Virtual Memory II

CSE 351 Autumn 2023

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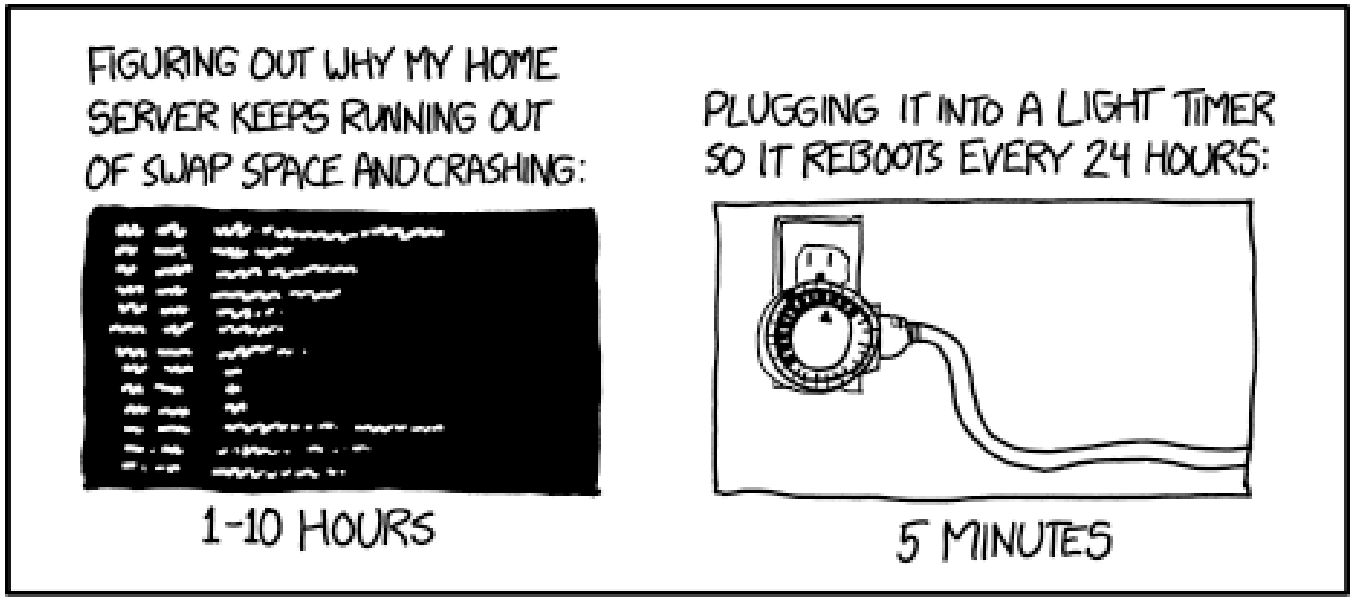
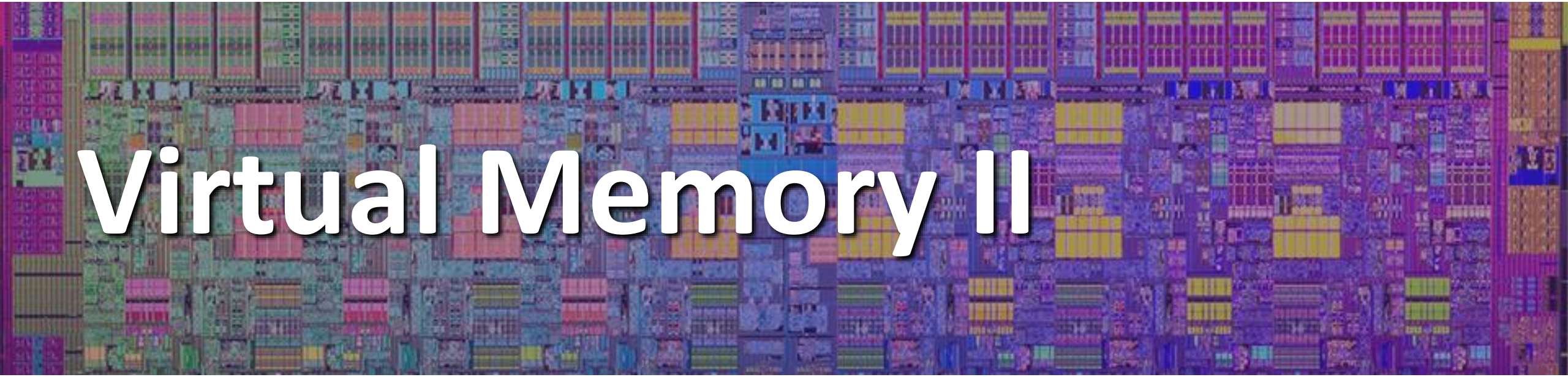


https://xkcd.com/1495/

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

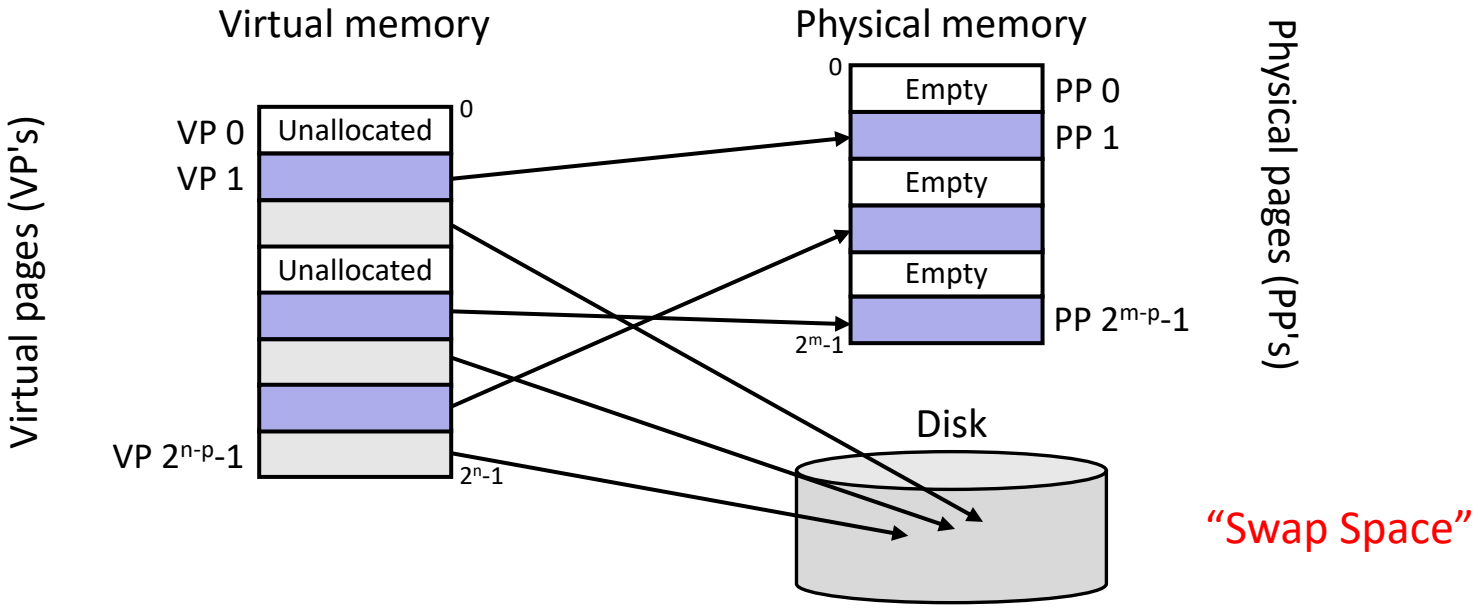
- No lessons in Week 11 – "normal" lectures
- Final exam: 12/11-13
  - Final review section on 12/7, final review session on 12/8



Virtual Memory II

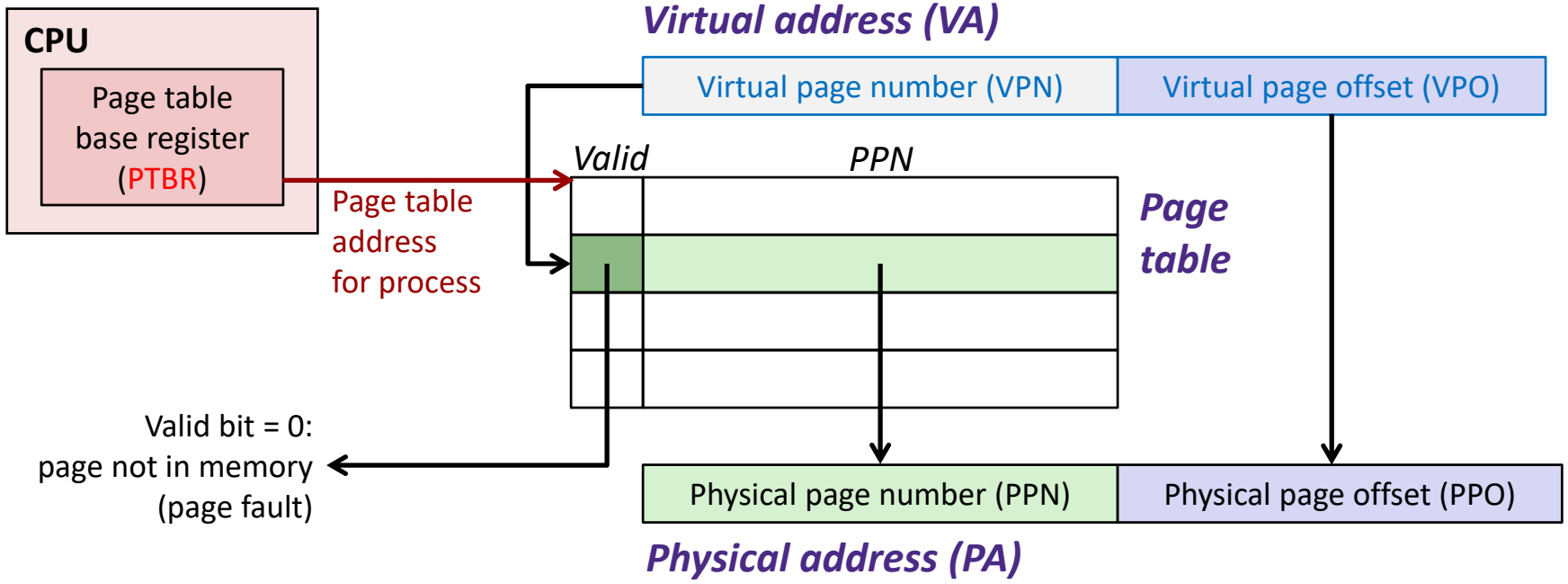
Lesson Summary (1/3)

- 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



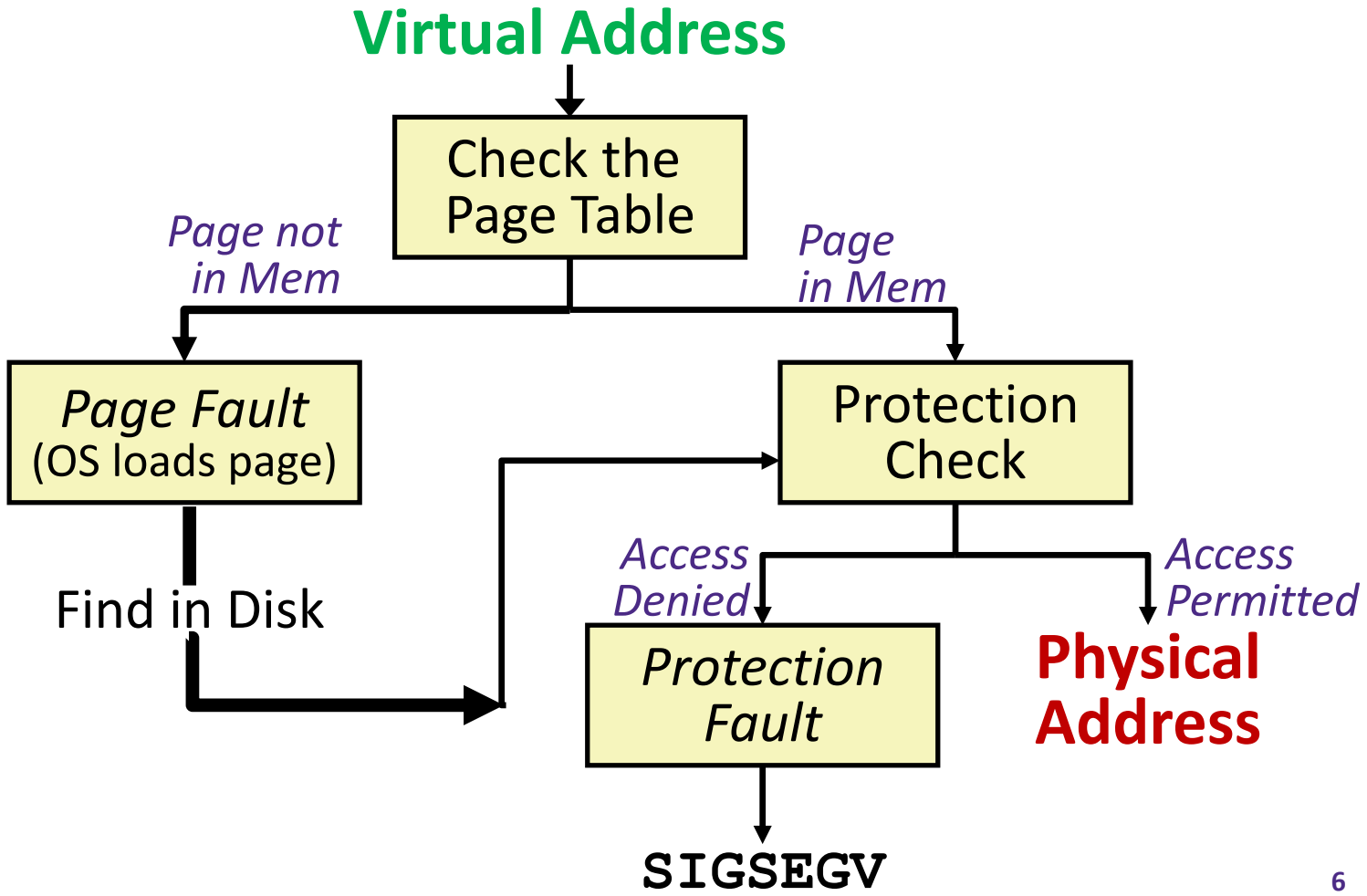
Lesson Summary (2/3)

- 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
  - Input: VPN, Output: PPN
  - *Page Fault:* Fetch page from disk to memory, update corresponding page table entry
  - *Page Table Hit:* Use existing page table entry

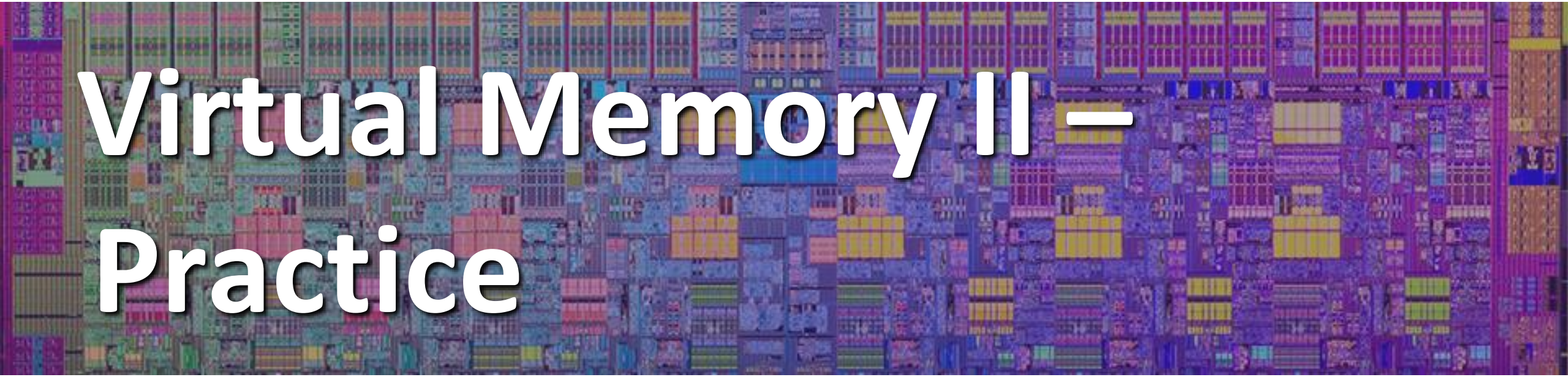


Lesson Q&A

- 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?

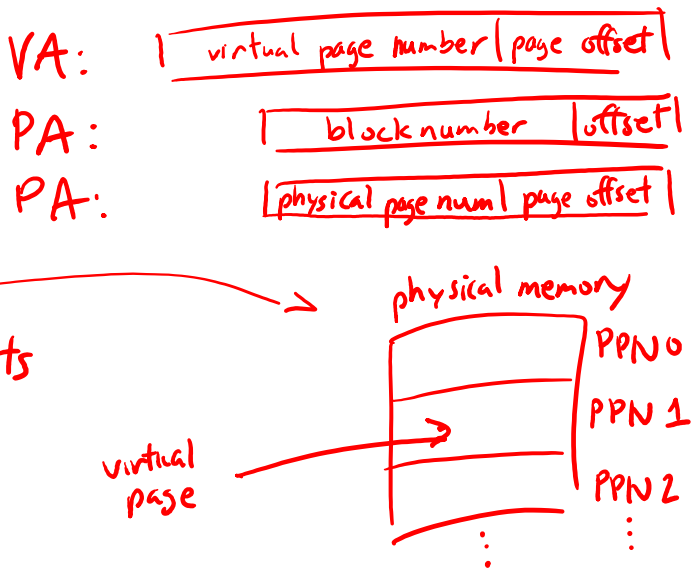


Virtual Memory II – Practice

Virtual Memory Concept Questions

- Which terms from caching are most similar/analogous to the new virtual memory terms?
  - block #, block size, cache line, cache set, index width, management bits, offset width, tag width

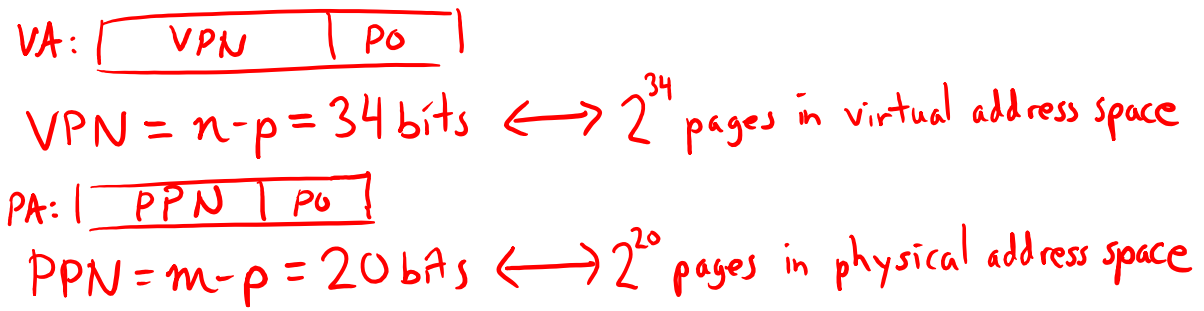
  - page size
    block size
  - page offset width
    (block) offset width
  - virtual page number
    block number
  - physical page number
    block number or cache set
  - page table entry
    cache line: data of interest + management bits
  - access rights
    management bits



VM Parameters Question

- How many bits wide are the following fields?
  - 16 KiB pages (2^{14} bytes, 2^{10} bytes) → $p = 14$ bits
  - 48-bit virtual addresses → $n = 48$ bits ⟷ 256 TiB virtual memory
  - 16 GiB physical memory (2^{34} bytes, 2^{30} bytes) → $m = 34$ bits

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



Memory Review Question

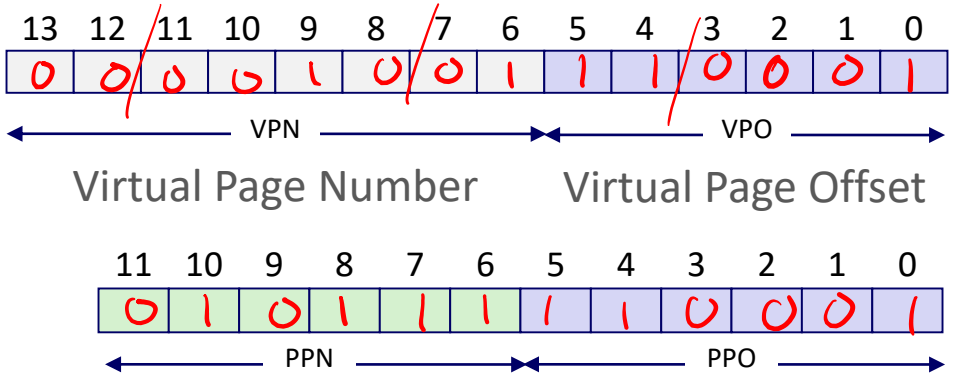
- What should the permission bits be for pages from the following sections of virtual memory?

Section	Read	Write	Execute
Stack	1	1	0
Heap	1	1	0
Static Data	1	1	0
Literals	1	0 (constants)	0
Instructions	1	0 (don't alter code)	1 (only instructions should be executable)

static in size

Homework Setup

- Simple Memory System Example
  - 14-bit virtual addresses n = 14 bits
  - 12-bit physical address m = 12 bits
  - Page size = 64 bytes = 2^6, p = 6 bits wide
  - Only showing first 16 entries of page table:
    - Other management bits not shown



VPN	PPN	Valid
0	28	1
1	–	0
2	33	1
3	02	1
4	–	0
5	16	1
6	–	0
7	–	0

VPN	PPN	Valid
8	13	1
9	17	1
A	09	1
B	–	0
C	–	0
D	2D	1
E	–	0
F	0D	1

- Questions:
  - Give a virtual address that causes a page fault.
    VPN of 1, 4, 6, 7, B, C, or E, any VPO
  - What virtual address corresponds to the physical address 0x5F1?
    PPN = 0x17 → VPN = 0x09, same offset so 0x0271

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