Memory (Part III):
Virtual Memory

Professor Travis Peters
CSCI 460 Operating Systems
Fall 2019

Some slides & figures adapted from Stallings instructor resources.

Some slides adapted from Adam Bates's F'18 CS423 course @ UIUC
https://courses.engr.illinois.edu/cs423/sp2018/schedule.html

Today

Announcements

- Project Proposal ***Due 11/01!***
- HW5 posted today (Due 11/01)
- PA2 posted today (Due 11/08) — two weeks… but start early ;)

Goals & Learning Objectives

- Understand Virtual Memory (and its connection to *paging* & *segmentation*)

Last Time…

Paging & Segmentation

- Programs broken into non-contiguous pieces (pages or segments)
- Logical addresses dynamically translated into physical addresses at run-time

→ ***Not all memory needs to be in MM during execution!***

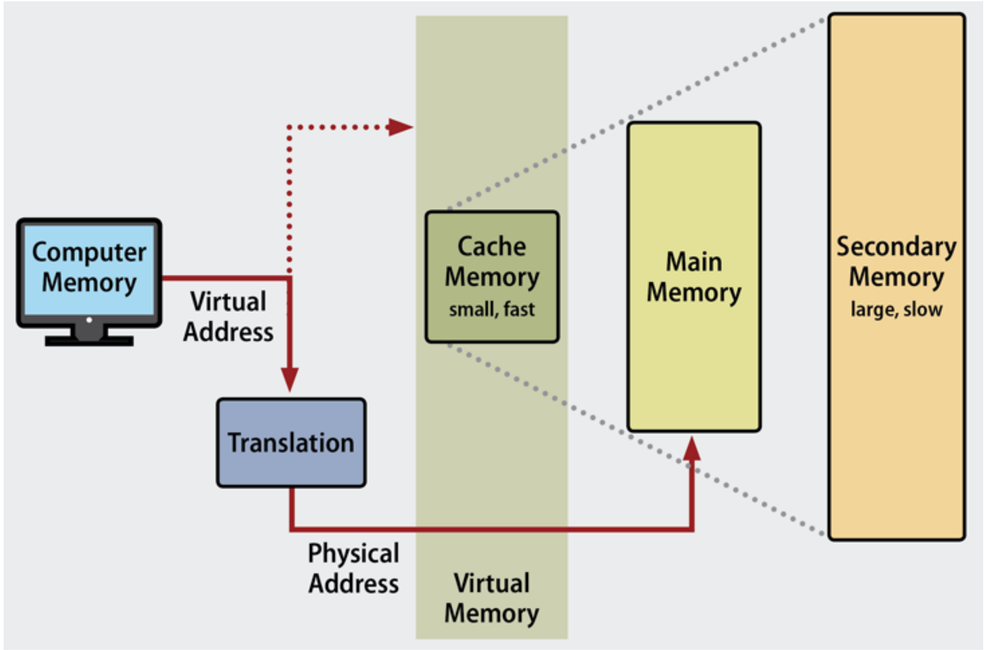


Image Credit: *https://www.enterprisestorageforum.com/storage-hardware/virtual-memory.html*

Virtual Memory — *The Basics*

Paging & Segmentation

- Programs broken into non-contiguous pieces (pages or segments)
- Logical addresses dynamically translated into physical addresses at run-time

→ ***Not all memory needs to be in MM during execution!***

So <u>what is</u> Virtual Memory?

- All memory can be addressed as if it were part of main memory
- References to memory are dynamically translated
- Limited only by the addressing scheme of the system & amount of secondary memory

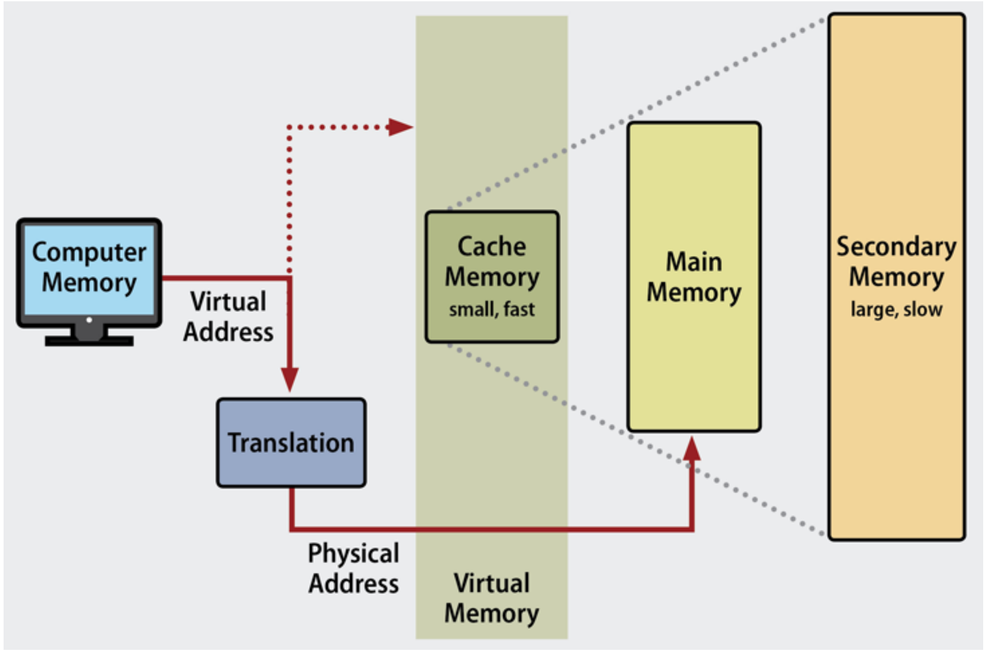
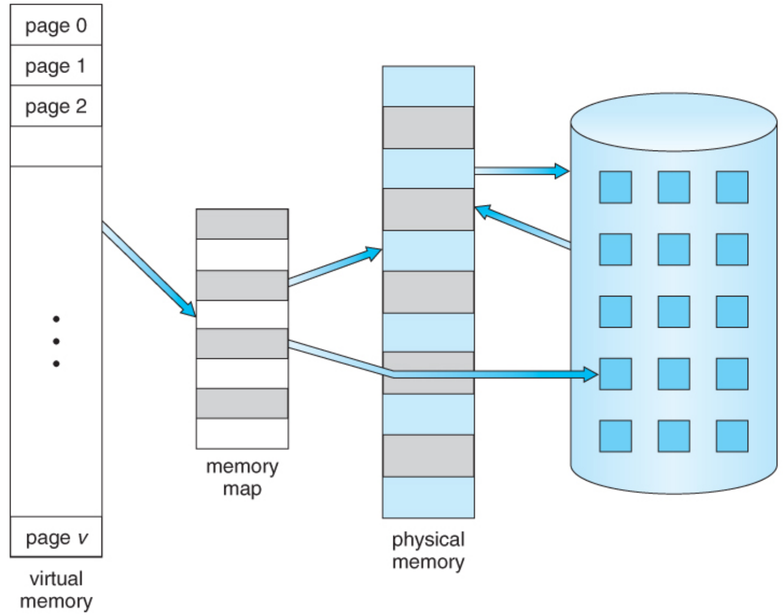


Image Credit: *https://www.enterprisestorageforum.com/storage-hardware/virtual-memory.html*

Virtual Memory — *How?*



How it Works

- To start, bring bare minimum of process into main memory (MM)
  - ***Resident Set*** == the part of a process in MM
- Access process memory in the normal way!

What if a logical address references a part of memory that is <u>not</u> in MM?

→ page/segment table(s) make it easy to know if something is *in* MM

→ generate interrupt: *"address not in memory!"* & move process to "blocked" state

→ bring missing part of process into MM (i.e., OS reads from disk)

→ …schedule other processes to run…

→ I/O interrupt indicates that missing process "piece" has been read/loaded in MM

→ blocked process moves back to "ready" state

Virtual Memory — *Why?*

1. **More processes can be maintained in main memory**
   - *We need not load all parts of every process, so MM can accommodate many more processes*
   - *More processes → more likelihood of processes ready to run → better processor utilization*

2. **A process may be larger than *all* of main memory!**
   - No need to worry about actual limitations of MM *(1MB, 1GB, 4GB, 16GB — whatever!)*
   - No need for programmer to worry about structure/size of program
     - OS breaks up program into arbitrary pieces; most are stored outside of MM
     - OS brings in pieces when needed

Any Limitations?

- Virtual Memory is only constrained by the availability of secondary memory
  - **Real Memory** — *where processes execute; main memory*
  - **Virtual Memory** — *where processes can be stored as needed; the perceived (available) memory space*

Virtual Memory — *Locality*

- **Principle of Locality**
  - Work (program/data references) within a process tend to cluster
  - Over a short period of time, execution is likely confined to small section of a program
  - ***Example:*** a particular (sub)routine

    → wasteful to spend time loading in all parts of a program in the short time before process is swapped/suspended

    → trigger a "fault" if something is needed that isn't in memory

    (i.e., tell OS to load something into MM)

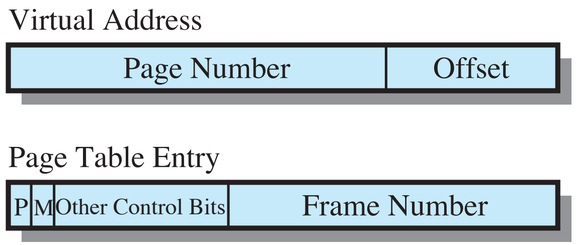
- **Thrashing**
  - Don't want to spend excessive time loading/unloading stuff into MM

    (i.e., handling swapping, rather than executing meaningful computations)
  - OS's job: try to "guess" based on recent history what is likely to be needed *(load/keep that stuff…)*

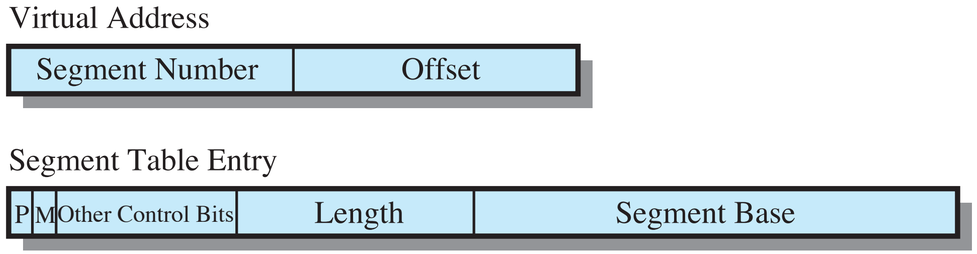
Towards Virtual Memory — Characteristics of Paging & Segmentation

Simple Paging	Virtual Memory Paging	Simple Segmentation	Virtual Memory Segmentation
Main memory partitioned into small fixed-size chunks called frames		Main memory not partitioned	
Program broken into pages by the compiler or memory management system		Program segments specified by the programmer to the compiler (i.e., the decision is made by the programmer)	
Internal fragmentation within frames		No internal fragmentation	
No external fragmentation		External fragmentation	
Operating system must maintain a page table for each process showing which frame each page occupies		Operating system must maintain a segment table for each process showing the load address and length of each segment	
Operating system must maintain a free frame list		Operating system must maintain a list of free holes in main memory	
Processor uses page number, offset to calculate absolute address		Processor uses segment number, offset to calculate absolute address	
All the pages of a process must be in main memory for process to run, unless overlays are used	Not all pages of a process need be in main memory frames for the process to run. Pages may be read in as needed	All the segments of a process must be in main memory for process to run, unless overlays are used	Not all segments of a process need be in main memory for the process to run. Segments may be read in as needed
	Reading a page into main memory may require writing a page out to disk		Reading a segment into main memory may require writing one or more segments out to disk

Memory Management Formats



Paging



Segmentation

If Page is Present (P)

→ ***use frame number***

If Page Modified (M)

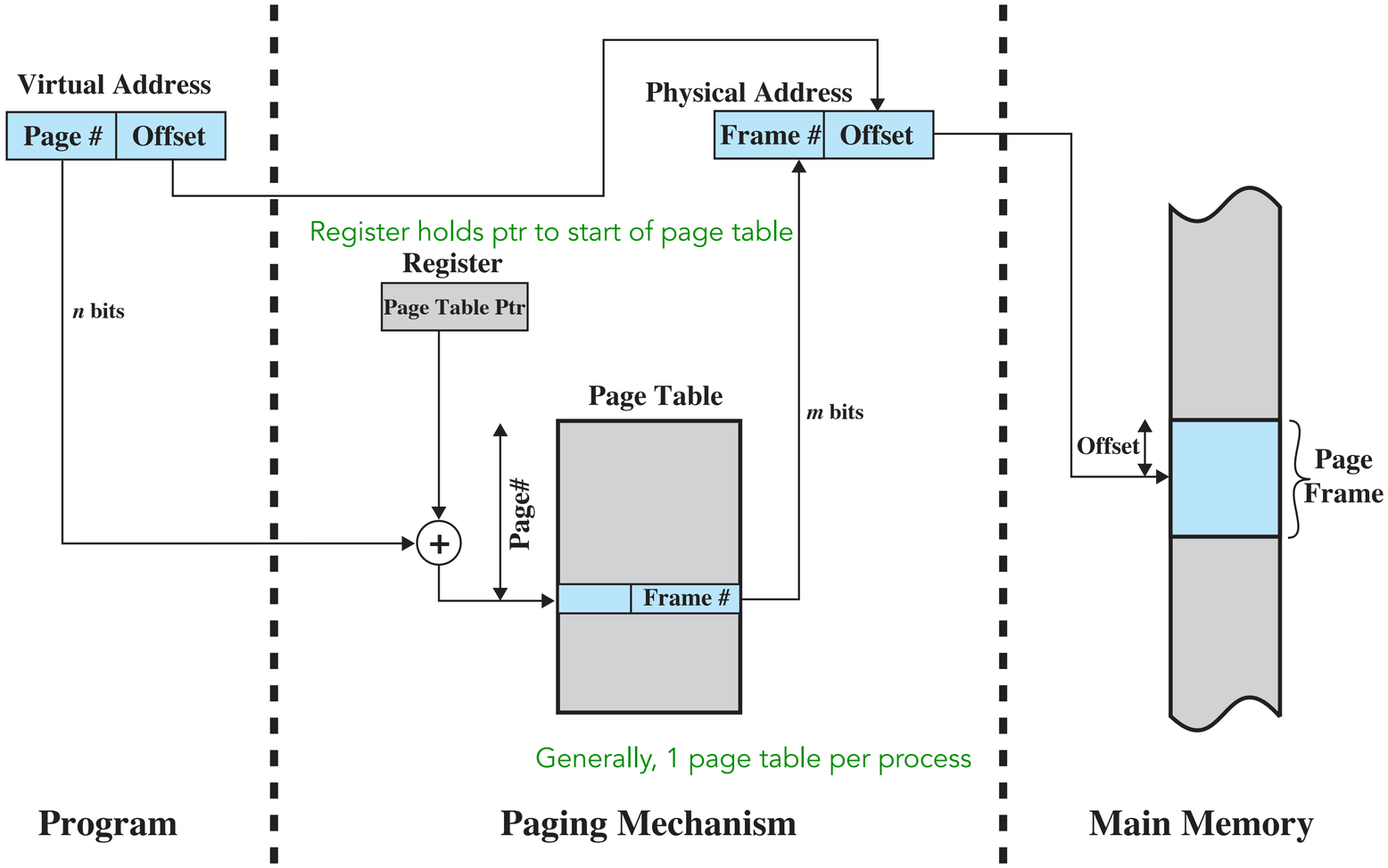
→ ***write out***

Address Translation in 1-Level Paging System

If Page is Present (P)
→ ***use frame number***

If Page Modified (M)
→ ***write out***

$(n > m)$ → more pages than frames



Any (potential) problems?

What if amount of VM is *huuuuge?!*

Example:
2^{31} = 2 GB Virtual Memory
2^{9} = 512 B pages

Q: How many pages are possible?
(How many page table entries could there be?)

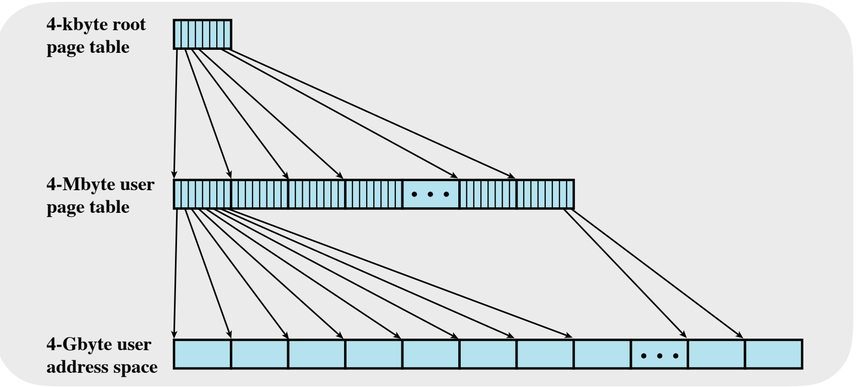
$$2^{31} \div 2^{9} = 2^{31-9} = 2^{22}$$

page table entries *per process*!

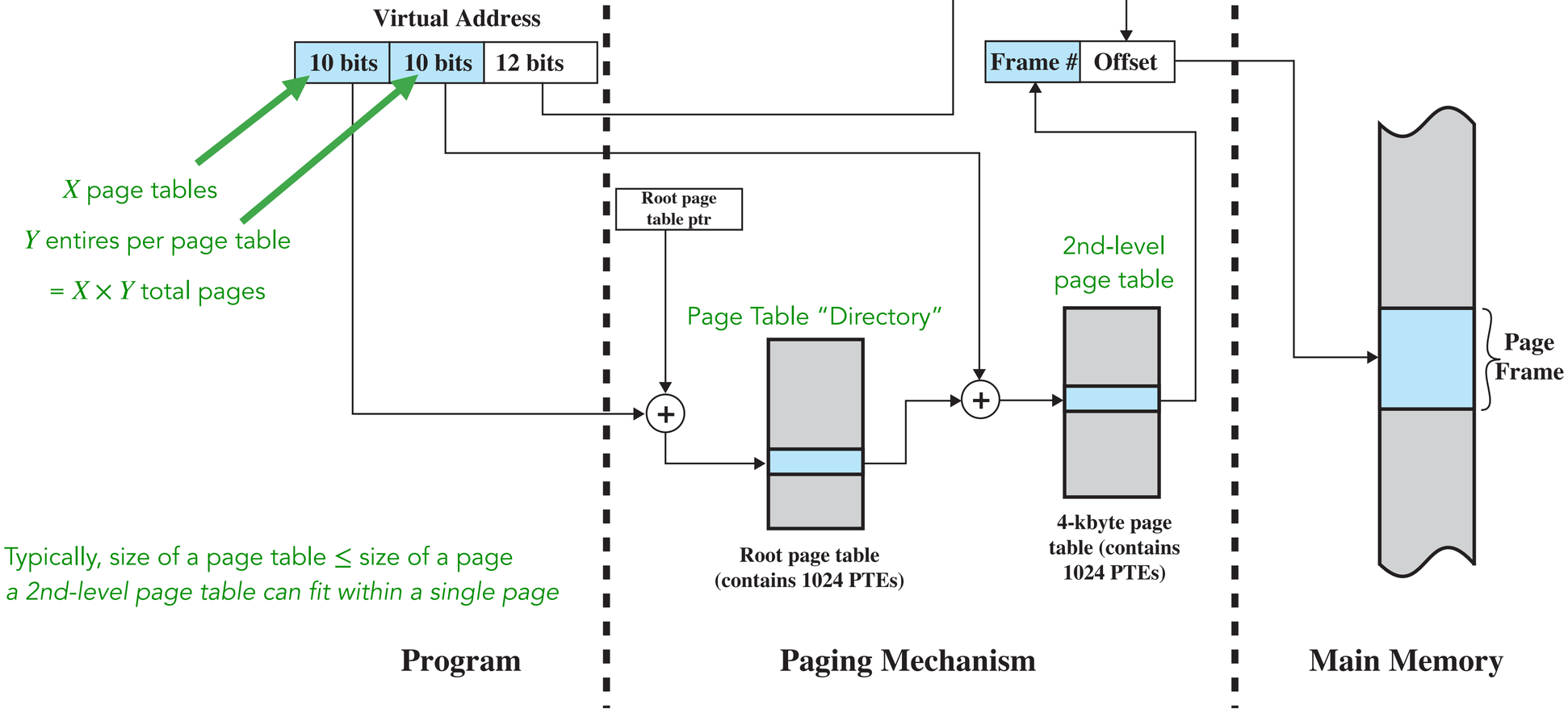
.
..
…

We could store page tables in VM as well!
Any problems with that?

Address Translation in 2-Level Paging System



Page tables themselves could be paged in/out…
but at least *part* of a page table must be in MM for a process to run… → ***2-Level Paging System***



Typically, size of a page table ≤ size of a page
i.e., a 2nd-level page table can fit within a single page