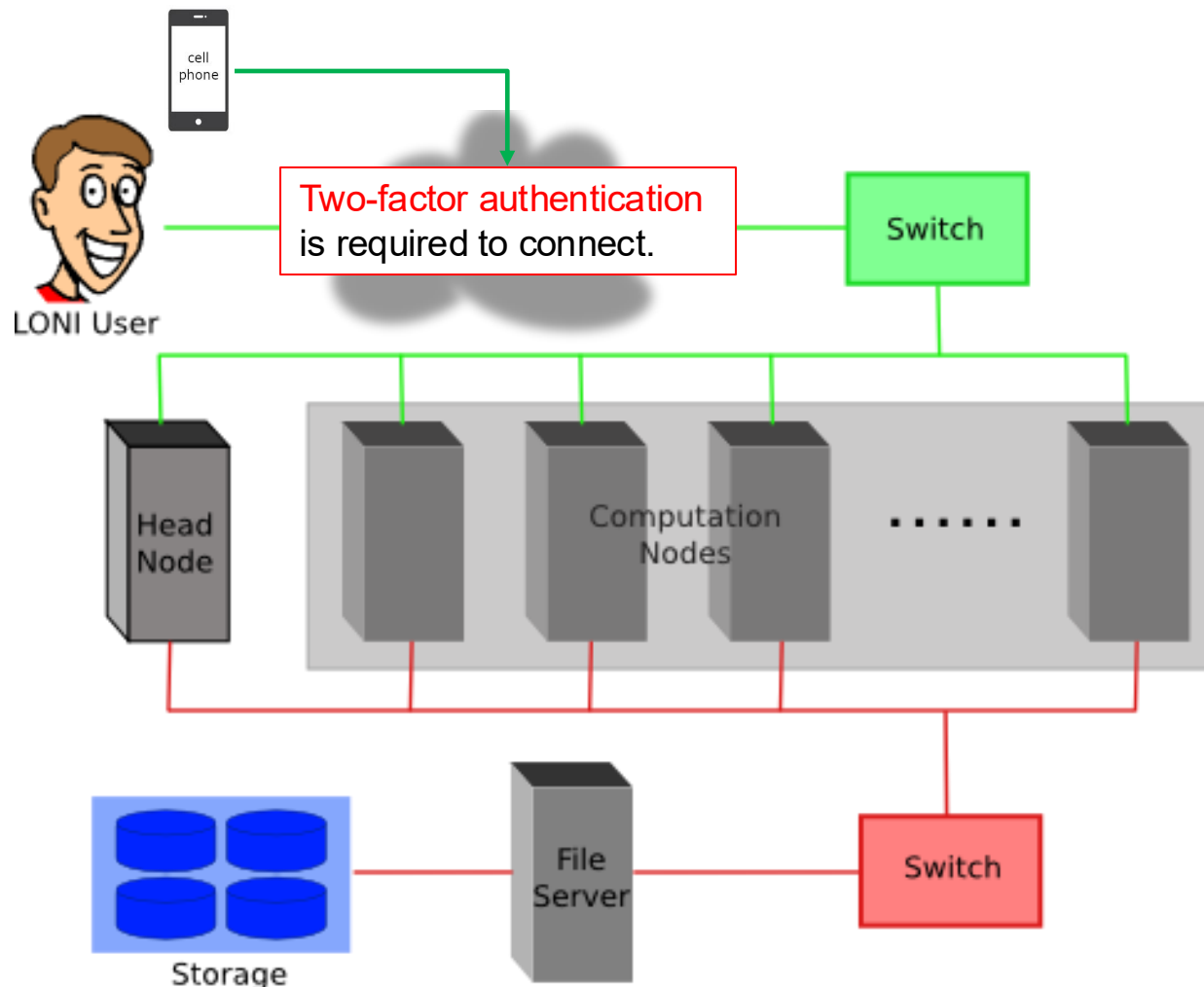
Term	Definition
Cluster	A set of connected computer nodes that work together. (E.g., QB2)
Node	A single, named host machine in the cluster. (E.g., qb010)
Core	The basic computation unit in a processor. (E.g. , QB2 has two 10-core processors → 20 cores)
Job	A user's request to use a certain amount of resources for a certain amount of time on cluster for his/her work.



1) Getting connected

i. General architecture

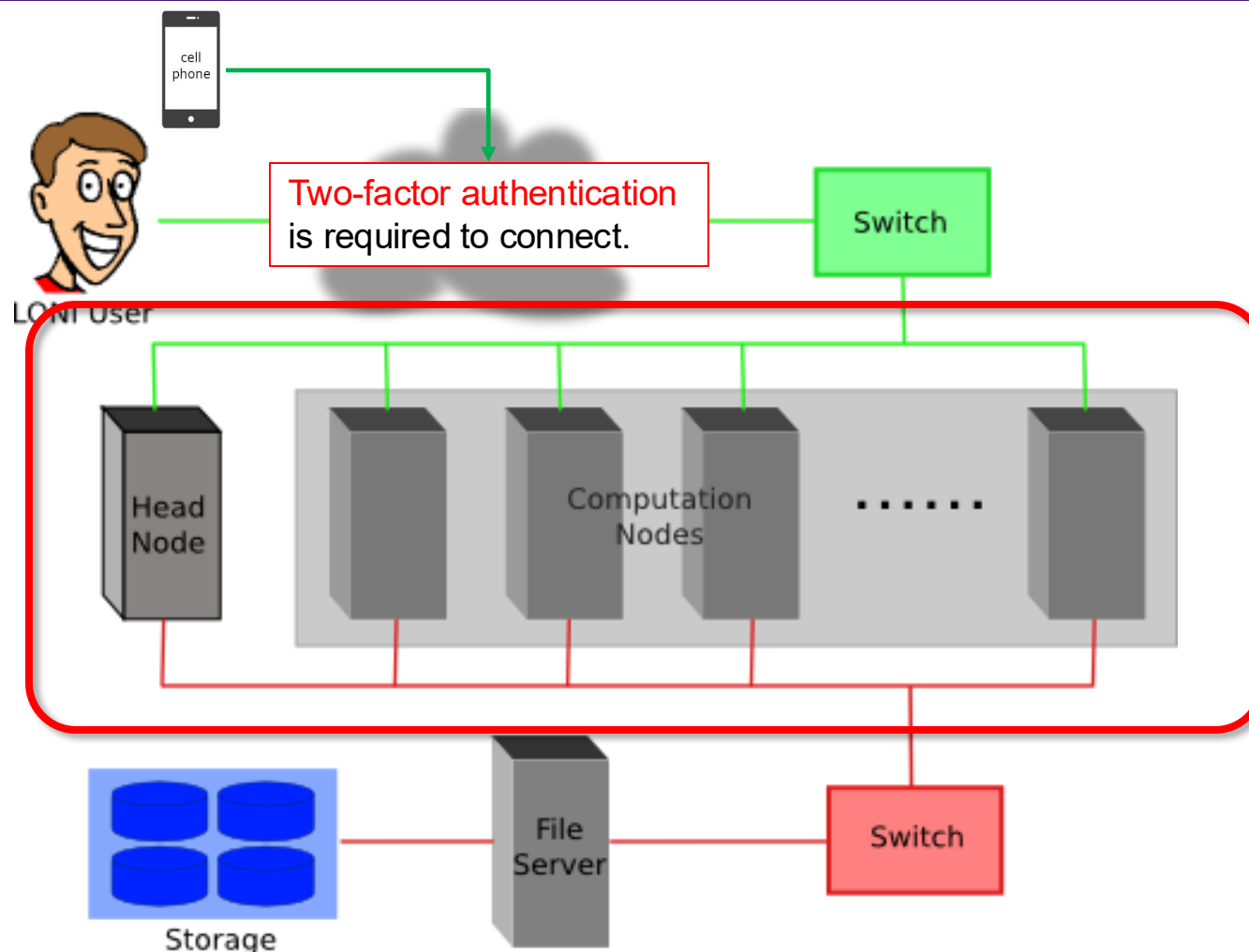
- Multiple compute nodes
- Multiple users
- Each user may have multiple jobs running simultaneously



1) Getting connected

i. General architecture

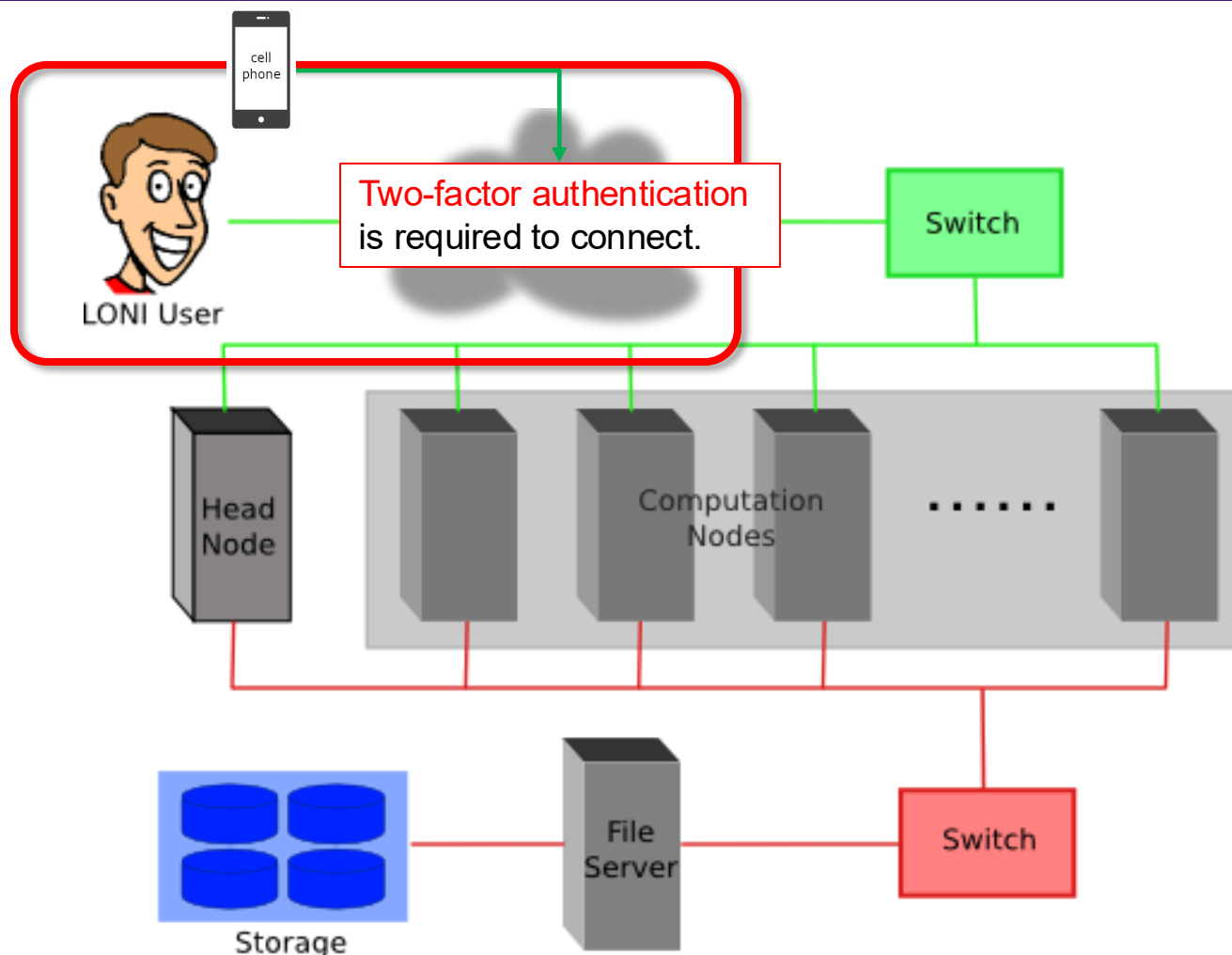
- Multiple compute nodes
- Multiple users
- Each user may have multiple jobs running simultaneously



1) Getting connected

i. General architecture

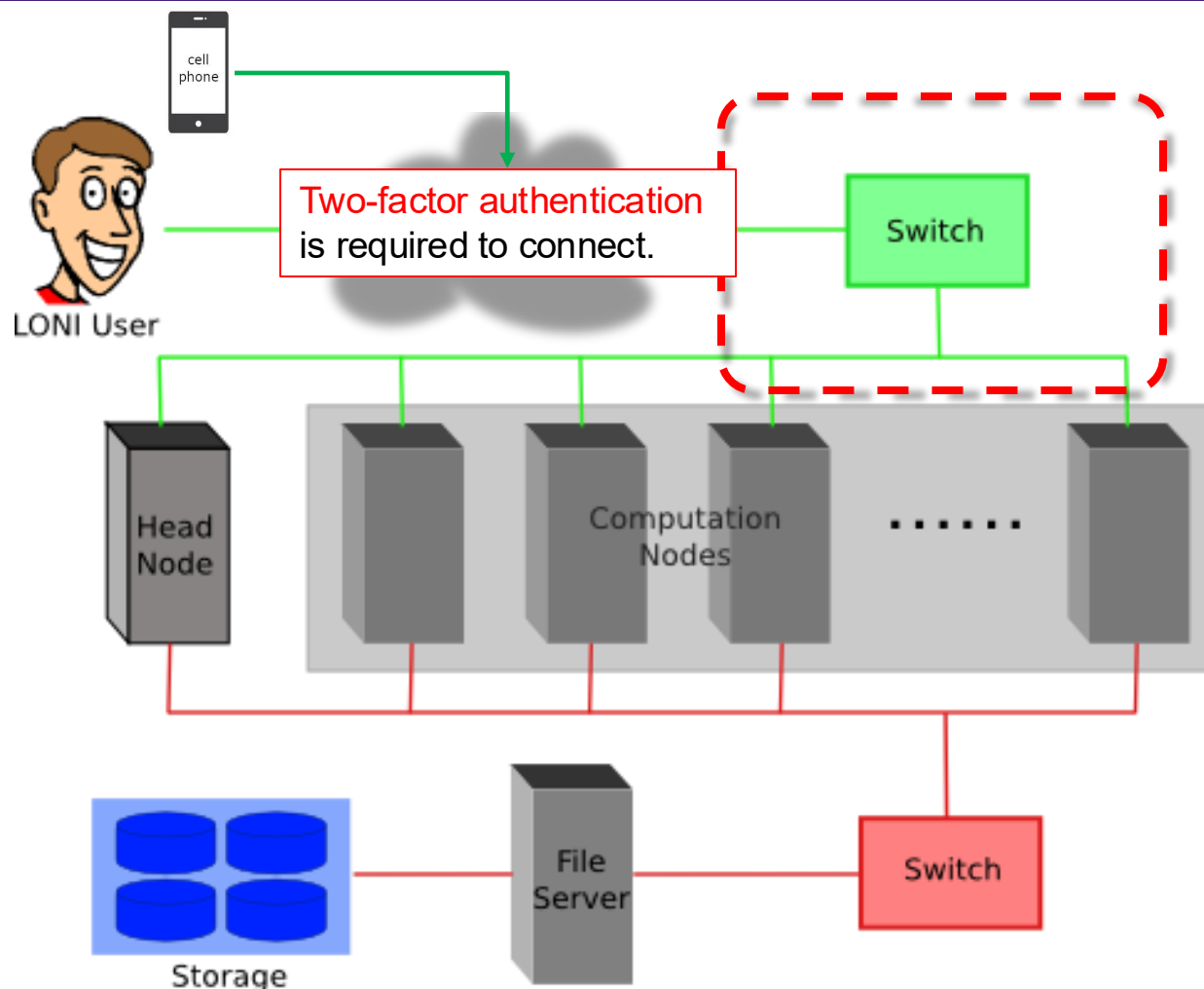
- Multiple compute nodes
- Multiple users
- Each user may have multiple jobs running simultaneously



1) Getting connected

i. General architecture

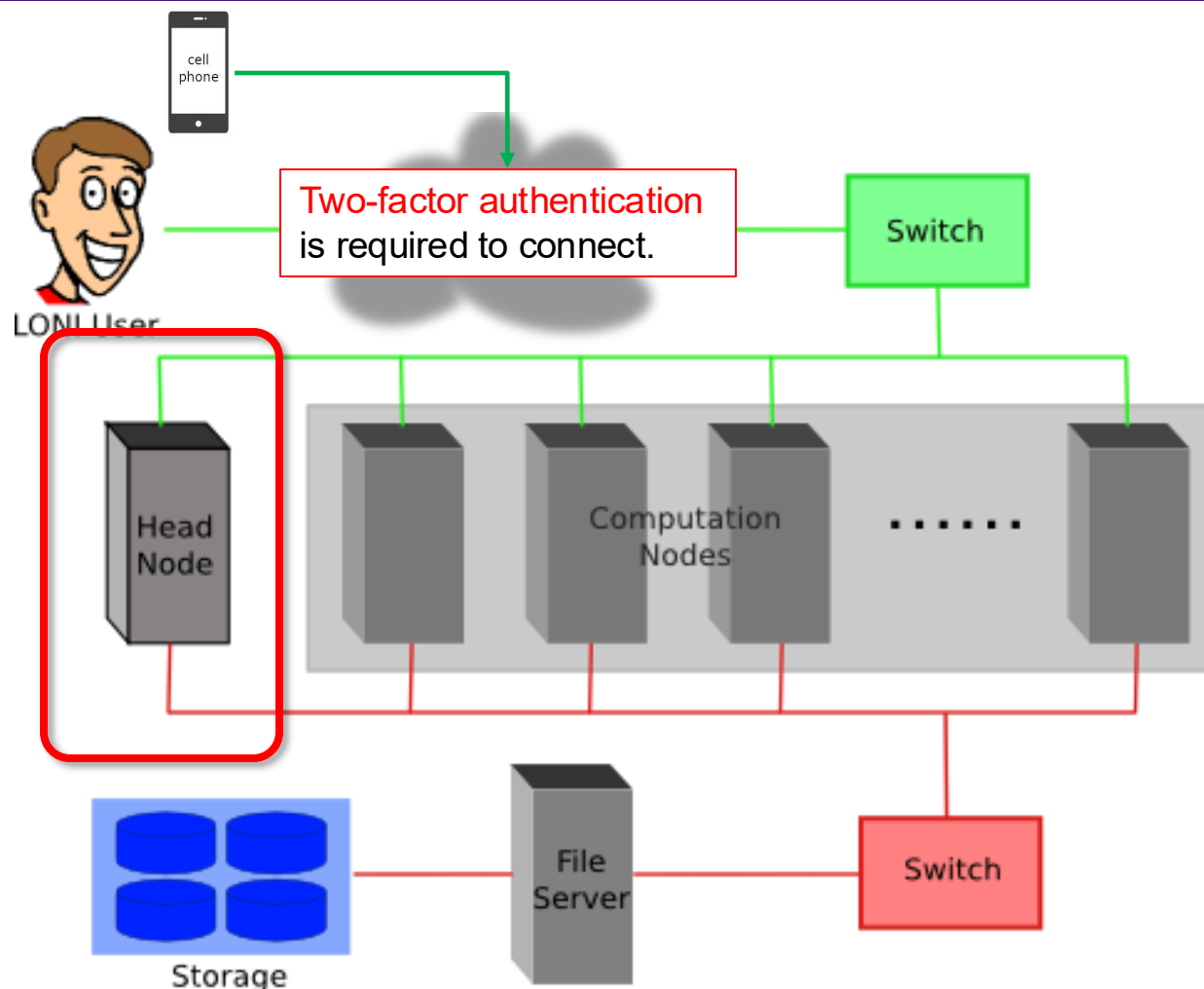
- Multiple compute nodes
- Multiple users
- Each user may have multiple jobs running simultaneously



1) Getting connected

i. General architecture

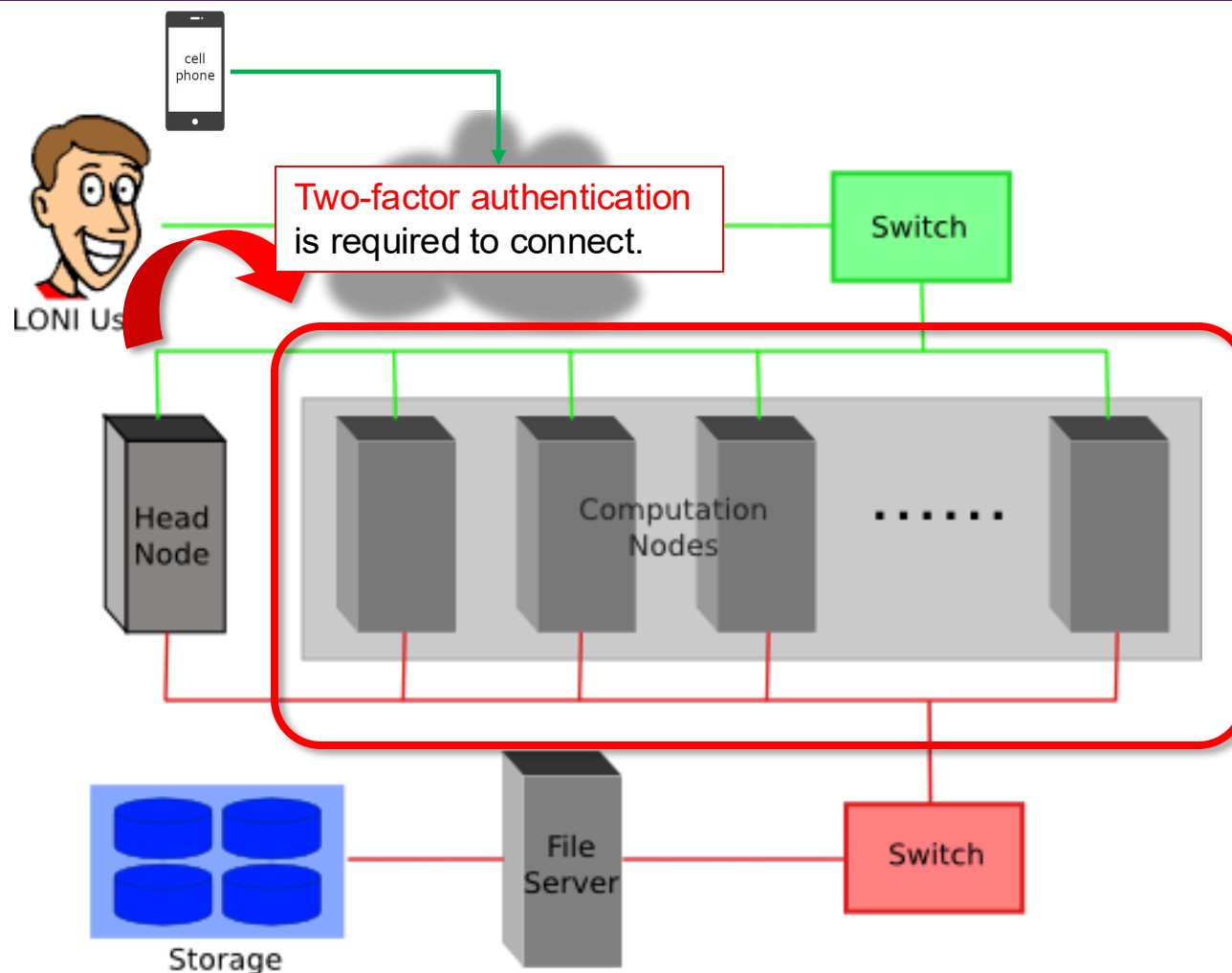
- Multiple compute nodes
- Multiple users
- Each user may have multiple jobs running simultaneously



1) Getting connected

i. General architecture

- Multiple compute nodes
- Multiple users
- Each user may have multiple jobs running simultaneously

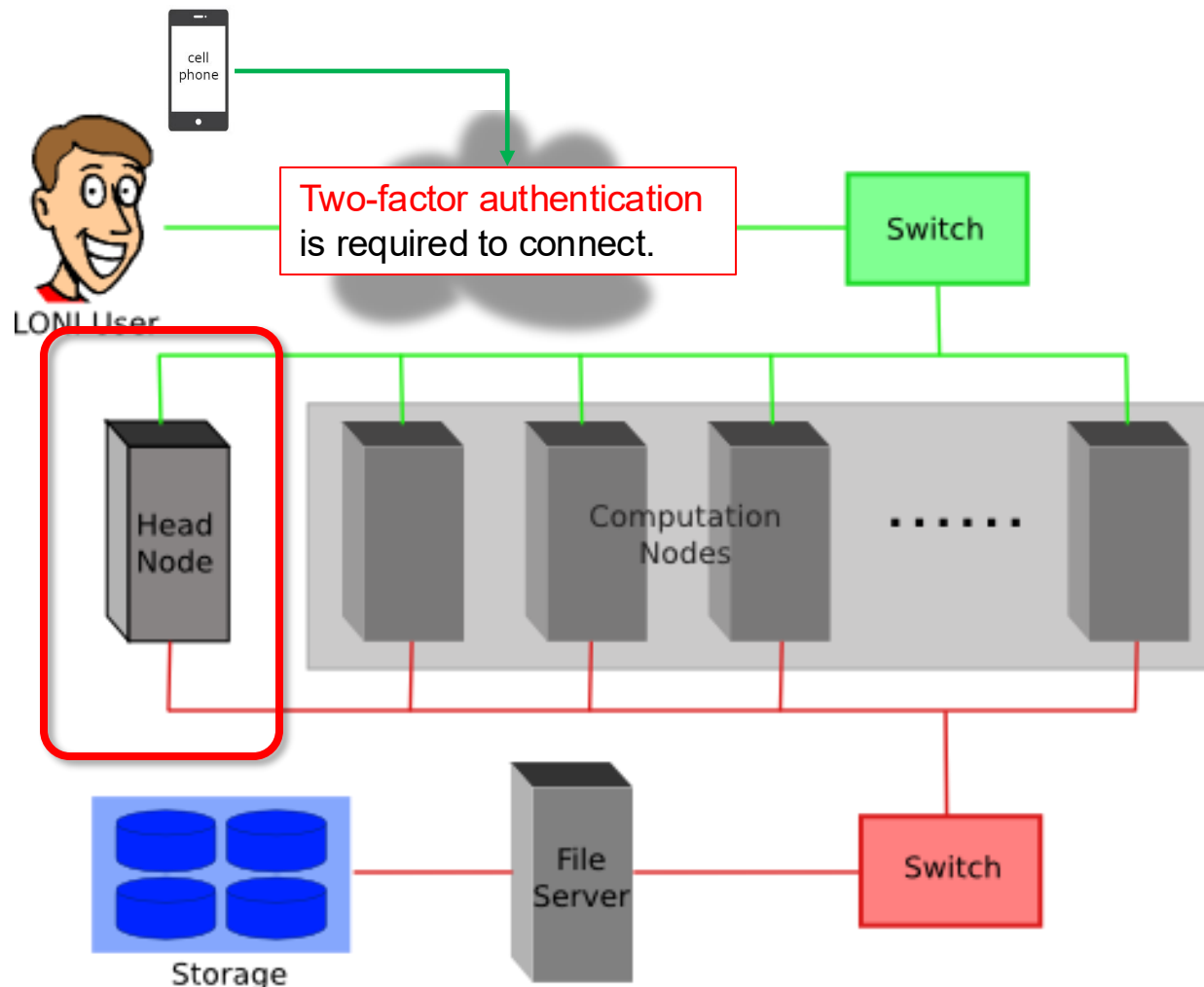


1) Getting connected

i. General architecture

- Multiple compute nodes
- Multiple users
- Each user may have multiple jobs running simultaneously

**DO NOT
RUN
JOBS ON
HEAD
NODE!!!**



ii. Logging in

Secure Shell (SSH)

ii. Logging in

Secure Shell (SSH)

Your OS ...	Tool you need ...

ii. Logging in

Secure Shell (SSH)

Your OS ...	Tool you need ...
Linux / Mac	Terminal

ii. Logging in

Secure Shell (SSH)

Your OS ...	Tool you need ...
Linux / Mac	Terminal
Windows	MobaXterm SSH Secure Shell Putty

ii. Logging in

Secure Shell (SSH)

Your OS ...	Tool you need ...
Linux / Mac	Terminal
Windows	MobaXterm SSH Secure Shell Putty
A web browser*	Open OnDemand (OOD) https://ondemand.smic.hpc.lsu.edu https://ondemand.mike.hpc.lsu.edu

* Must via a wired connection from LSU Baton Rouge campus (or via VPN)

ii. Logging in

Secure Shell (SSH)

Cluster		Remote Host Address
LSU HPC	SMIC	smic.hpc.lsu.edu
	Deep Bayou	db1.hpc.lsu.edu
	SuperMike III	mike.hpc.lsu.edu
LONI HPC	QB-3	qbc.loni.org
	QB-4	qbd.loni.org

ii. Logging in

ssh ~~-X~~ username @ remote host address

ii. Logging in

a) Linux / Mac

```
File Edit View Search Terminal Help
fchen14@feng-thinkpad:~$ ssh fchen14@mike.hpc.lsu.edu
fchen14@mike.hpc.lsu.edu's password:
Last login: Mon Aug 18 11:26:16 2014 from fchen14-4.lsu.edu
#####
Send questions and comments to the email ticket system at sys-help@loni.org.
#####

SuperMike-II at LSU (Open for general use)

1-Dec-2012

SuperMike-II is a 146 TFlops Peak Performance, 440 node, 16 processor Red Hat
Enterprise Linux 6 cluster from Dell with 2.6 GHz Intel Xeon 64-bit processors
and 32 GB RAM per node. GPUs and additional memory are available on some nodes.
This cluster is for authorized users of the LSU community. Access is restricted
to those who meet the criteria as stated on our website.

1-Feb-2013

SuperMike-II is open for general use. Please report problems to our email ticket
system at sys-help@loni.org so that we can address them.

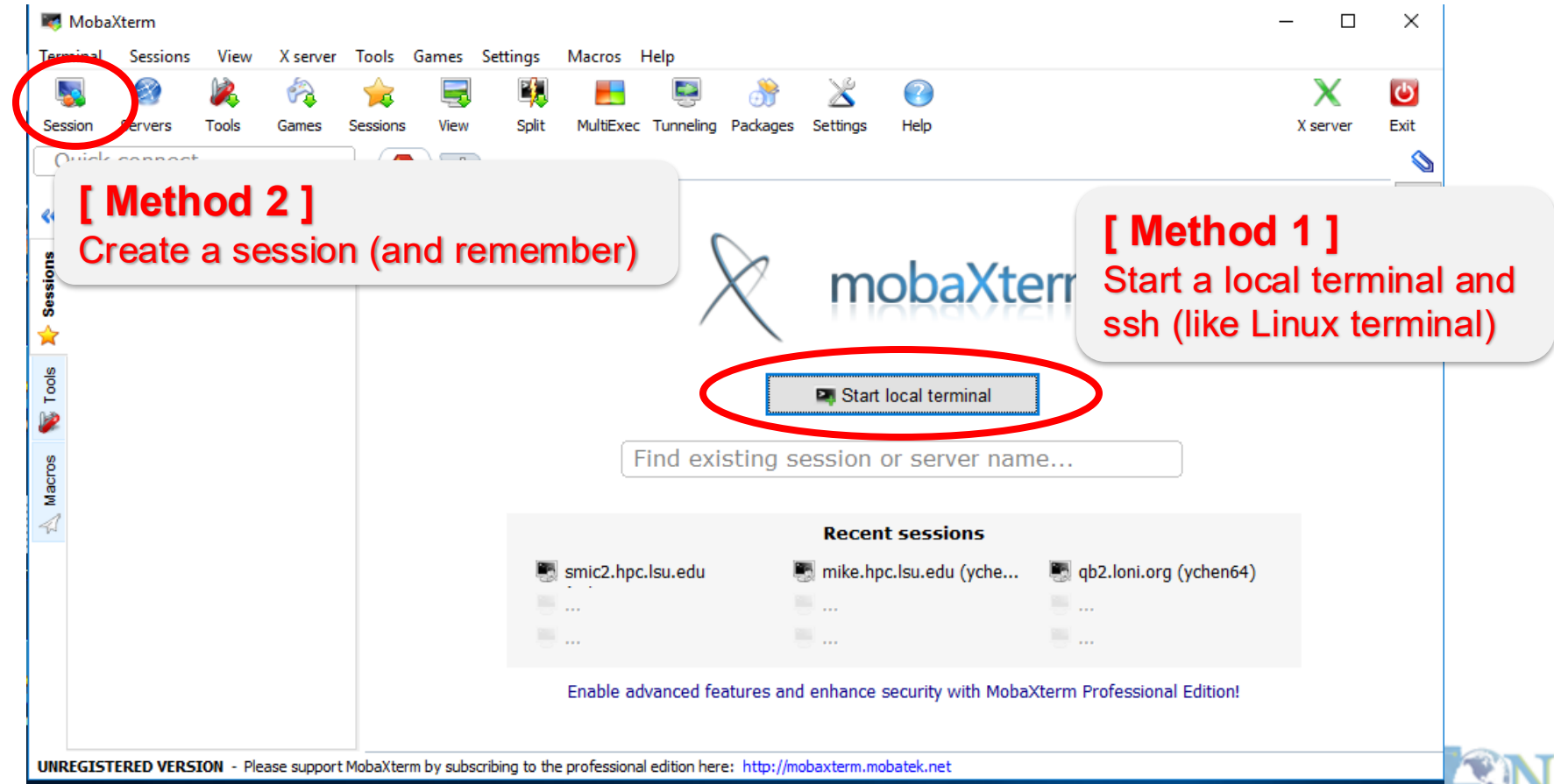
Quotas for the /home volume are enabled at 5 GB. Please do
```

1) Getting connected

ii. Logging in

b) Windows

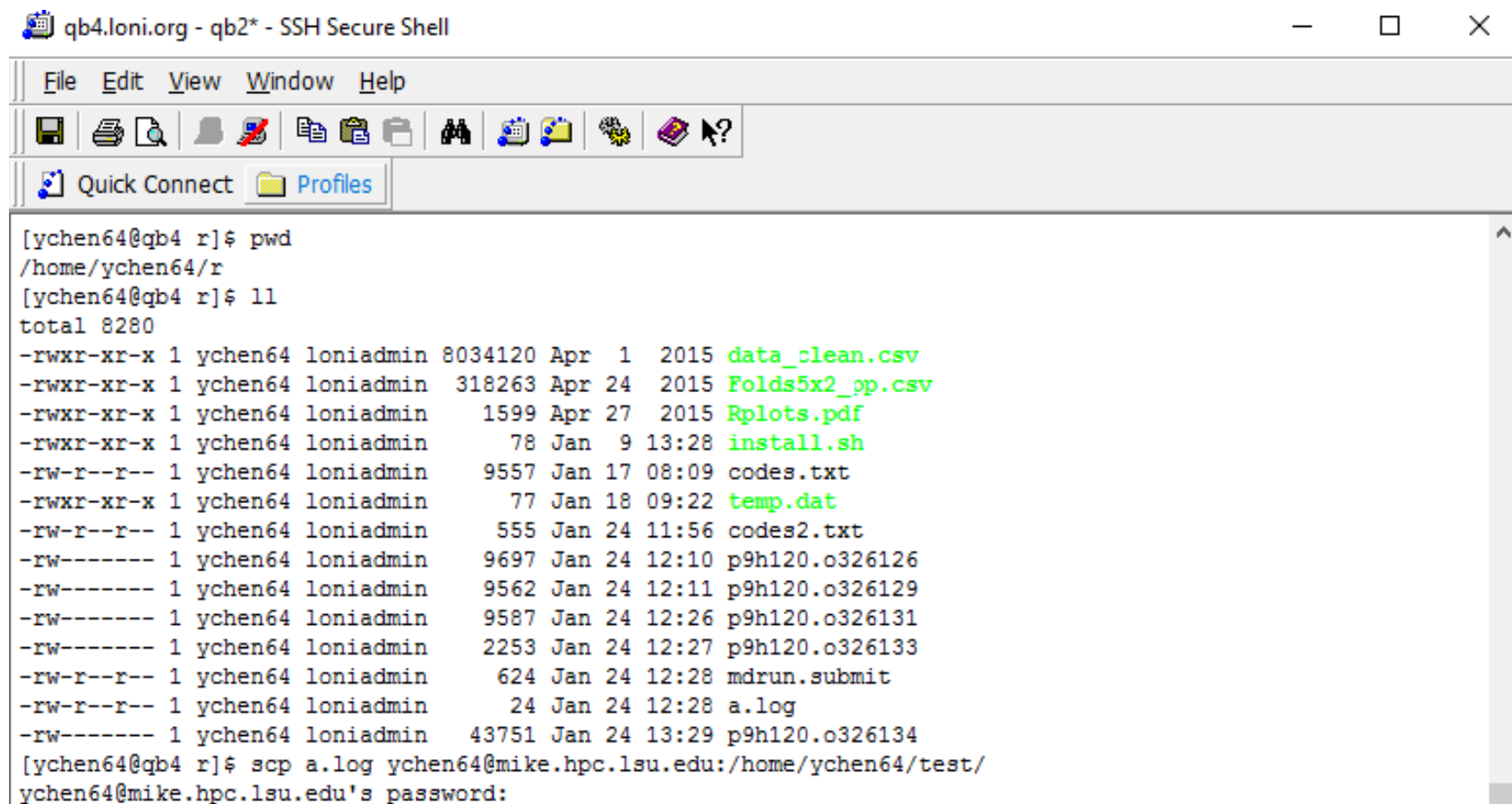
- MobaXterm



ii. Logging in

b) Windows

- SSH Secure Shell



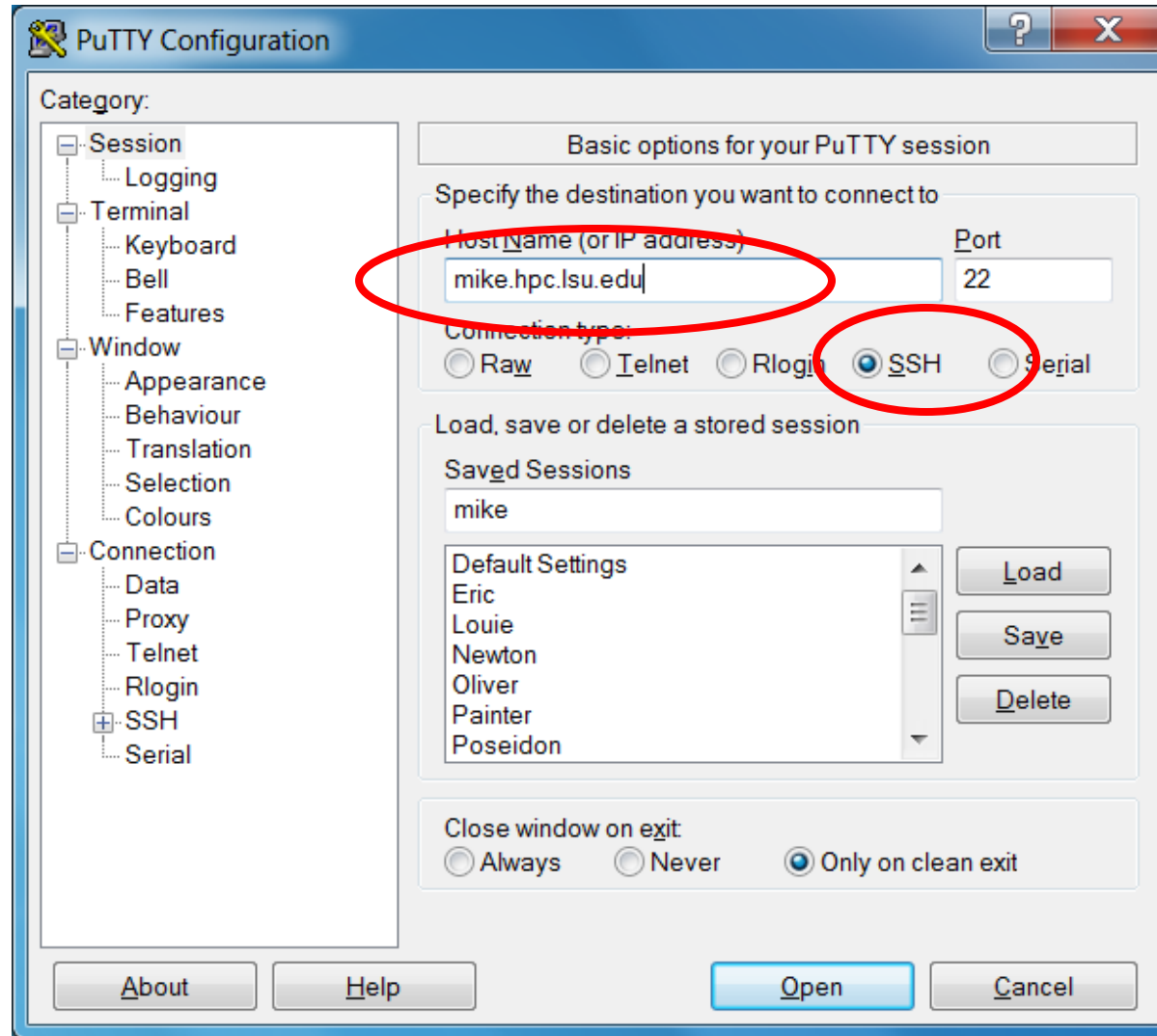
```
qb4.loni.org - qb2* - SSH Secure Shell
File Edit View Window Help
Quick Connect Profiles
[ychen64@qb4 r]$ pwd
/home/ychen64/r
[ychen64@qb4 r]$ ll
total 8280
-rwxr-xr-x 1 ychen64 loniadmin 8034120 Apr  1  2015 data_clean.csv
-rwxr-xr-x 1 ychen64 loniadmin 318263 Apr 24  2015 Folds5x2_op.csv
-rwxr-xr-x 1 ychen64 loniadmin 1599 Apr 27  2015 Rplots.pdf
-rwxr-xr-x 1 ychen64 loniadmin 78 Jan  9 13:28 install.sh
-rw-r--r-- 1 ychen64 loniadmin 9557 Jan 17 08:09 codes.txt
-rwxr-xr-x 1 ychen64 loniadmin 77 Jan 18 09:22 temp.dat
-rw-r--r-- 1 ychen64 loniadmin 555 Jan 24 11:56 codes2.txt
-rw----- 1 ychen64 loniadmin 9697 Jan 24 12:10 p9h120.o326126
-rw----- 1 ychen64 loniadmin 9562 Jan 24 12:11 p9h120.o326129
-rw----- 1 ychen64 loniadmin 9587 Jan 24 12:26 p9h120.o326131
-rw----- 1 ychen64 loniadmin 2253 Jan 24 12:27 p9h120.o326133
-rw-r--r-- 1 ychen64 loniadmin 624 Jan 24 12:28 mdrun.submit
-rw-r--r-- 1 ychen64 loniadmin 24 Jan 24 12:28 a.log
-rw----- 1 ychen64 loniadmin 43751 Jan 24 13:29 p9h120.o326134
[ychen64@qb4 r]$ scp a.log ychen64@mike.hpc.lsu.edu:/home/ychen64/test/
ychen64@mike.hpc.lsu.edu's password:
```

1) Getting connected

ii. Logging in

b) Windows

- Putty



ii. Logging in

- ❖ Special note: **X11 forwarding**
 - Enables graphic user interface (GUI)

ii. Logging in

- ❖ Special note: **X11 forwarding**
 - Enables graphic user interface (GUI)

You are using...		To enable X11 forwarding...

ii. Logging in

- ❖ Special note: **X11 forwarding**
 - Enables graphic user interface (GUI)

You are using...	To enable X11 forwarding...
Linux (e.g., Ubuntu)	<code>ssh -X username@server.address</code>

ii. Logging in

- ❖ Special note: **X11 forwarding**
 - Enables graphic user interface (GUI)

You are using...	To enable X11 forwarding...
Linux (e.g., Ubuntu)	ssh -X username@server.address
Mac	a) Install X server (e.g. XQuartz) b) ssh -X username@server.address

ii. Logging in

- ❖ Special note: **X11 forwarding**
 - Enables graphic user interface (GUI)

You are using...		To enable X11 forwarding...
Linux (e.g., Ubuntu)		ssh -X username@server.address
Mac		a) Install X server (e.g. XQuartz) b) ssh -X username@server.address
Windows		

ii. Logging in

- ❖ Special note: **X11 forwarding**
 - Enables graphic user interface (GUI)

You are using...		To enable X11 forwarding...
Linux (e.g., Ubuntu)		ssh -X username@server.address
Mac		a) Install X server (e.g. XQuartz) b) ssh -X username@server.address
Windows	MobaXterm	Enabled by default (can be disabled in “Advanced SSH Settings”)

ii. Logging in

- ❖ Special note: **X11 forwarding**
 - Enables graphic user interface (GUI)

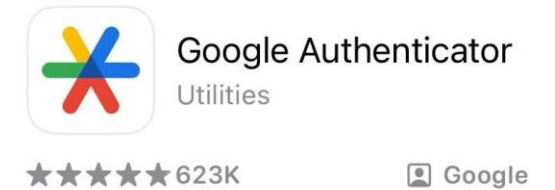
You are using...		To enable X11 forwarding...
Linux (e.g., Ubuntu)		ssh -X username@server.address
Mac		a) Install X server (e.g. XQuartz) b) ssh -X username@server.address
Windows	MobaXterm	Enabled by default (can be disabled in “Advanced SSH Settings”)
	Putty	a) Install X server (e.g. Xming) b) Connection → SSH → X11 → Enable X11 forwarding

ii. Logging in

Useful commands	
who	Check who is on the node
balance / showquota	Check allocation balance
history	Command history
mkdir	Make a folder
ls	List a folder -a List all files including hidden -l Shows files with a long listing format
cd	Change directory
pwd	Show current directory
cp	Copy
rm	Remove files (CAREFUL!)
Up arrow (↑)	Move back in history
Tab	Fill in unique file name
Tab Tab	Press tab twice, show all available file names

1. Install an authenticator on your smartphone

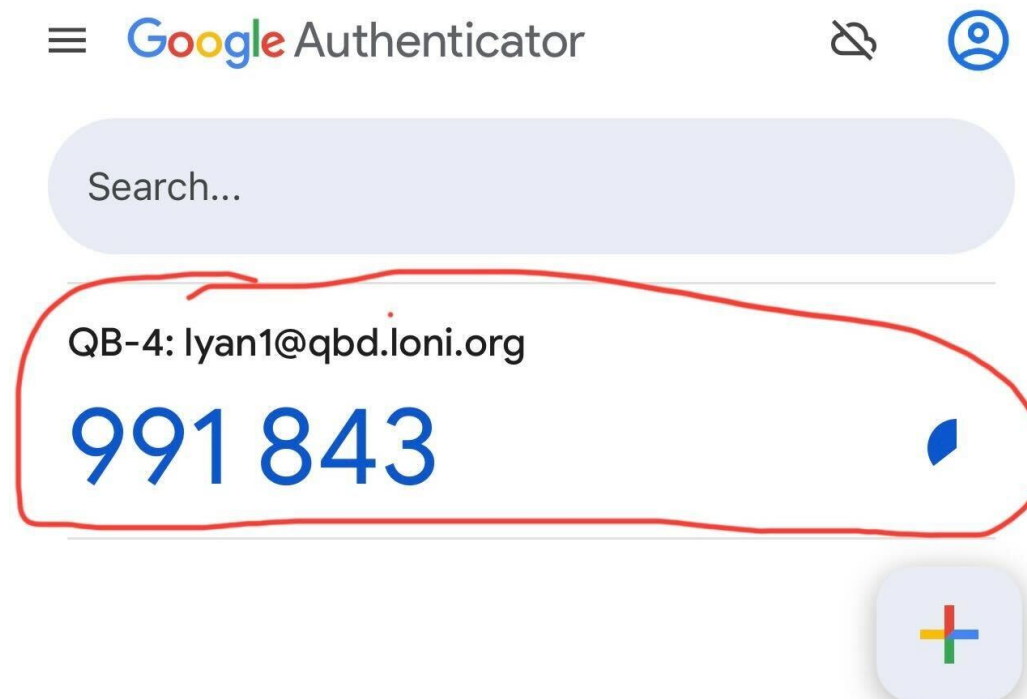
We recommend [Google Authenticator](#), but any Time-based One-Time Password (TOTP) authenticator (e.g. [Microsoft Authenticator](#), [Authy](#) etc.) would do. You can search for these authenticators in the app store for any apps on your phone.



2. Log in to the cluster using your credentials: `ssh -X username@qbd.loni.org`

You will see a QR code along with some text and a prompt for the one-time token:

4. Type the 6-digit one-time token at the prompt and press enter.



Note: the token will expire in 30 seconds after being generated. If it expires, simply use the new token.

5. Log out and log back in with your ssh client. You should see the token prompt after entering your password.

6. Enter the token in your authenticator at the prompt as you did in Step 4.

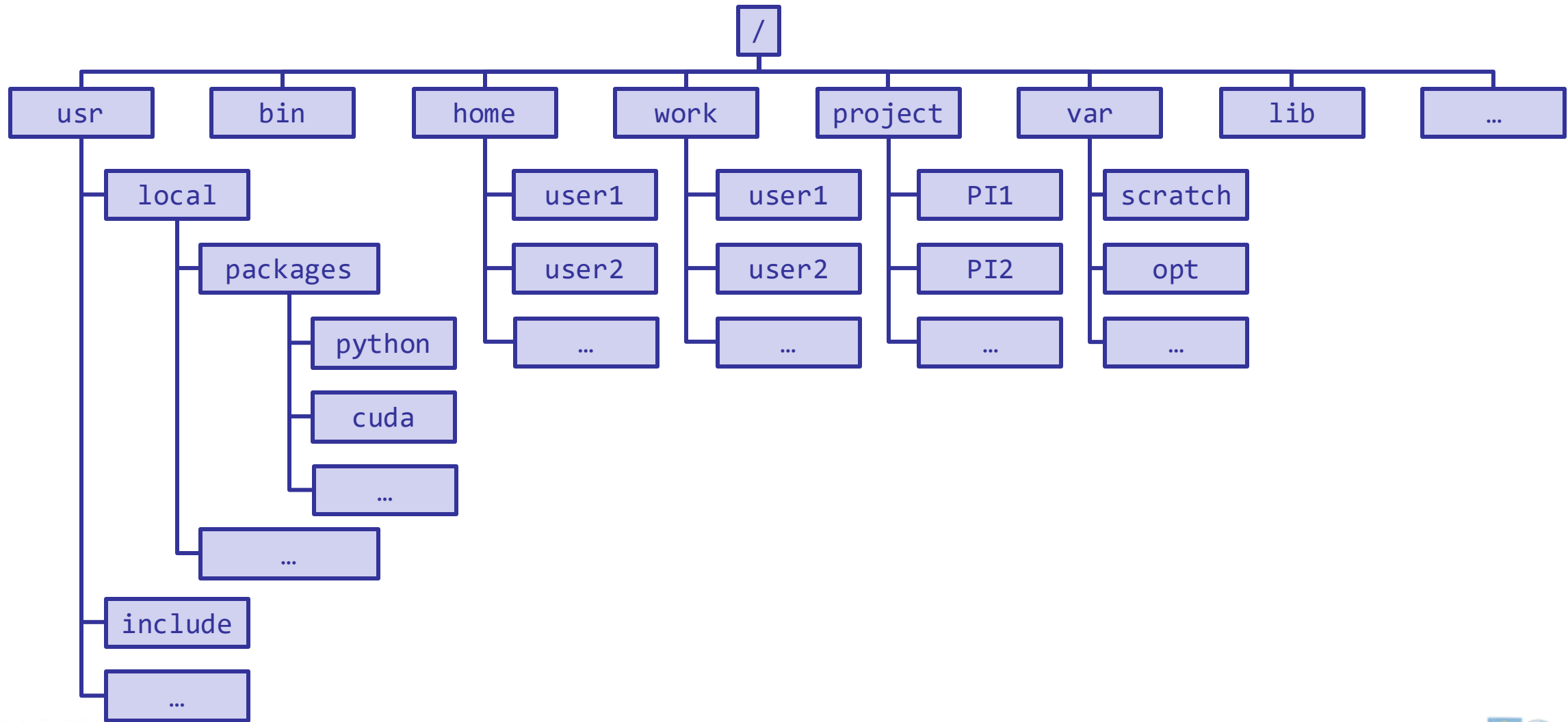
- If you log in successfully, no token will be required again for the next 12 hours if you log in from the same IP address. You do not need to type your password everytime.
- In the future, you only need to repeat **Step 5** and **6** to log in.

If you do not have a smartphone or the authenticators do not work on your phone, you can also choose to use desktop applications. [KeepPassXC](#) is an excellent choice, which also provides a browser extension and can be used as a password manager. If you need help setting it up, please contact us at sys-help@loni.org.

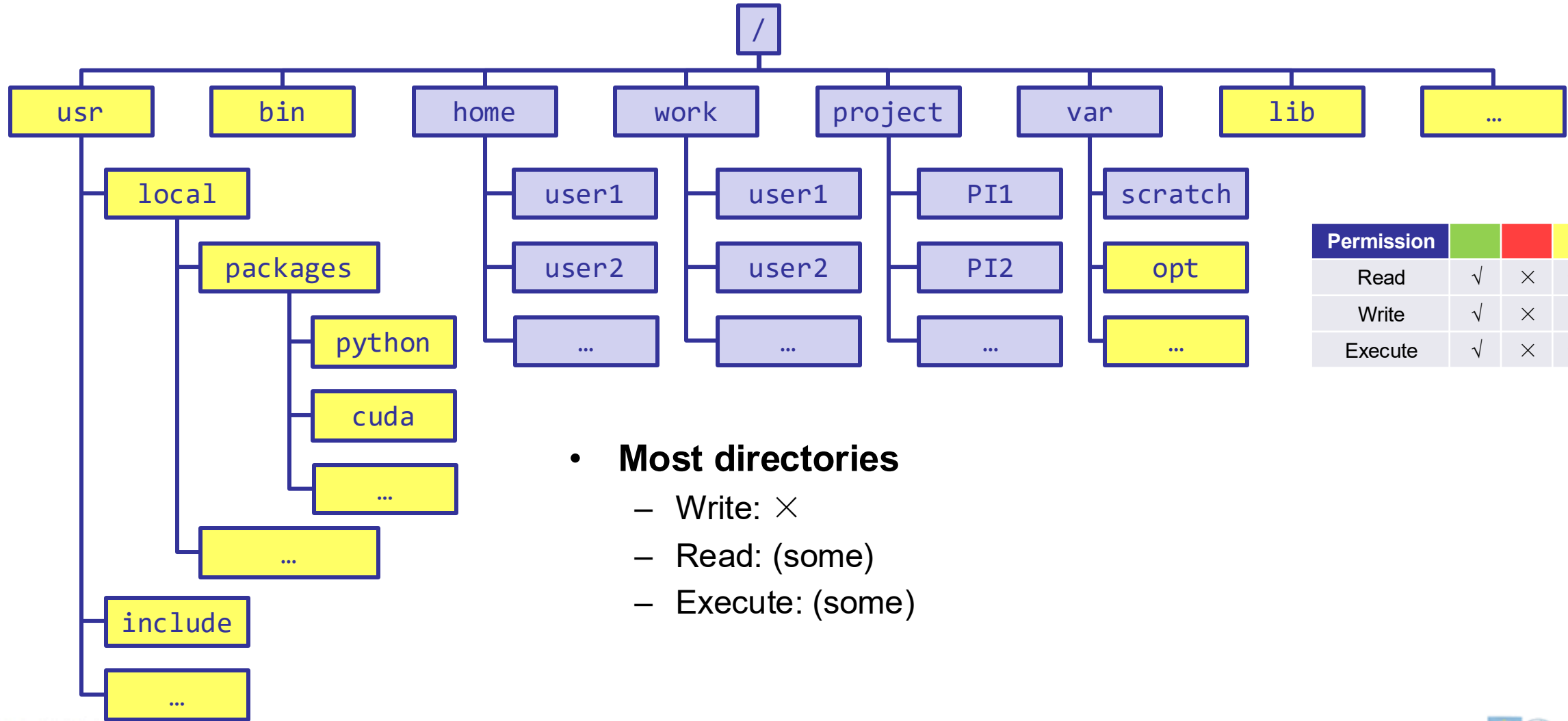
- **HPC User Environment 1**

1. Intro to HPC
 - 1) Why HPC?
 - 2) What is HPC?
 - 3) Our HPC
2. Getting started
 - 1) Accounts
 - 2) Allocation
- 3. Into the cluster**
 - 1) Getting connected
 - 2) File system
4. Software environment
 - 1) Preinstalled (modules)
 - 2) User installation

2) File system

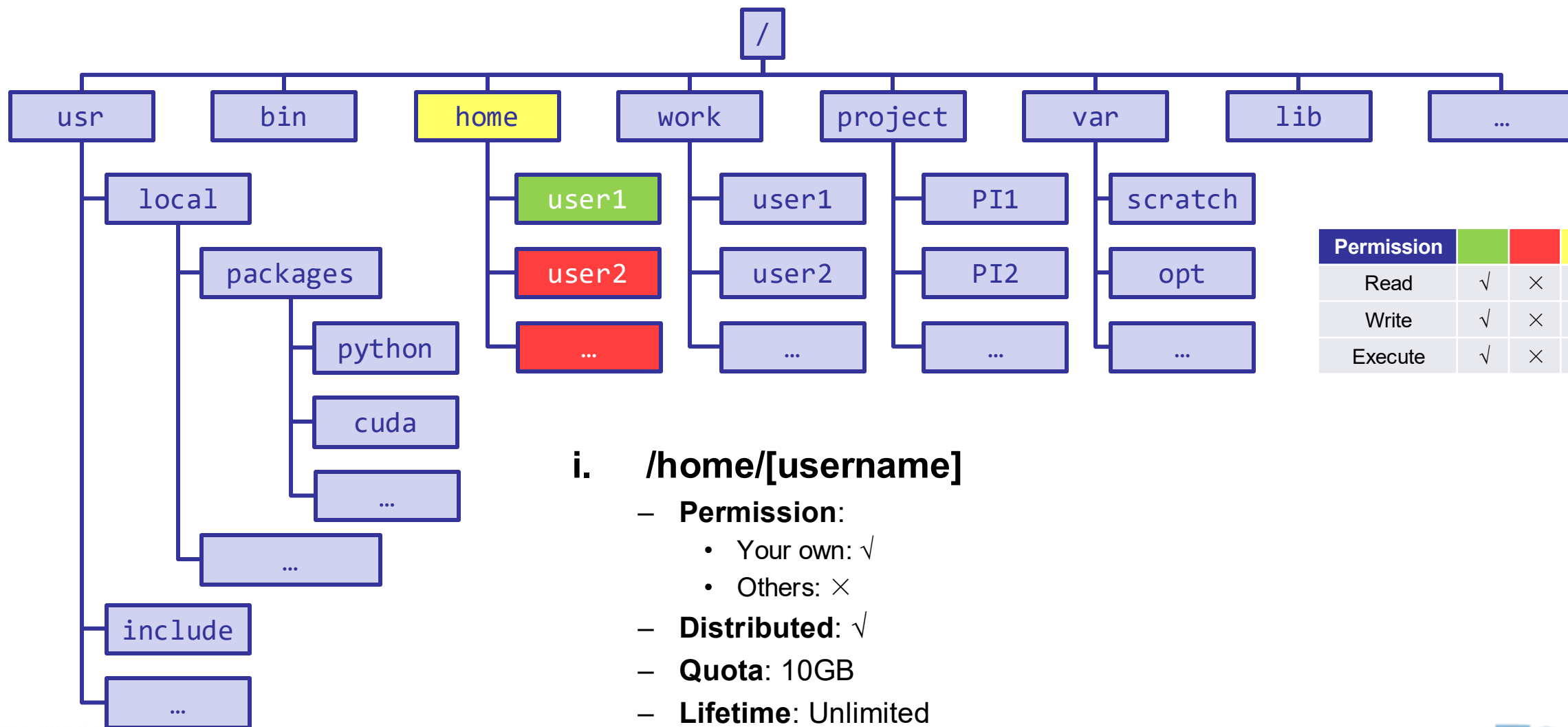


2) File system



Permission	Green	Red	Yellow
Read	√	×	√*
Write	√	×	×
Execute	√	×	√*

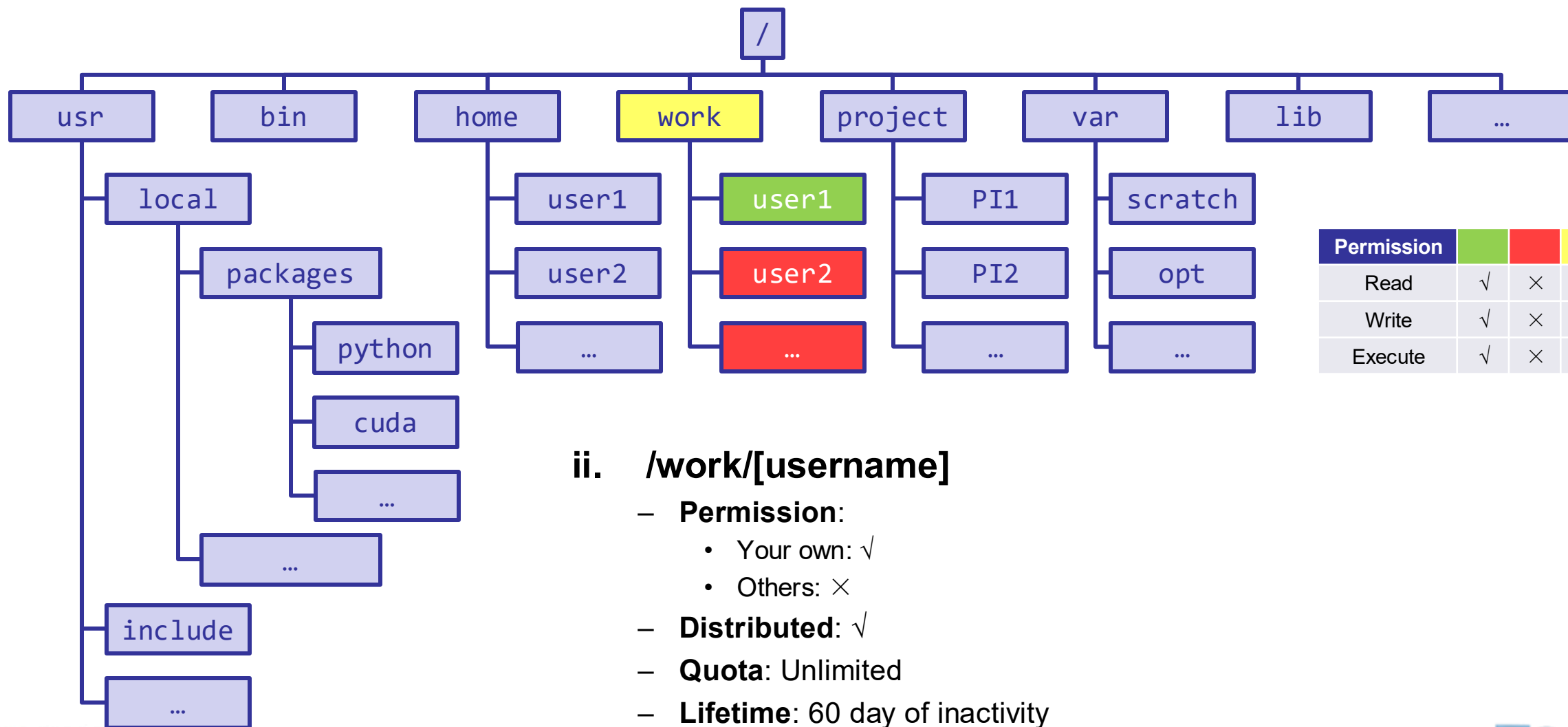
- **Most directories**
 - Write: ×
 - Read: (some)
 - Execute: (some)



Permission	Green	Red	Yellow
Read	√	×	√*
Write	√	×	×
Execute	√	×	√*

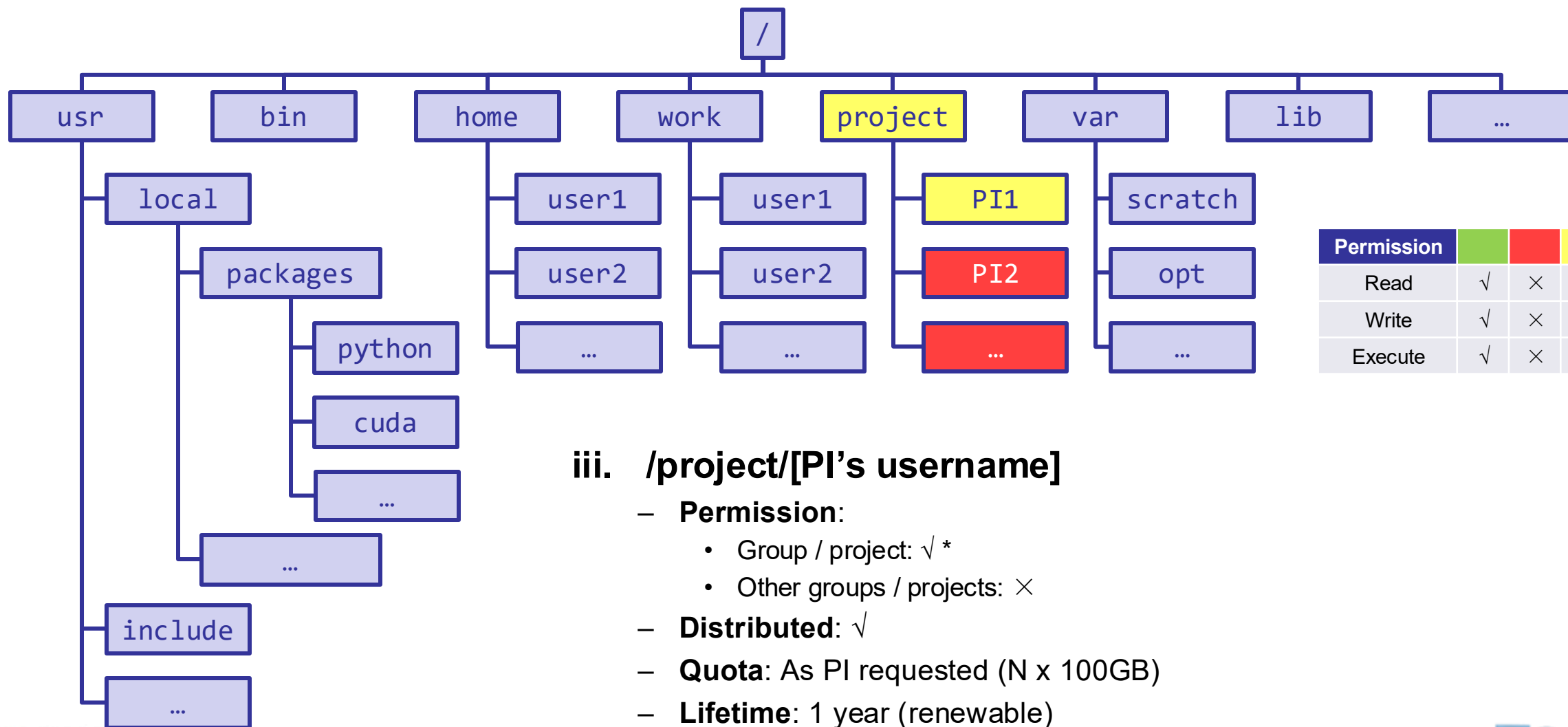
i. /home/[username]

- **Permission:**
 - Your own: √
 - Others: ×
- **Distributed:** √
- **Quota:** 10GB
- **Lifetime:** Unlimited
- **Best for:** Code/executables



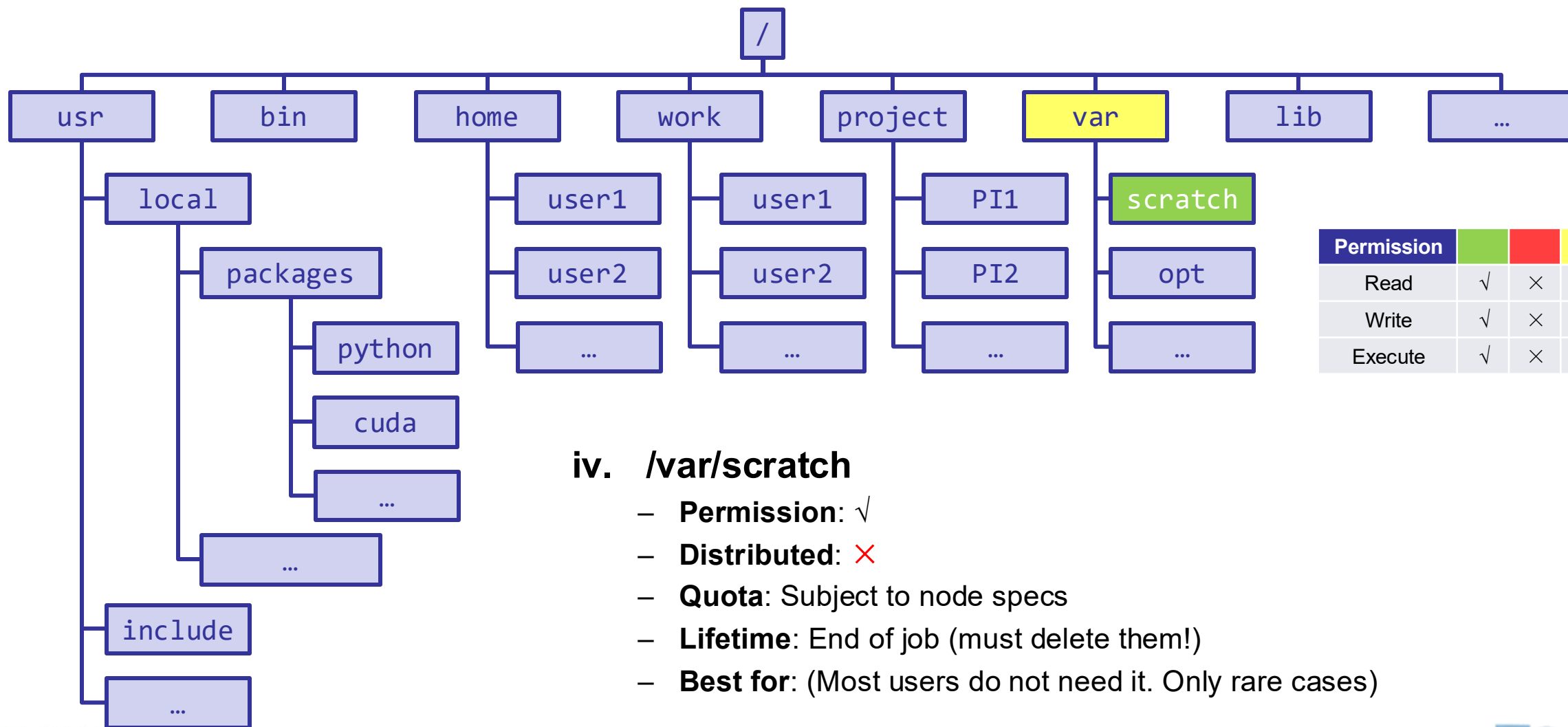
ii. /work/[username]

- **Permission:**
 - Your own: √
 - Others: ×
- **Distributed:** √
- **Quota:** Unlimited
- **Lifetime:** 60 day of inactivity
- **Best for:** Job input / output



iii. /project/[PI's username]

- **Permission:**
 - Group / project: √ *
 - Other groups / projects: ×
- **Distributed:** √
- **Quota:** As PI requested (N x 100GB)
- **Lifetime:** 1 year (renewable)
- **Best for:** Specific project / group sharing. **NOT for archive.**



iv. `/var/scratch`

- **Permission:** √
- **Distributed:** ×
- **Quota:** Subject to node specs
- **Lifetime:** End of job (must delete them!)
- **Best for:** (Most users do not need it. Only rare cases)

File system summary

Directory (folder)	Distributed	Throughput	Lifetime	Quota	Best for
/home/[username]	√	Low	Unlimited	10GB	Code / executables
/work/[username]	√	High	60 days of inactivity	Unlimited	Job input/output
/project/[Pi's username]	√	Medium / High	1 year (renewable)	As PI requested (N x 100GB)	Specific project / group sharing. NOT for archive!
/var/scratch	×	High	End of job	Subject to node specs	(Most users do not need it. Only rare cases)

- **Tips**
 - **Neither /work nor /project** is for long-term storage
 - /work directory will be created **1 hour** after the first cluster login
 - /project directory: **Only PI w/ active allocations** can apply! (See appendix or contact us)
 - **Never** write output to your home directory!
 - Check current disk quota and usage: **balance / showquota**

- File transfer

Commands	
scp / rsync	<p>From/to a Unix/Linux/Mac machine (including between the clusters)</p> <ul style="list-style-type: none">• Syntax:<ul style="list-style-type: none">- scp <options> <source> <destination>- rsync <options> <source> <destination>
wget	<p>From a download link on a website (usually opened with a web browser)</p> <ul style="list-style-type: none">• Syntax:<ul style="list-style-type: none">- wget <link>

2) File system

- File transfer

The screenshot displays the MobaXterm interface. On the left, a file explorer window shows the directory structure of /home/ychen64/. A red circle highlights the 'fftw-3.3.4' directory. On the right, a terminal window shows a file transfer log with the following columns: permissions, user, group, size, date, and filename. The log entries include:

Permissions	User	Group	Size	Date	Filename
-rw-r--r--	1 ychen64	Admins	29816176	Oct 13 2016	R-3.2.3.tar.gz
-rw-r--r--	1 ychen64	Admins	4959	Nov 23 2016	showacct
-rw-r--r--	1 ychen64	Admins	0	Nov 23 2016	0
drwxr-xr-x	5 ychen64	Admins	4096	Feb 21 23:19	r-3.2.3
drwxr-xr-x	4 ychen64	Admins	4096	Mar 1 08:44	packages
drwxr-xr-x	2 ychen64	Users	4096	Mar 17 14:38	test
-rw-r--r--	1 ychen64	Admins	83	Mar 17 14:39	test2
-rw-r--r--	1 ychen64	Admins	223842	Mar 17 15:30	test3
-rw-r--r--	1 root	root	72028352	Apr 19 17:10	md-run_10.xtc
-rw-r--r--	1 ychen64	Admins	179	Apr 23 13:16	gaussian.inp
-rw-r--r--	1 ychen64	Admins	614400	Apr 23 13:16	water.chk
-rw-r--r--	1 ychen64	Admins	11602	Apr 23 13:16	gaussian.log
-rw-r--r--	1 ychen64	Admins	5547014	May 15 09:13	#test.gro.1#
-rw-r--r--	1 ychen64	Admins	9861277	May 15 09:33	combine.pdb
-rw-r--r--	1 ychen64	Admins	5547012	May 15 09:34	combine.gro
-rw-r--r--	1 ychen64	Admins	30377498	May 17 15:46	test.gro
-rw-r--r--	1 ychen64	Admins	30377498	May 17 15:52	test1.gro
-rw-----	1 ychen64	Admins	6442	May 17 15:53	v.o273847
-rw-r--r--	1 ychen64	Admins	30377498	May 17 15:55	test2.gro
-rw-----	1 ychen64	Admins	6445	May 17 15:55	v.o273848
-rw-r--r--	1 ychen64	Admins	12223	May 17 16:02	1.log
-rw-r--r--	1 ychen64	Admins	11200	May 17 16:02	2.log
-rw-r--r--	1 ychen64	Admins	558	May 17 16:19	v.submit
-rw-r--r--	1 ychen64	Admins	12365	May 17 16:19	3.log
-rw-----	1 ychen64	Admins	1637	May 17 16:19	v.o273860
-rw-r--r--	1 ychen64	Admins	561	May 17 16:19	v2.submit
-rw-r--r--	1 ychen64	Admins	10057	May 17 16:20	4.log
-rw-----	1 ychen64	Admins	1637	May 17 16:20	v.o273861
-rw-r--r--	1 ychen64	Admins	5903	May 19 16:33	nuwal2.log
-rw-r--r--	1 ychen64	Admins	0	May 30 09:38	file.out
-rw-r--r--	1 ychen64	Admins	4641	May 30 09:42	launcher.150.log.old
-rw-r--r--	1 ychen64	Admins	1705	May 30 09:44	launcher.150.log
drwxr-xr-x	14 ychen64	Admins	4096	Jun 3 13:06	tmp

UNREGISTERED VERSION - Please support MobaXterm by subscribing to the professional edition here: <http://mobaxterm.mobatek.net>

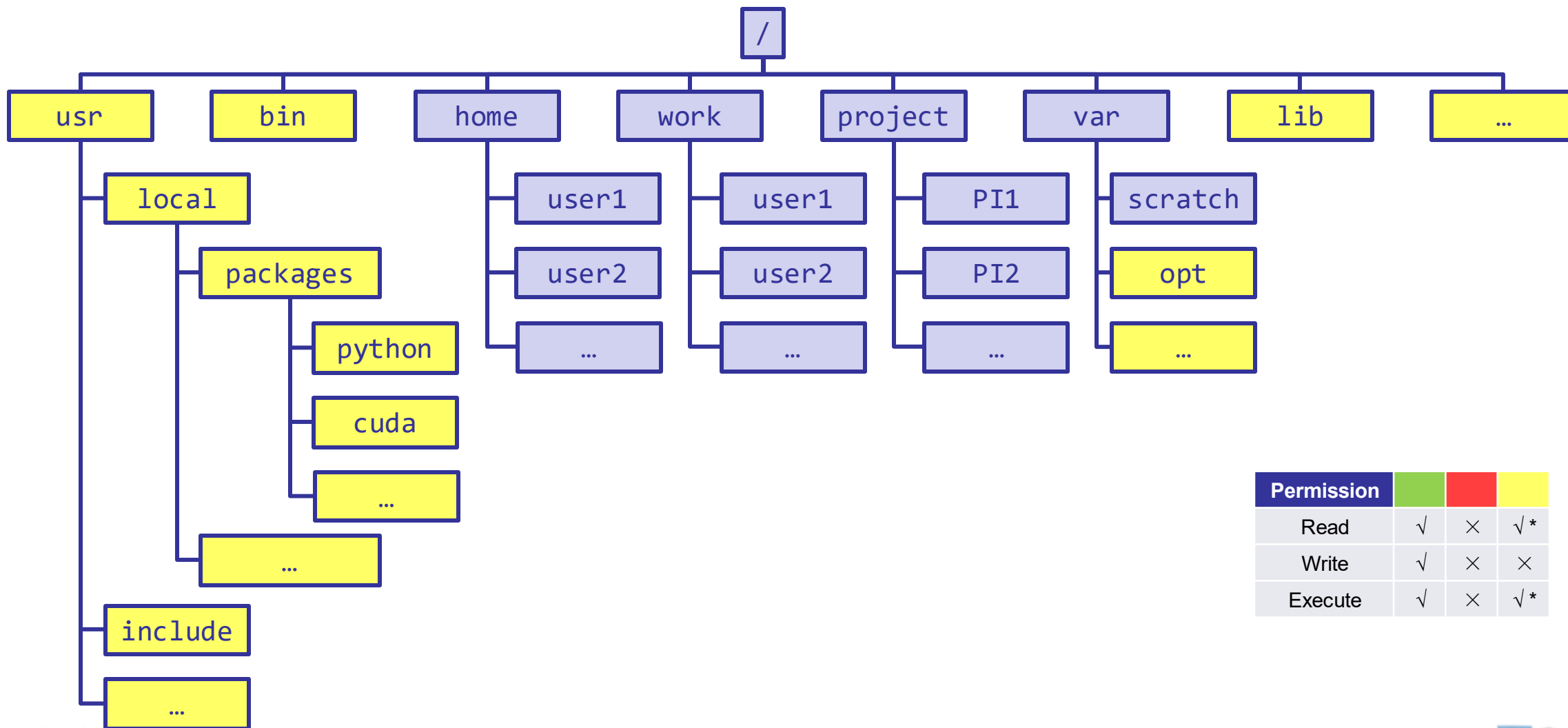
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4. **Software environment**
 - 1) Preinstalled (modules)
 - 2) User installation

- **HPC User Environment 1**

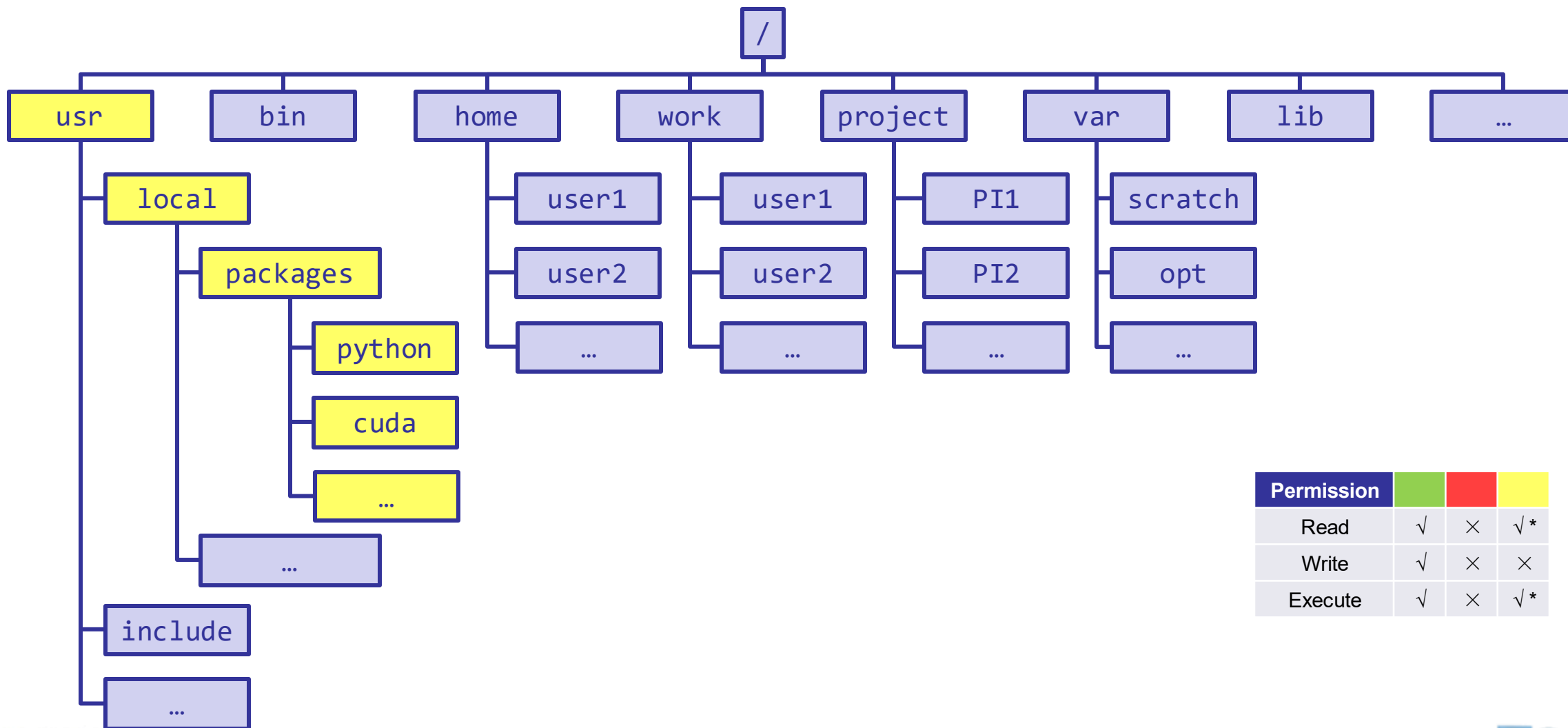
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1) Preinstalled (modules)



Permission	Green	Red	Yellow
Read	√	×	√*
Write	√	×	×
Execute	√	×	√*

1) Preinstalled (modules)



1) Preinstalled (modules)

- **Modules**

- Software that **can be loaded / unloaded** on demand.
- List of modules **preinstalled system-wide**: <https://www.hpc.lsu.edu/docs/guides/index.php>

Category	Modules
Mathematical & utility	FFTW, HDF5, NetCDF, PETSc ...
Applications	Amber, CPMD, NWChem, NAMD, Gromacs, R, LAMMPS ...
Visualization	VisIt, VMD, GaussView ...
Programming Tools	Totalview, DDT, TAU ...

1) Preinstalled (modules)

- **Modules**

Useful commands	
module available (module av)	List available modules on the cluster
module list (module li)	List currently loaded modules
module load [module name]	Load module(s)
module unload [module name]	Unload module(s)
module swap [module 1] [module 2]	Unload a Module 1 and load Module 2
module purge	Unload all modules
module display [module name]	Display module information and all environmental variables changes when loaded

1) Preinstalled (modules)

- **Modules**

- Auto-load modules: `~/modules`

- **HPC User Environment 1**

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2) User installation

You can't...	You can...

You can't...	You can...
<ul style="list-style-type: none">• yum / apt-get• sudo (!!!)• ...	

You can't...	You can...
<ul style="list-style-type: none">• yum / apt-get• sudo (!!!)• ...	<ul style="list-style-type: none">• Build from source• Use virtual environment (e.g., conda) *• Advanced methods (e.g., Singularity) *• Ask HPC staff for help• ...

- **Recommended paths:**
 - a) /home (for yourself)
 - b) /project (for group sharing or large applications)

- **Two types of software packages:**
 - Preinstalled (modules)
 - User installed

■ HPC User Environment 1

1. Intro to HPC
 - 1) Why HPC?
 - 2) What is HPC?
 - 3) Our HPC → **LSU HPC (SMIC, Deep Bayou, SuperMike III) / LONI (QB3, QB4)**
2. Getting started
 - 1) Accounts → **Need an account sponsor! Most likely a faculty**
 - 2) Allocation → **Request a new one or join an existing one**
3. Into the cluster
 - 1) Getting connected → **Logging in via SSH; Do NOT run jobs on head node**
 - 2) File system → **Know your /home, /work, /project**
4. Software environment
 - 1) Preinstalled → **Use modules**
 - 2) User installation → **No sudo or yum**

- **HPC User Environment 2**

1. Queuing system
2. How to run jobs

- **Contact user services**

- Email Help Ticket: sys-help@loni.org
- Telephone Help Desk: +1 (225) 578-0900

- **Storage allocation ≠ computing allocation (what we talked about today)**
- **PI can apply for extra disk space on the /project volume for you and his/her entire research group if**
 - your research requires some files to remain on the cluster for a fairly long period of time; **and**
 - their size exceeds the quota of the /home
- **The unit is 100 GB**
- **Storage allocations are good for 1 year, but can be extended based on the merit of the request**
- **Examples of valid requests**
 - I am doing a 12-month data mining project on a large data set
 - The package I am running requires 10 GB of disk space to install
- **Examples of invalid requests**
 - I do not have time to transfer the data from my scratch space to my local storage and I need a temporary staging area

- **An example of a simple module file (`~/my_module/gitkey`):**

```
#%Module
proc ModulesHelp { } {
    puts stderr { my compiled version of git.
}
}
module-whatism {version control using git}
set GIT_HOME /home/fchen14/packages/git-master/install
prepend-path PATH $GIT_HOME/bin
```

- **Add the path to the key to the `MODULEPATH` environment variable:**

```
$ export MODULEPATH=~/my_module:$MODULEPATH
```

- **Then try to use:**

```
$ module load gitkey
$ which git
$ module unload gitkey
$ which git
```

- 1. <https://www.4freephotos.com/CPU-schematic-6037.html>
- 2. https://en.wikipedia.org/wiki/Apple_A16#/media/File:Apple_A16.jpg
- 2. https://www.cpu-monkey.com/en/cpu-apple_a16_bionic