Virtual Memory II
CSE 351 Autumn 2023

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Teaching Assistants:

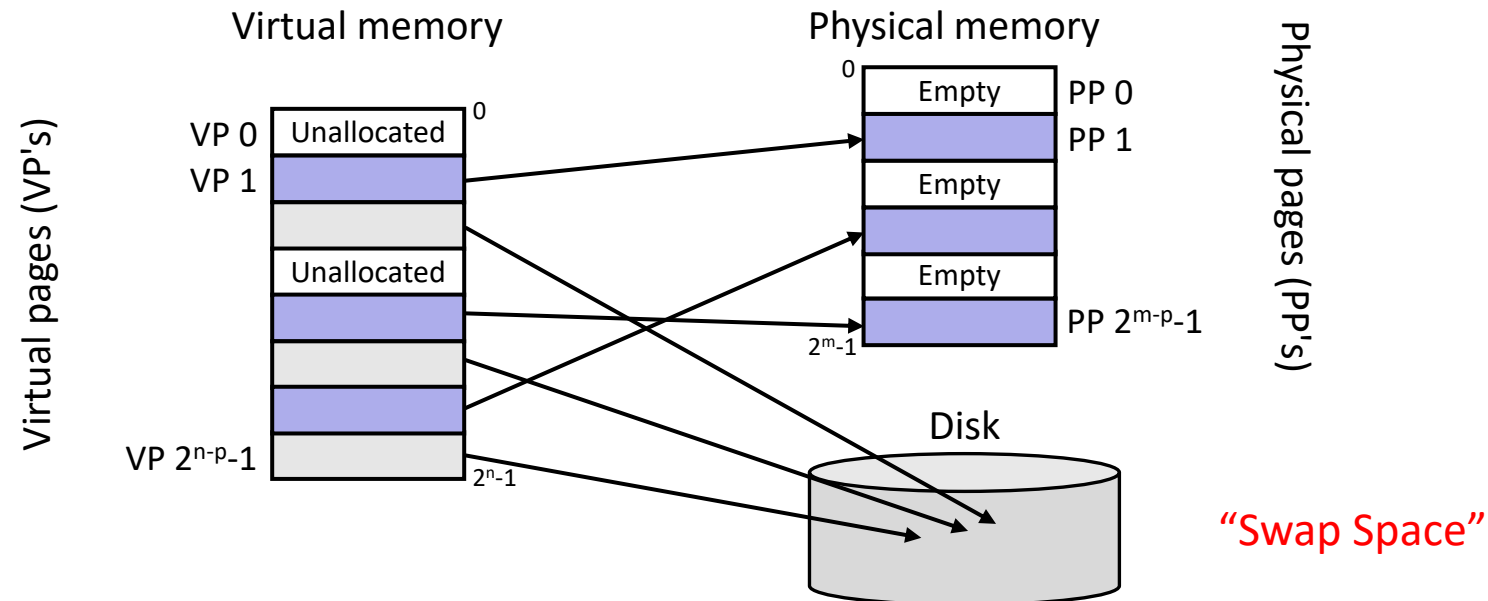|	
Afifah Kashif	Malak Zaki
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Ellis Haker	Simran Bagaria
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https://xkcd.com/1495/
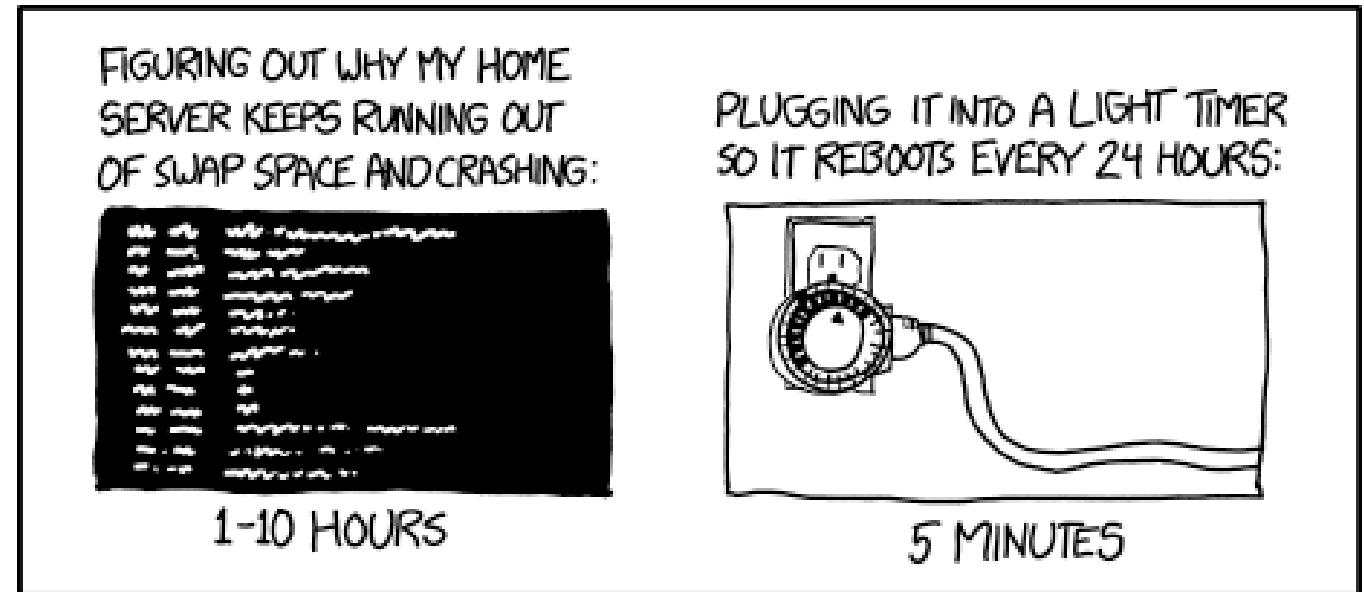
Relevant Course Information

❖ HW24 due Friday, HW25 due next Wednesday (12/6)

❖ Today is the last day to submit Lab 4

❖ Lab 5 due next Thursday (12/7)
   ▪ The most significant amount of C programming you will do in this class – combines lots of topics from this class: pointers, bit manipulation, structs, examining memory
   ▪ Understanding the concepts *first* and efficient *debugging* will save you lots of time
   ▪ Light style grading

❖ Final exam: 12/11-13
   ▪ Final review section on 12/7, final review session on 12/8

Virtual Memory II

Lesson Summary (1/3)

❖ Can think of physical memory as a cache of virtual memory

- Data is transferred between physical memory and swap space (disk) in **pages**

- Physical memory has caching parameters and properties
  - Large page size, fully associative, write-back, replacement policy

- Caveats: virtual pages may not exist, data doesn't have to exist in both physical memory and disk

Virtual memory

Physical memory

Virtual pages (VP's)

Physical pages (PP's)

VP 0	Unallocated	0
VP 1		
	Unallocated	
VP $2^{n-p}-1$		2^n-1

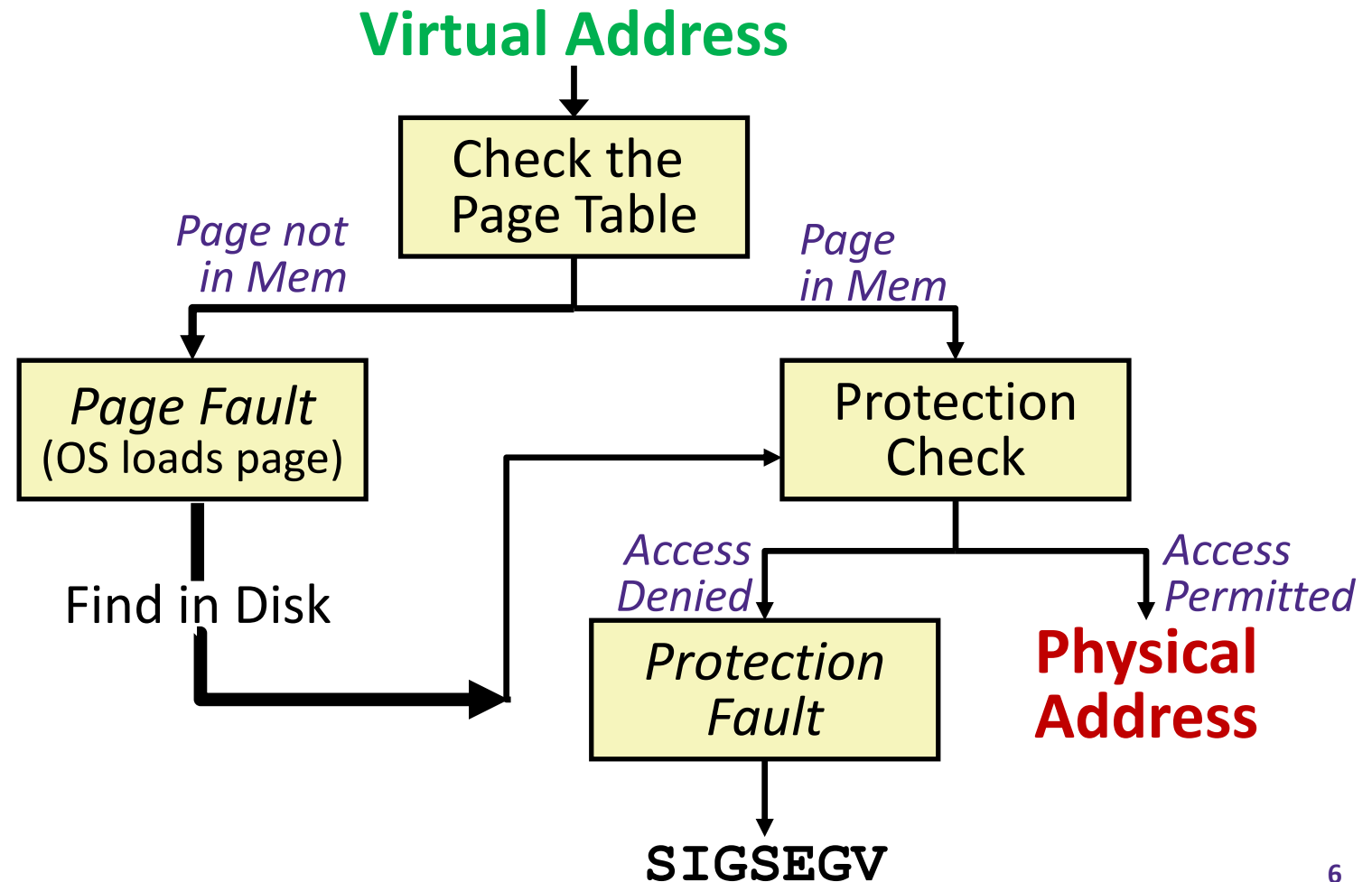| 0		
	Empty	PP 0
		PP 1
	Empty	
	Empty	
		PP $2^{m-p}-1$
2^m-1		

Disk

"Swap Space"

Lesson Summary (2/3)

❖ Address translation done via *page tables*

- Lookup tables (one per process) that map VPN → PPN

- Uses management bits: valid bit, access rights (read, write, execute)

- Stored in memory – page table for currently-running process is pointed to by *page table base register* (PTBR)
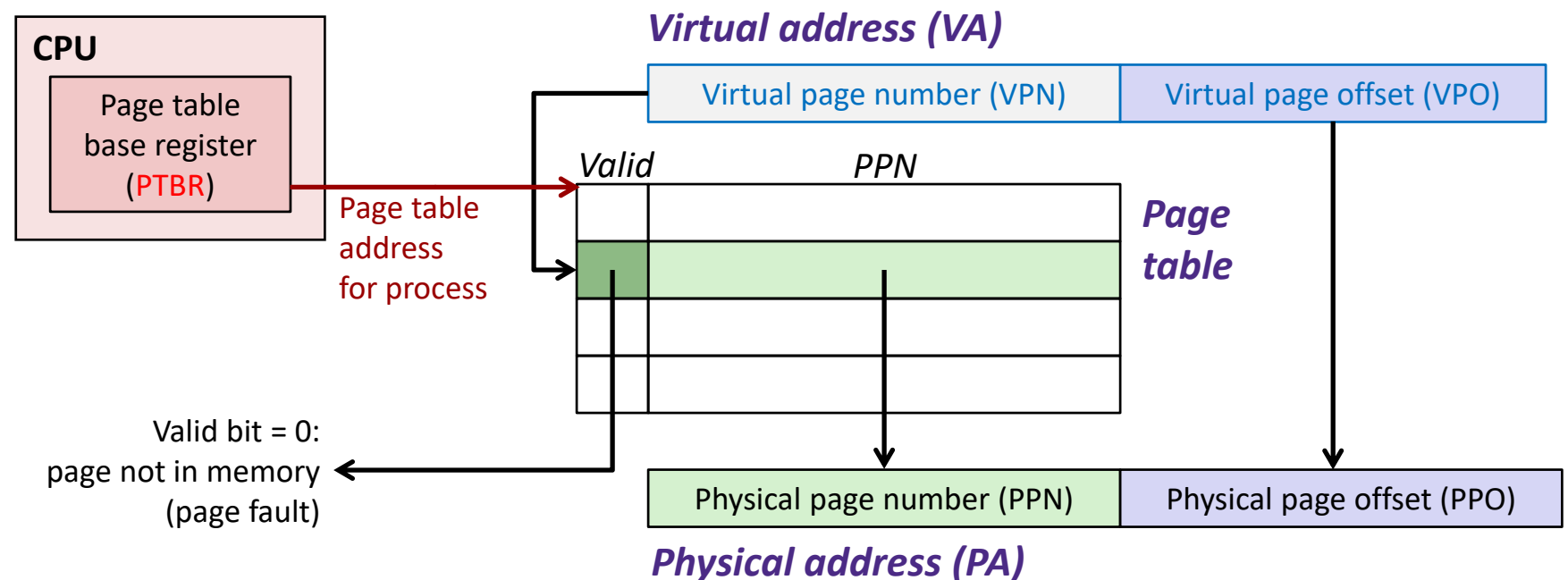
Lesson Summary (2/3)

❖ The address translation story (SO FAR) is check the page table in memory

- <u>Input</u>: VPN, <u>Output</u>: PPN

- *Page Fault:* Fetch page from disk to memory, update corresponding page table entry

- *Page Table Hit:* Use existing page table entry

Virtual Address

Check the
Page Table

*Page not
in Mem*

*Page
in Mem*

Page Fault
(OS loads page)

Protection
Check

Find in Disk

*Access
Denied*

*Access
Permitted*

*Protection
Fault*
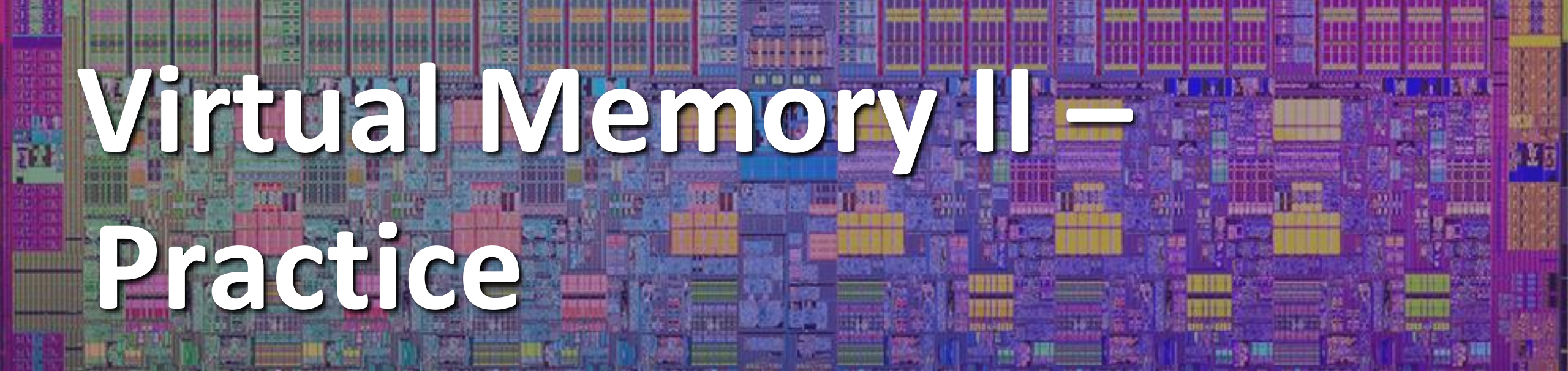
**Physical
Address**

`SIGSEGV`

6

Lesson Q&A

❖ Terminology:

- Paging: page size (P), page offset width (p) virtual page number (VPN), physical page numbers (PPN)
- Page table (PT): page table entry (PTE), access rights (read, write, execute)

❖ Learning Objectives:

- Determine virtual memory parameters related to addresses, page tables, [and TLBs].
- Perform address translations (virtual address → physical address).
- Describe the relationships between virtual memory parameters and policies.

❖ What lingering questions do you have from the lesson?

Virtual Memory II – Practice

Virtual Memory Concept Questions

❖ Which terms from caching are most similar/analogous to the new virtual memory terms?

- page size

- page offset width

- virtual page number

- physical page number

- page table entry

- access rights

VM Parameters Question

❖ How many bits wide are the following fields?

- 16 KiB pages

- 48-bit virtual addresses

- 16 GiB physical memory

	VPN	PPN
(A)	34	24
(B)	32	18
(C)	30	20
(D)	34	20

Memory Review Question

❖ What should the permission bits be for pages from the following sections of virtual memory?

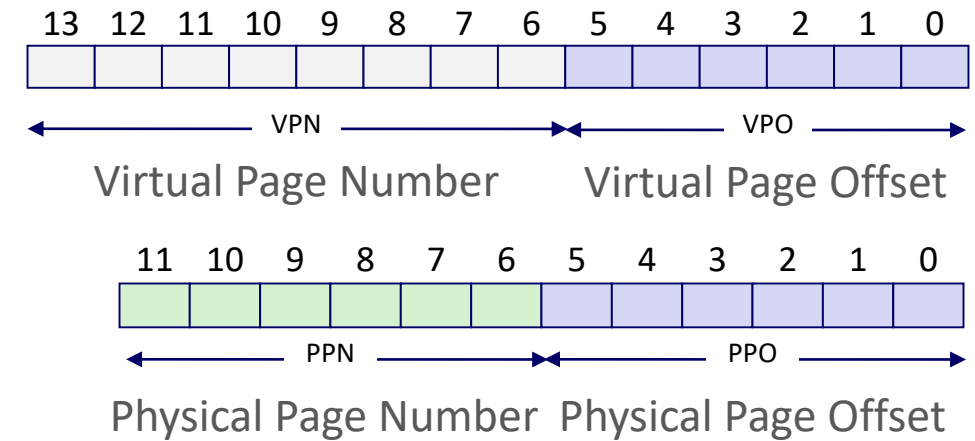| Section	Read	Write	Execute
Stack			
Heap			
Static Data			
Literals			
Instructions			

Homework Setup

❖ **Simple Memory System Example**

- 14-bit virtual addresses
- 12-bit physical address
- Page size = 64 bytes
- Only showing first 16 entries of page table:
  - Other management bits not shown

❖ **Questions:**

- Give a virtual address that causes a page fault.

- What virtual address corresponds to the physical address `0x5F1`?

13	12	11	10	9	8	7	6	5	4	3	2	1	0

◄——————— VPN ———————►◄——————— VPO ———————►

Virtual Page Number   Virtual Page Offset

11	10	9	8	7	6	5	4	3	2	1	0

◄——————— PPN ———————►◄——————— PPO ———————►

Physical Page Number   Physical Page Offset

VPN	PPN	Valid		VPN	PPN	Valid
0	28	1		8	13	1
1	–	0		9	17	1
2	33	1		A	09	1
3	02	1		B	–	0
4	–	0		C	–	0
5	16	1		D	2D	1
6	–	0		E	–	0
7	–	0		F	0D	1

Group Work Time

❖ During this time, you are encouraged to work on the following:
1) If desired, continue your discussion
2) Work on the homework problems
3) Work on the current lab

❖ Resources:
▪ You can revisit the lesson material
▪ Work together in groups and help each other out
▪ Course staff will circle around to provide support