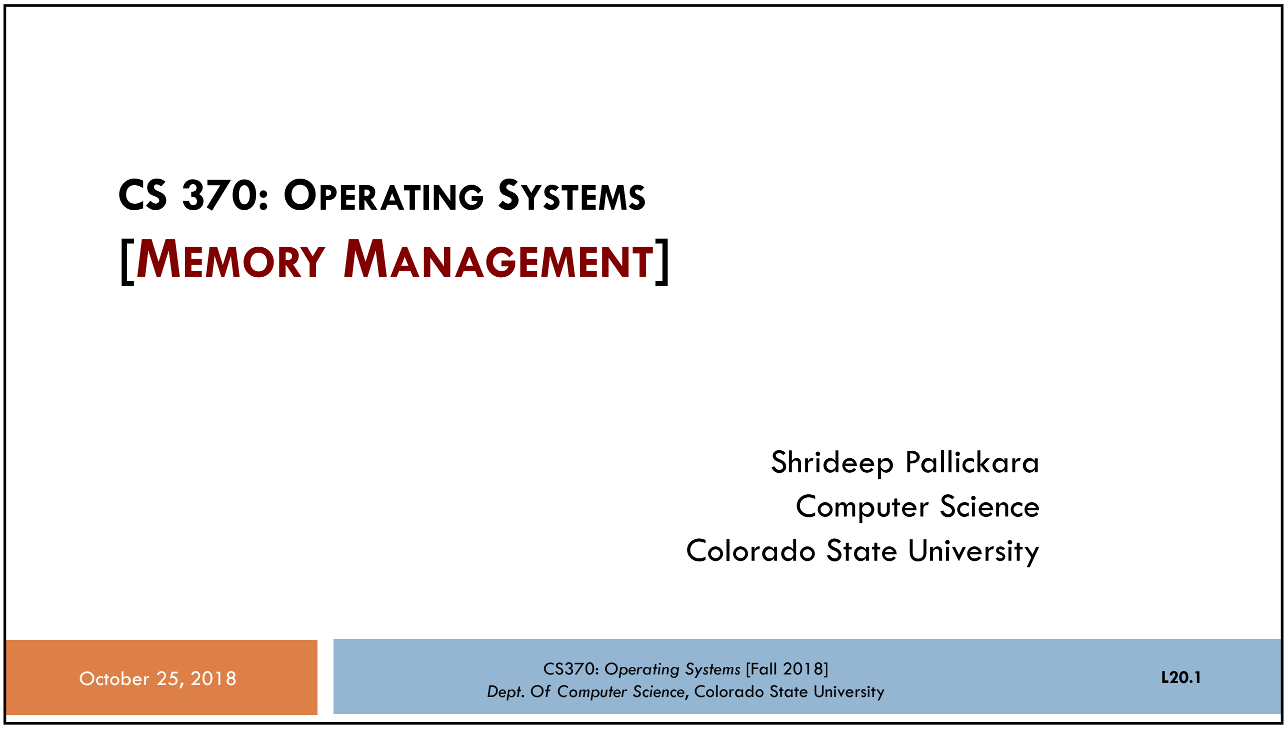

CS 370: Operating Systems
[Memory Management]

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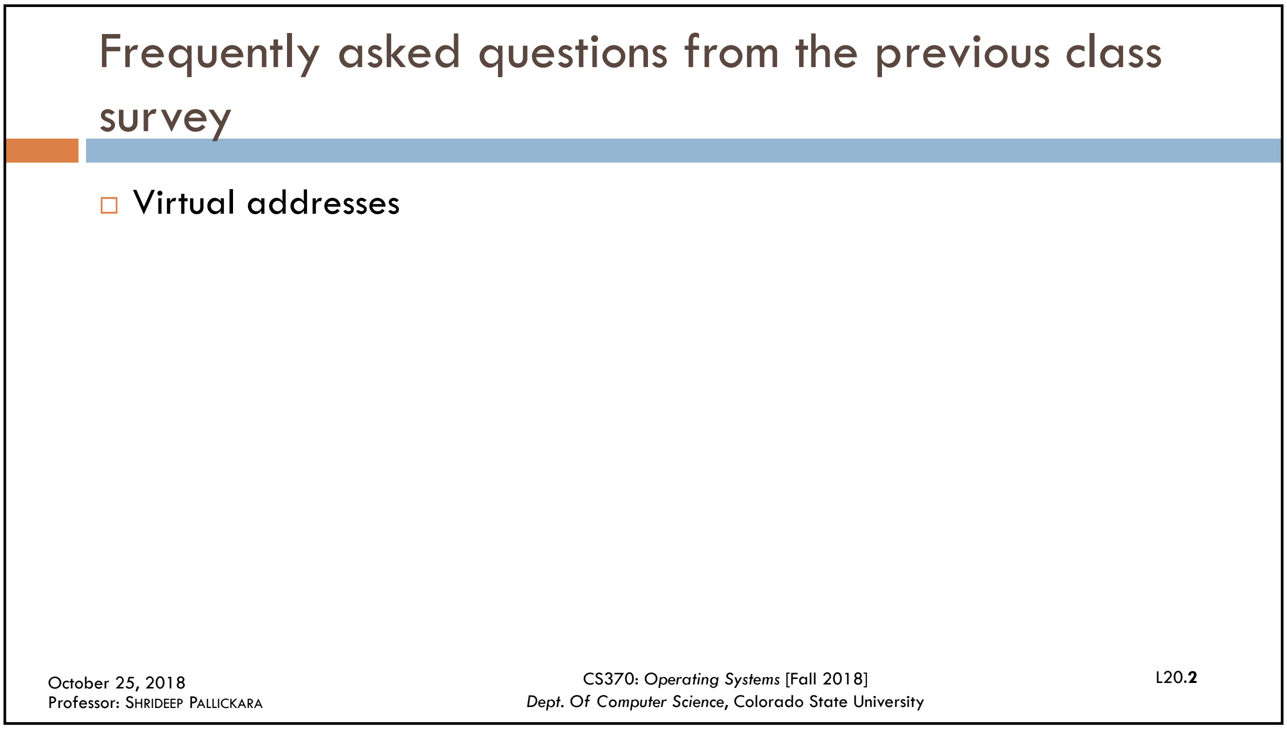
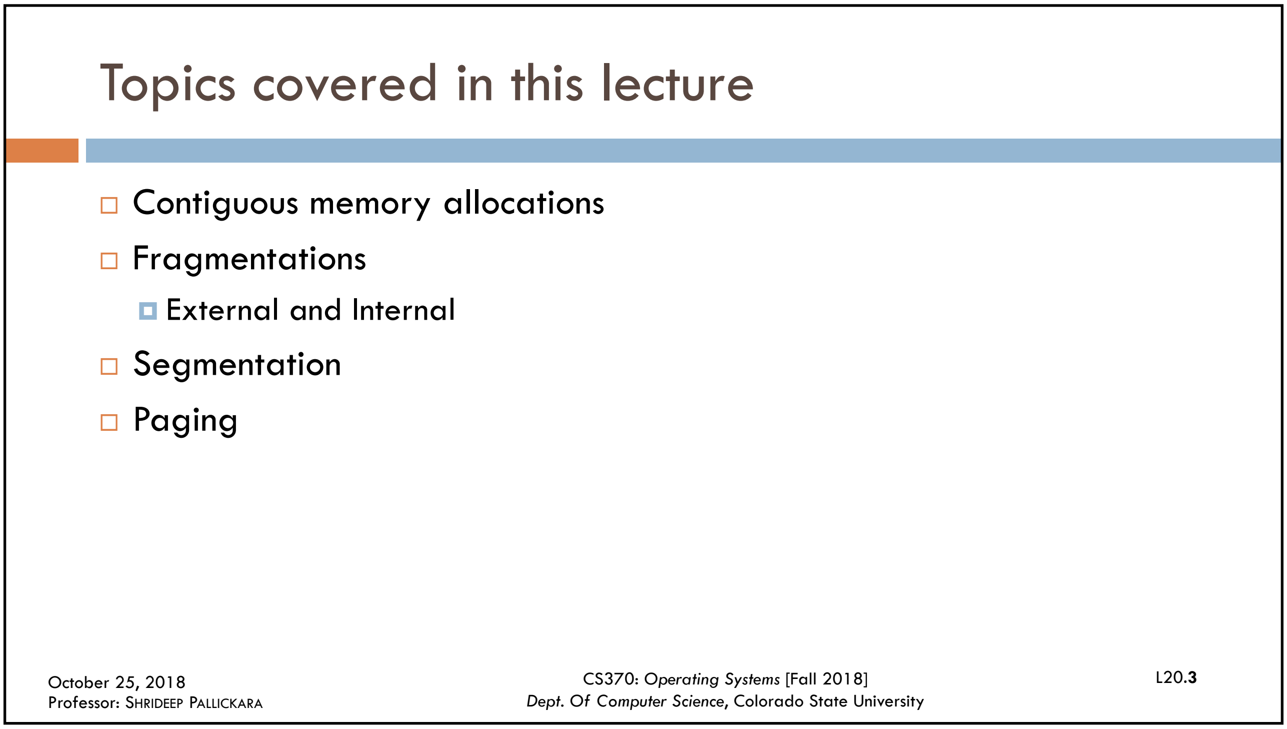


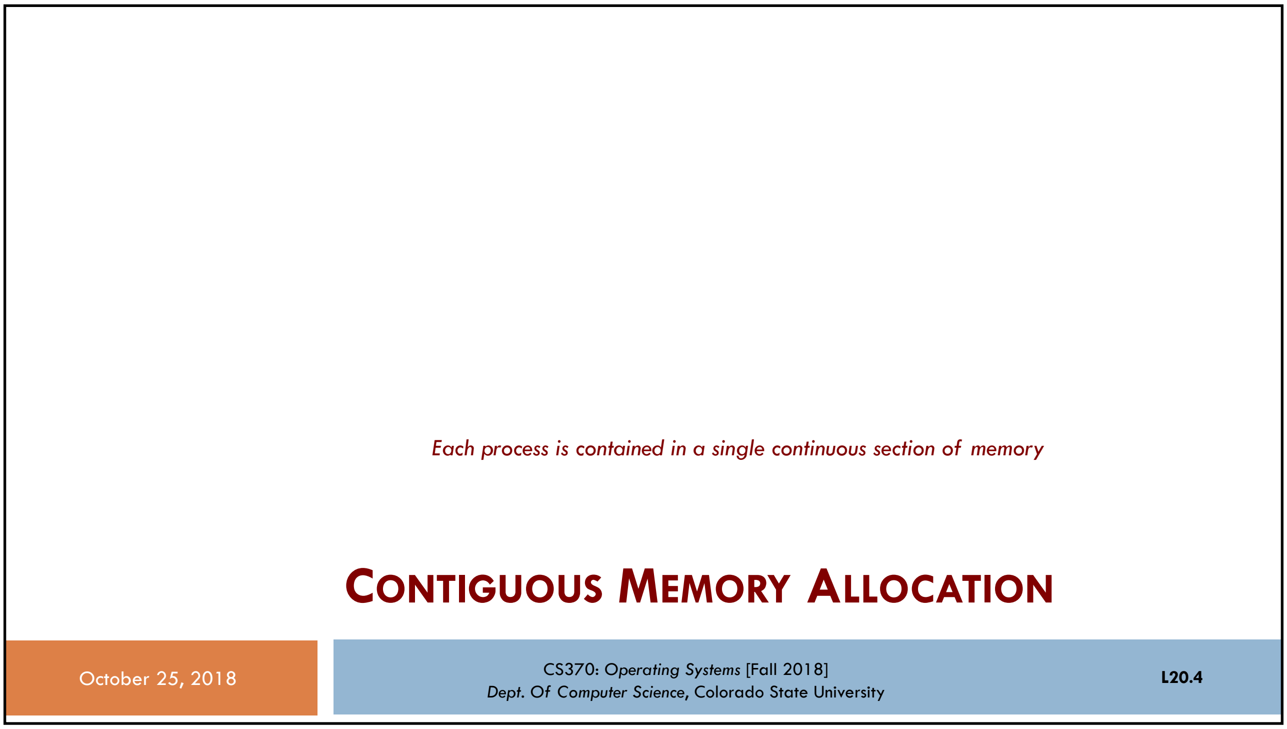
Frequently asked questions from the previous class survey

- □ Virtual addresses



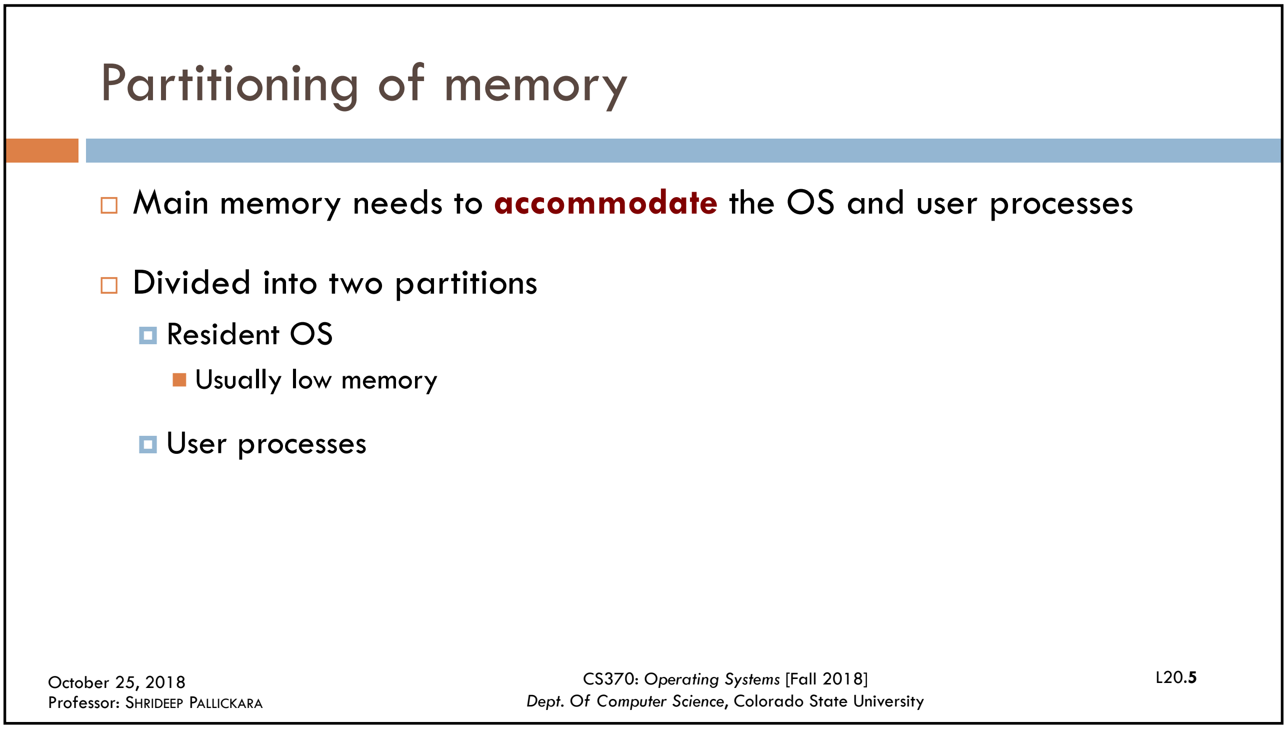
Topics covered in this lecture

- □ Contiguous memory allocations
- □ Fragmentations
  - External and Internal
- □ Segmentation
- □ Paging



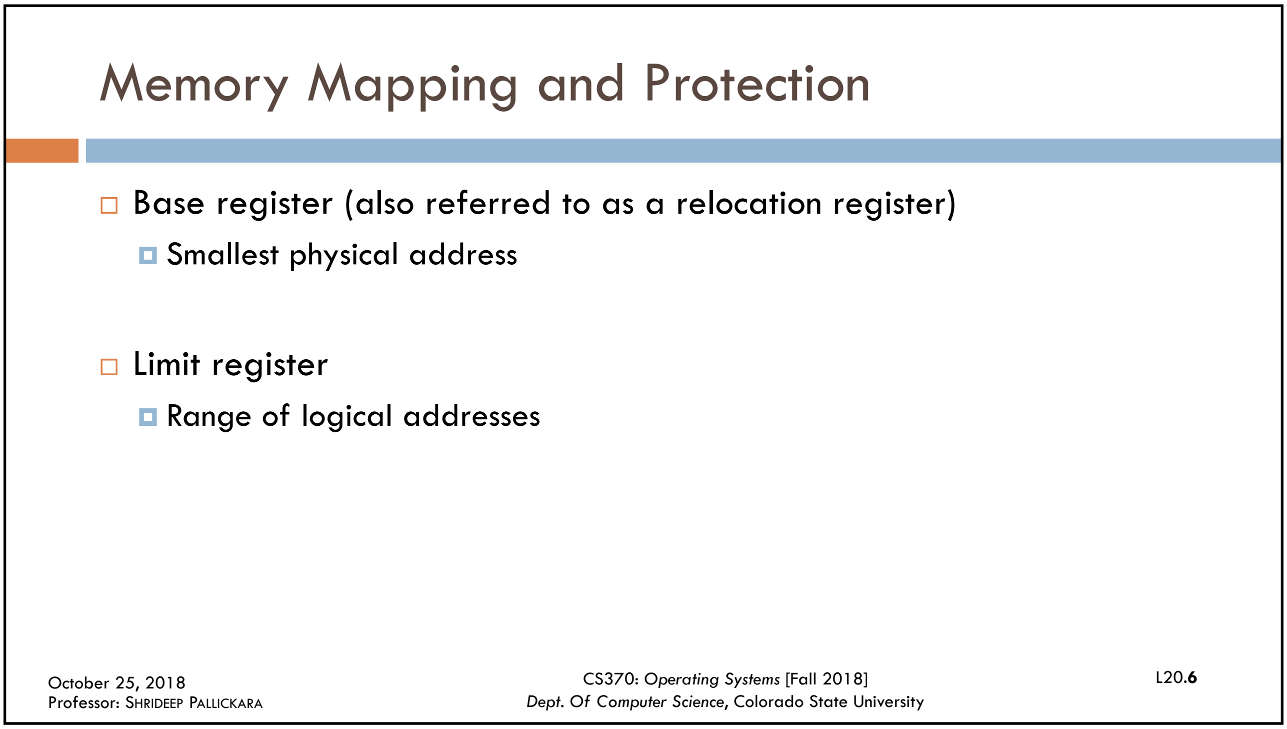
Each process is contained in a single continuous section of memory

CONTIGUOUS MEMORY ALLOCATION



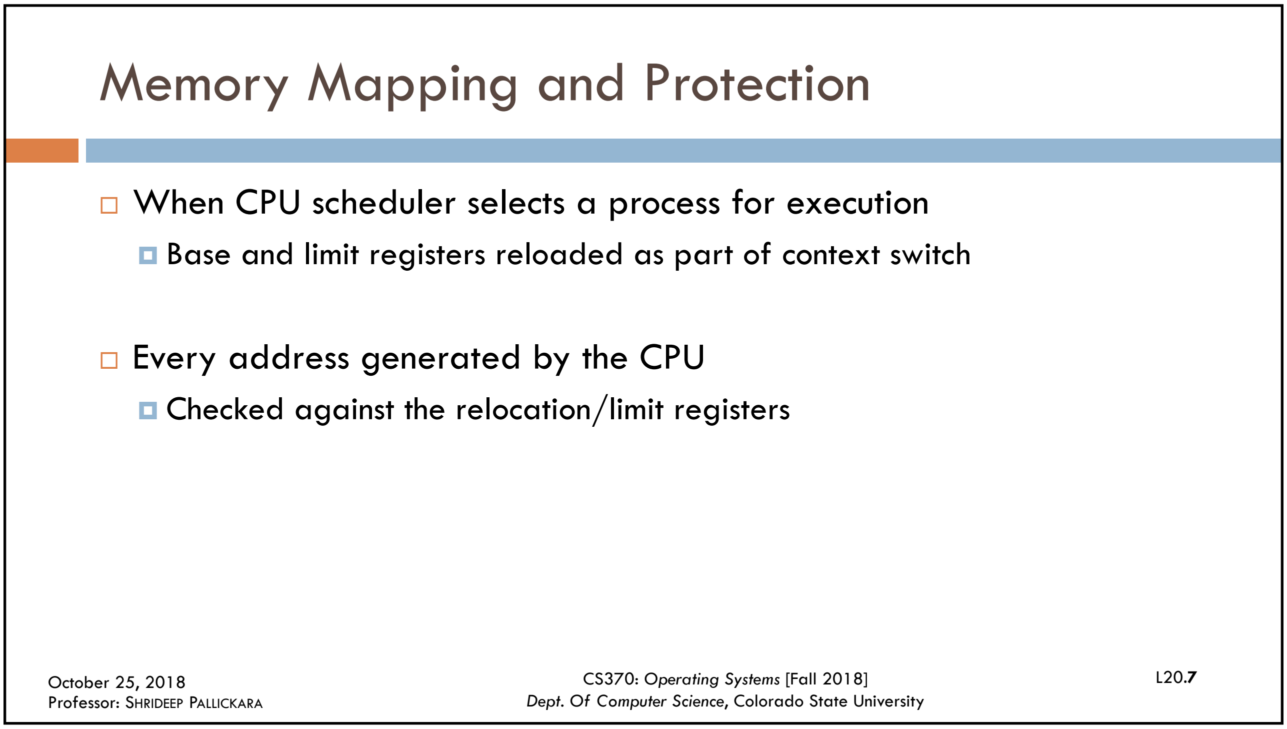
Partitioning of memory

- Main memory needs to **accommodate** the OS and user processes
- Divided into two partitions
  - Resident OS
    - Usually low memory
  - User processes



Memory Mapping and Protection

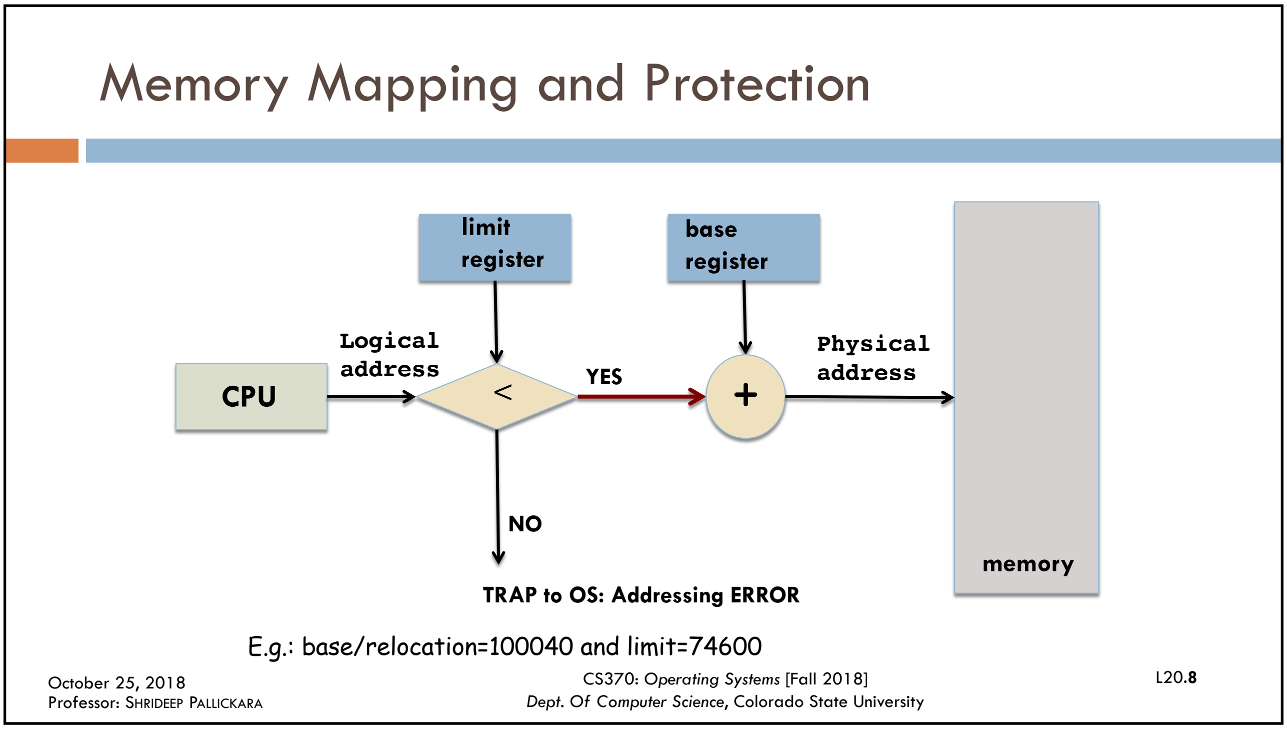
- Base register (also referred to as a relocation register)
  - Smallest physical address
- Limit register
  - Range of logical addresses



Memory Mapping and Protection

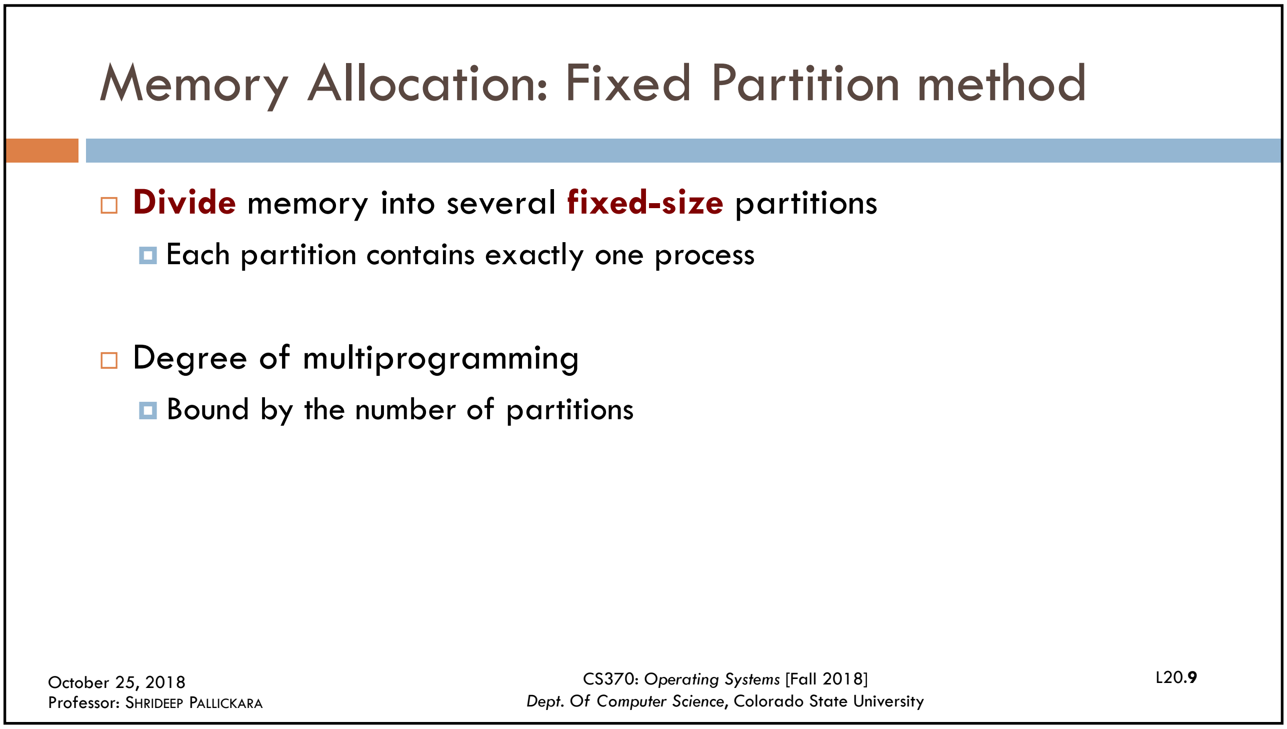
- When CPU scheduler selects a process for execution
  - Base and limit registers reloaded as part of context switch

- Every address generated by the CPU
  - Checked against the relocation/limit registers



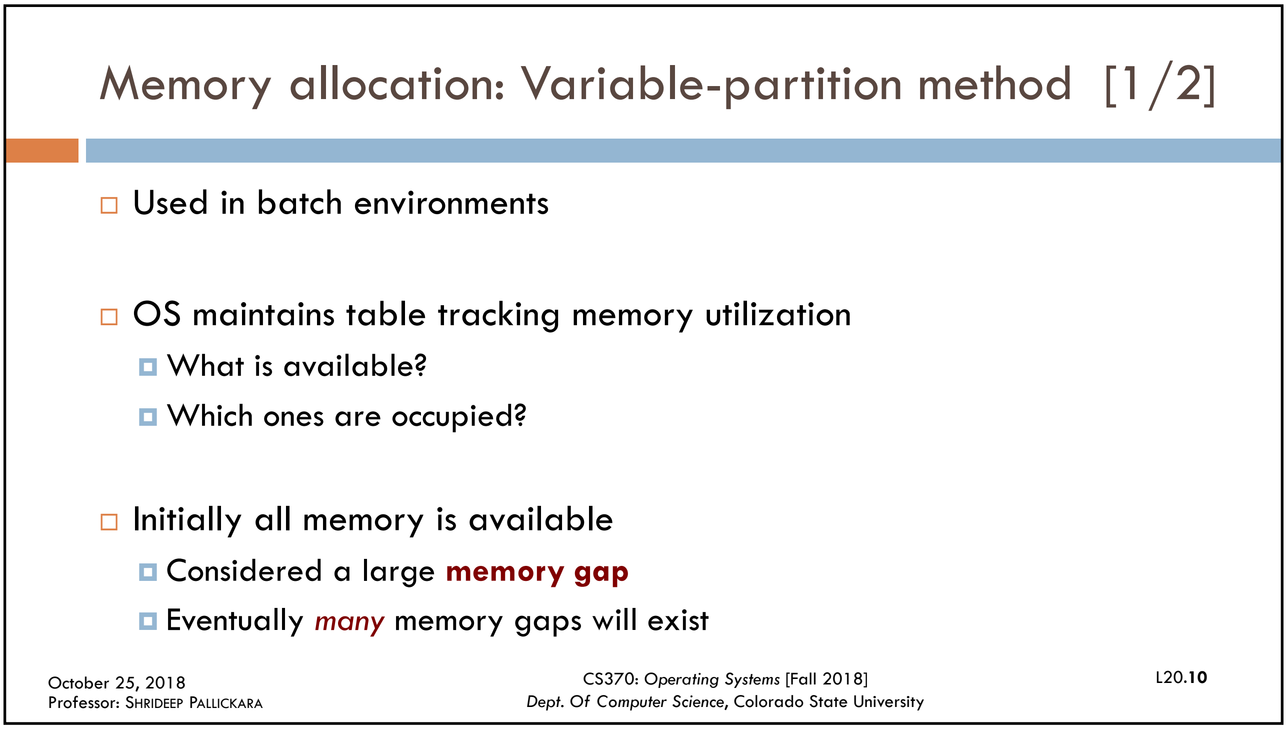
Memory Mapping and Protection

E.g.: base/relocation=100040 and limit=74600



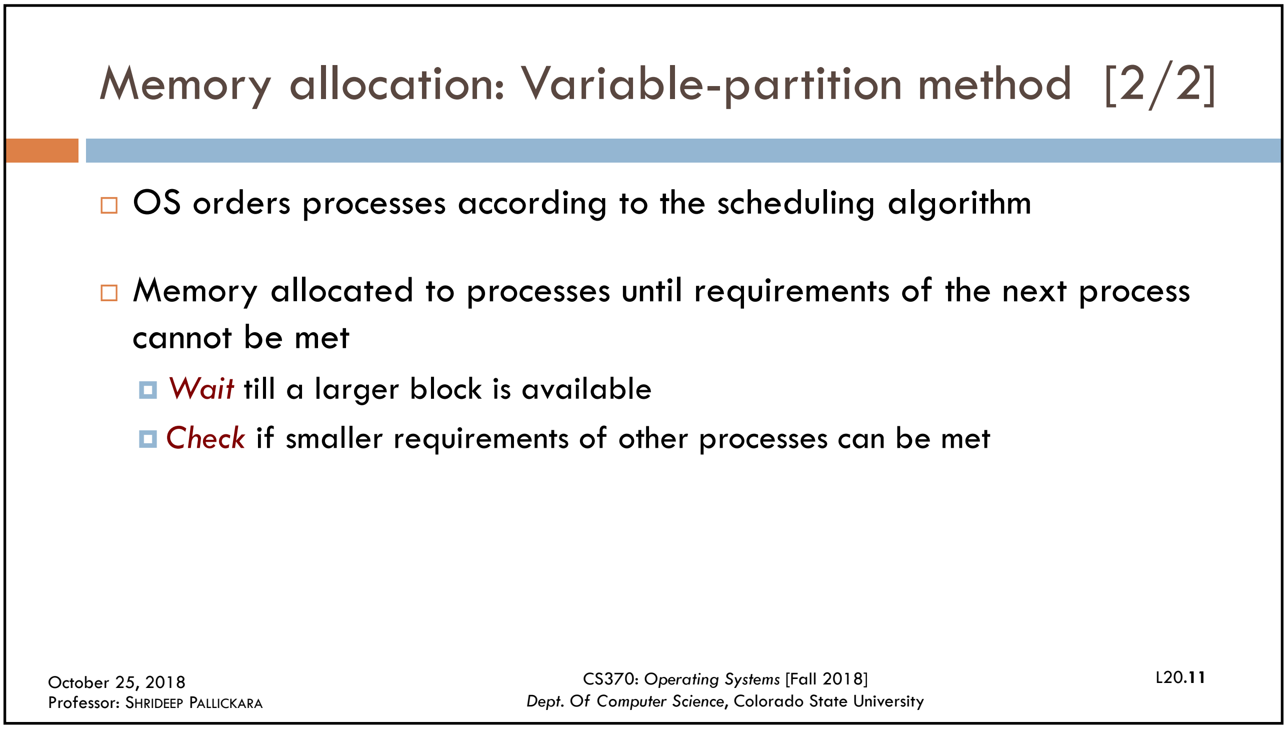
Memory Allocation: Fixed Partition method

- **Divide** memory into several **fixed-size** partitions
  - Each partition contains exactly one process
- Degree of multiprogramming
  - Bound by the number of partitions



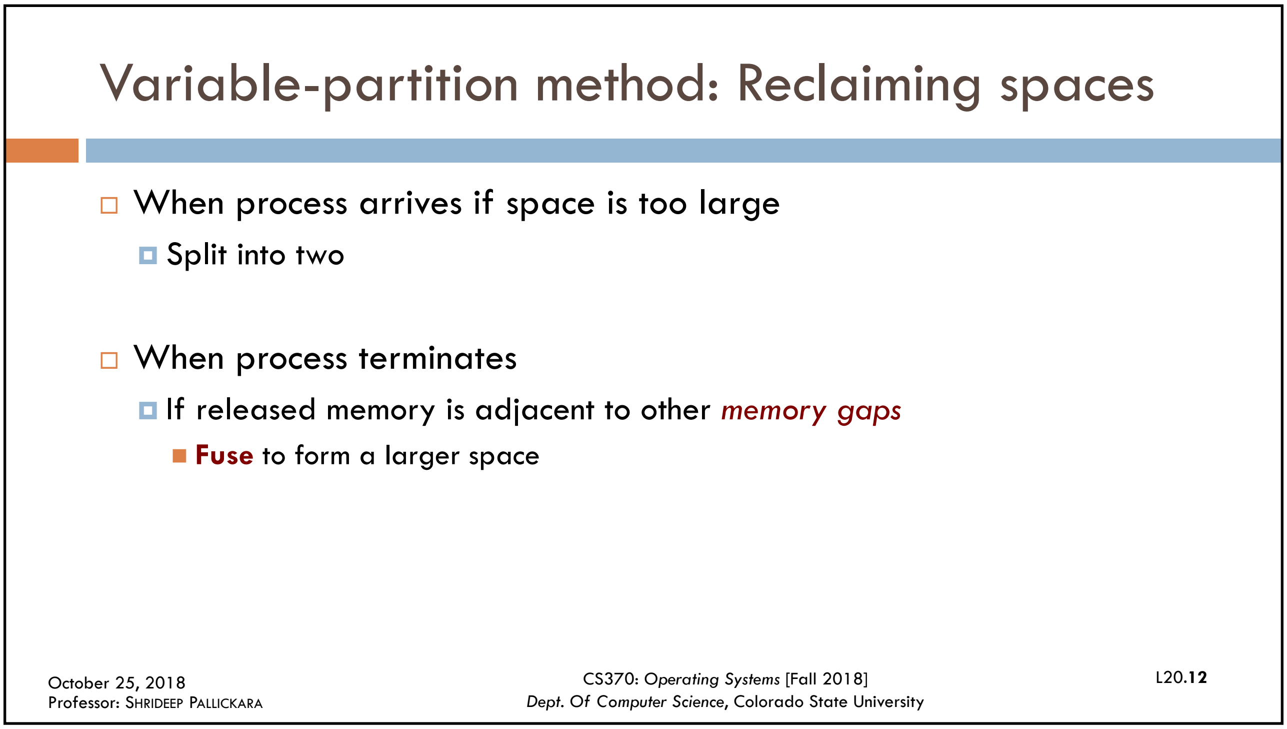
Memory allocation: Variable-partition method [1/2]

- Used in batch environments
- OS maintains table tracking memory utilization
  - What is available?
  - Which ones are occupied?
- Initially all memory is available
  - Considered a large **memory gap**
  - Eventually *many* memory gaps will exist



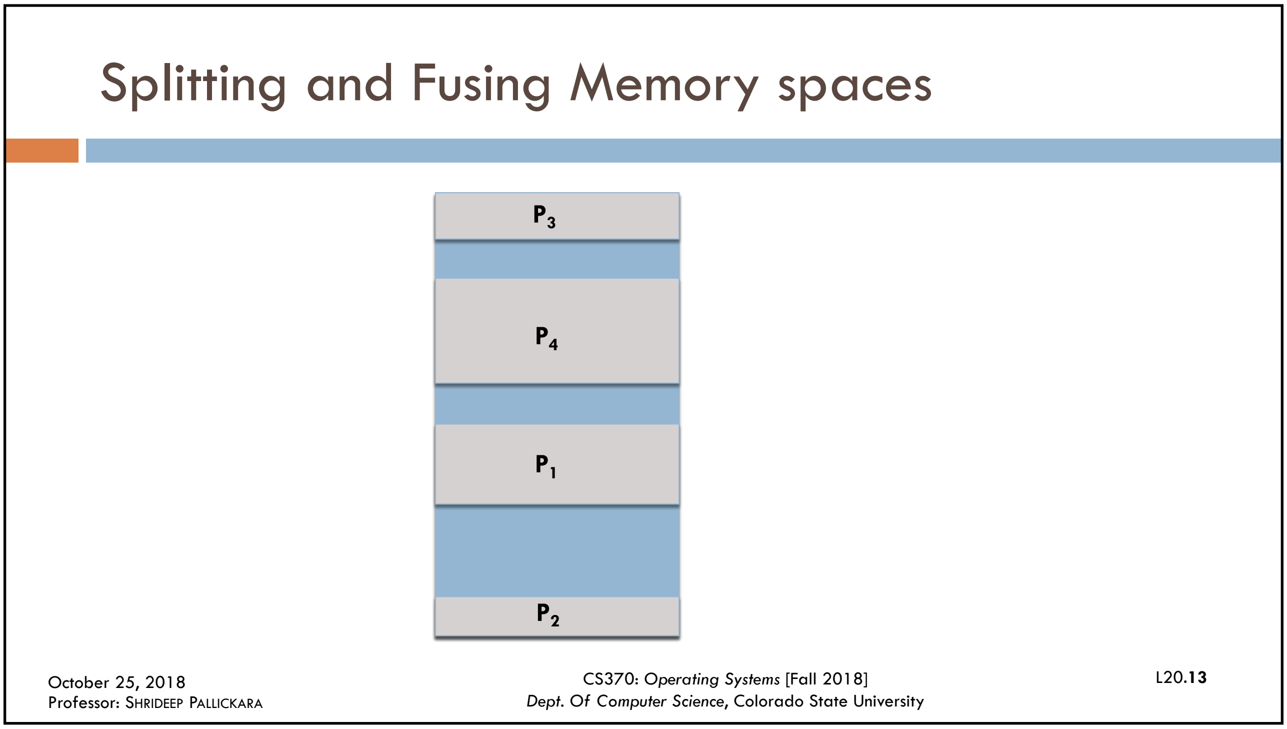
Memory allocation: Variable-partition method [2/2]

- OS orders processes according to the scheduling algorithm
- Memory allocated to processes until requirements of the next process cannot be met
  - *Wait* till a larger block is available
  - *Check* if smaller requirements of other processes can be met

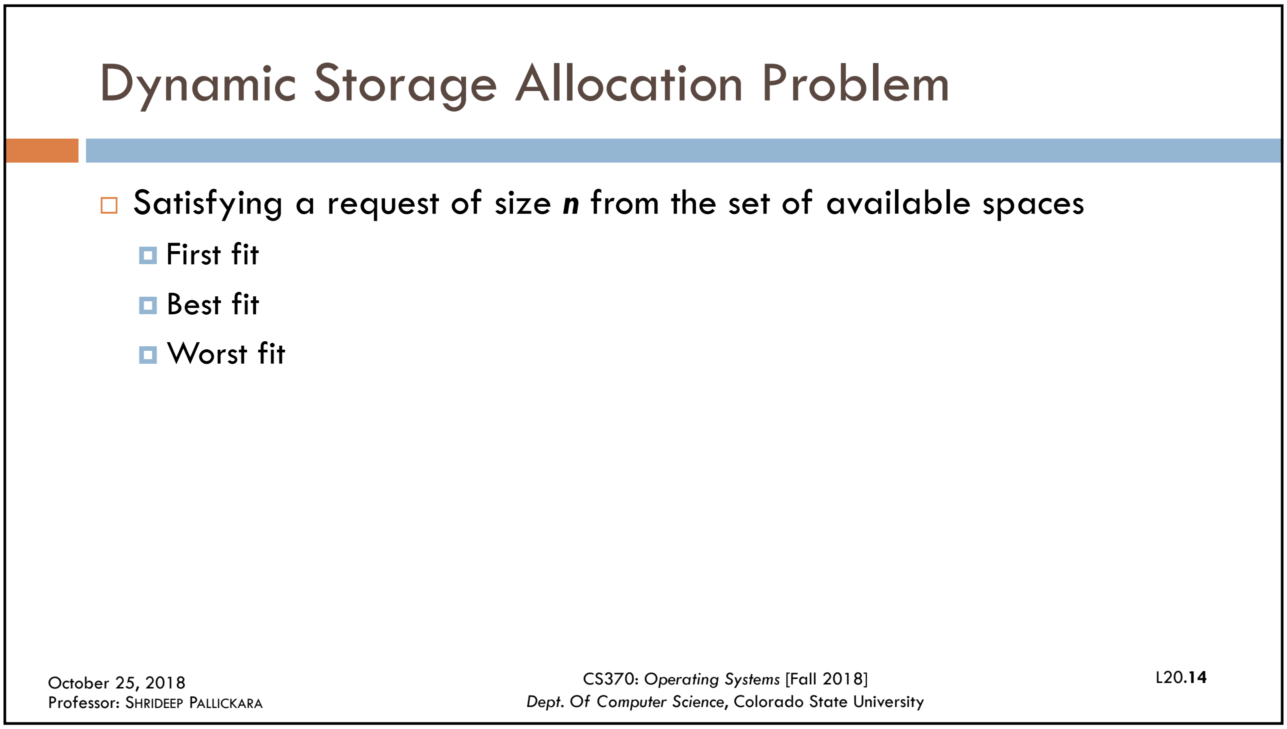


Variable-partition method: Reclaiming spaces

- When process arrives if space is too large
  - Split into two
- When process terminates
  - If released memory is adjacent to other *memory gaps*
    - **Fuse** to form a larger space

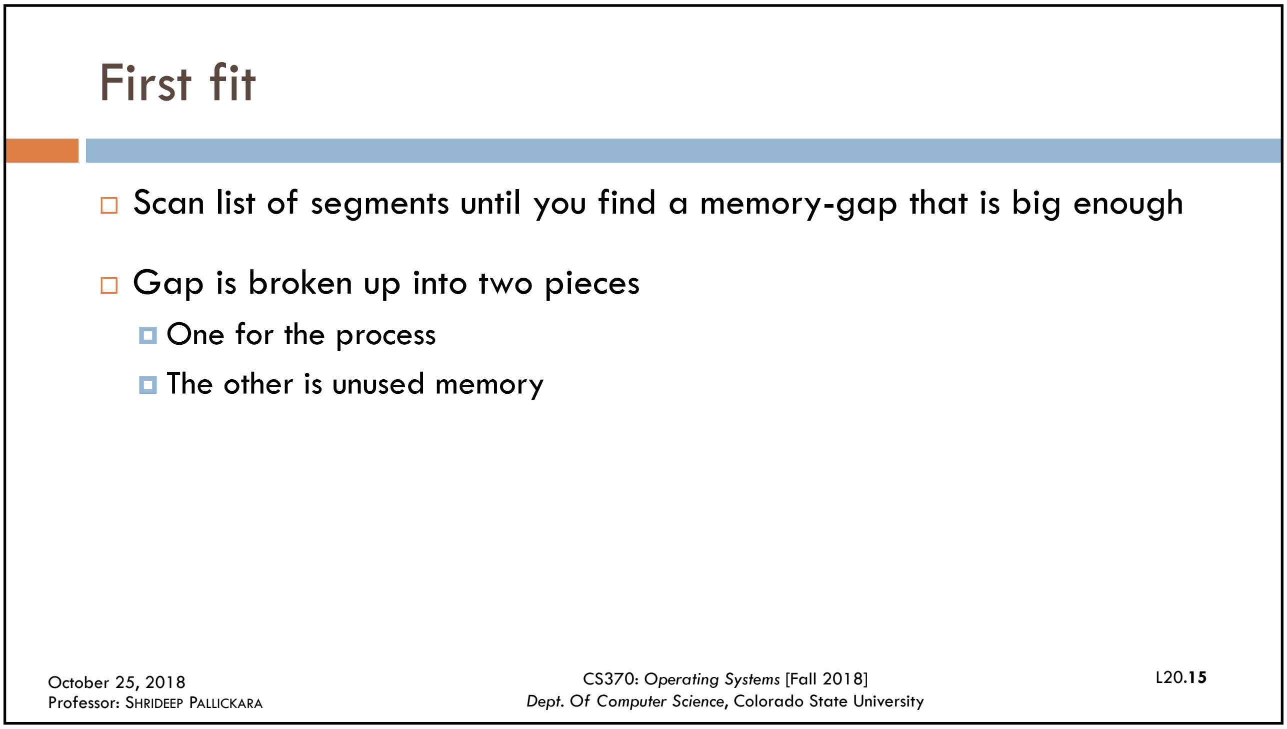


Splitting and Fusing Memory spaces



Dynamic Storage Allocation Problem

- Satisfying a request of size ***n*** from the set of available spaces
  - First fit
  - Best fit
  - Worst fit



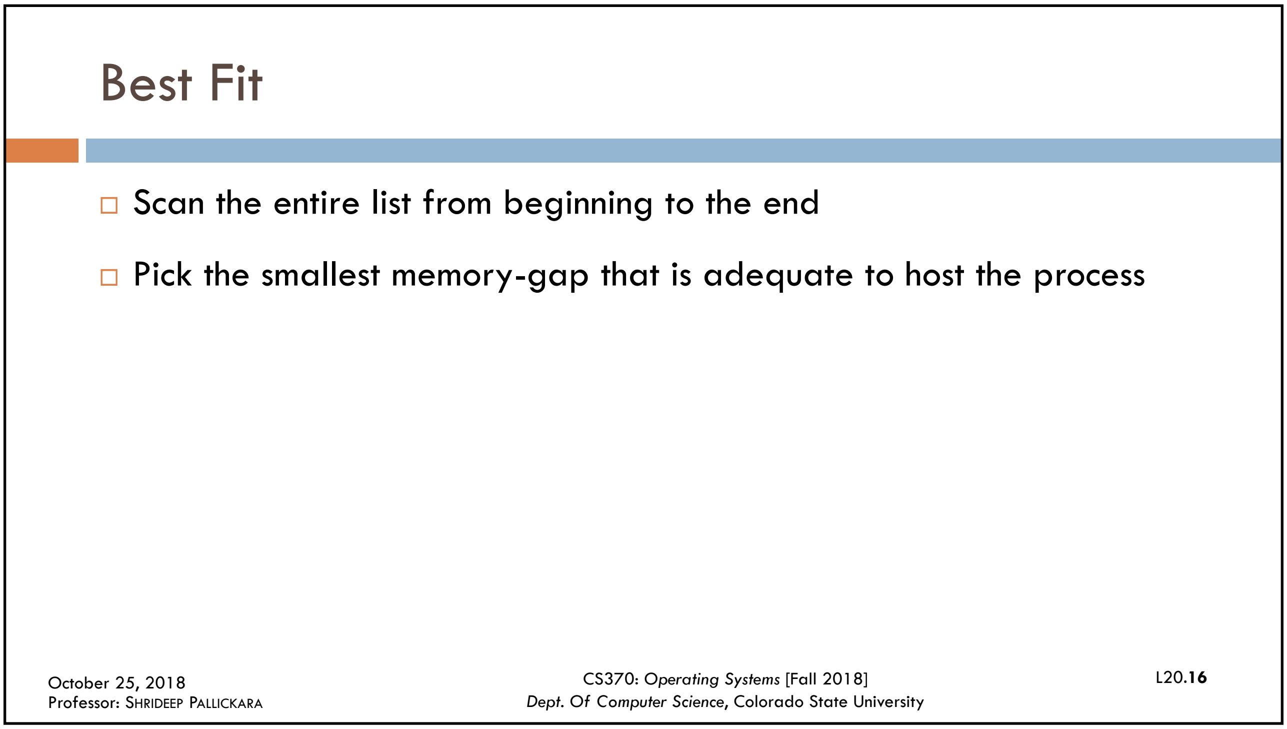
First fit

- □ Scan list of segments until you find a memory-gap that is big enough
- □ Gap is broken up into two pieces
  - One for the process
  - The other is unused memory

October 25, 2018
Professor: Shrideep Pallickara

CS370: *Operating Systems* [Fall 2018]
Dept. Of Computer Science, Colorado State University

L20.**15**



Best Fit

- □ Scan the entire list from beginning to the end
- □ Pick the smallest memory-gap that is adequate to host the process

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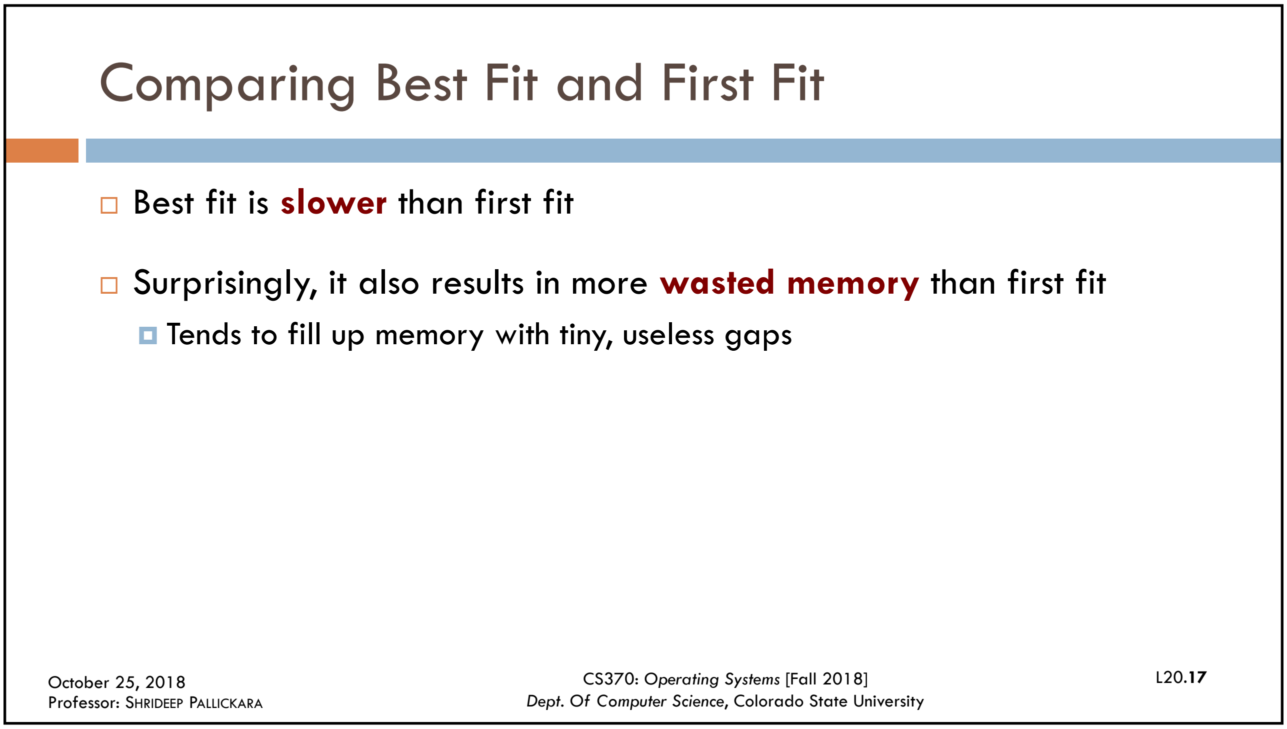
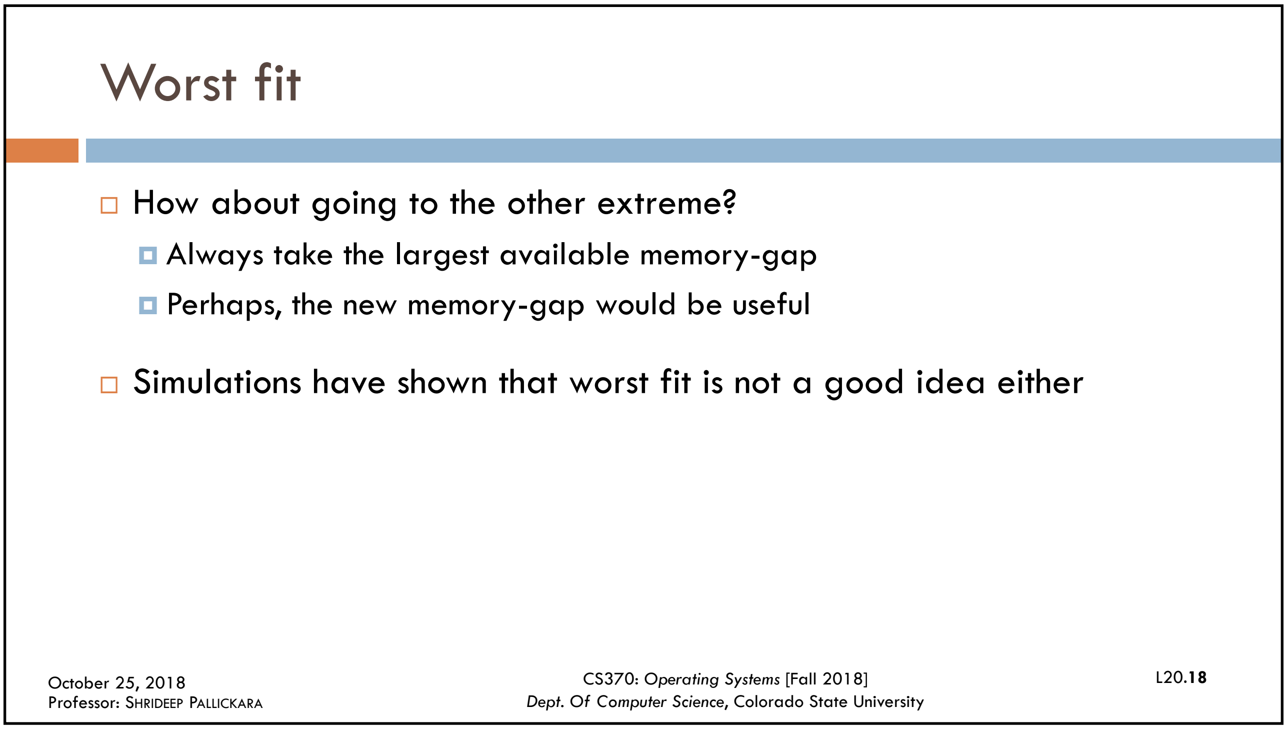
L20.**16**



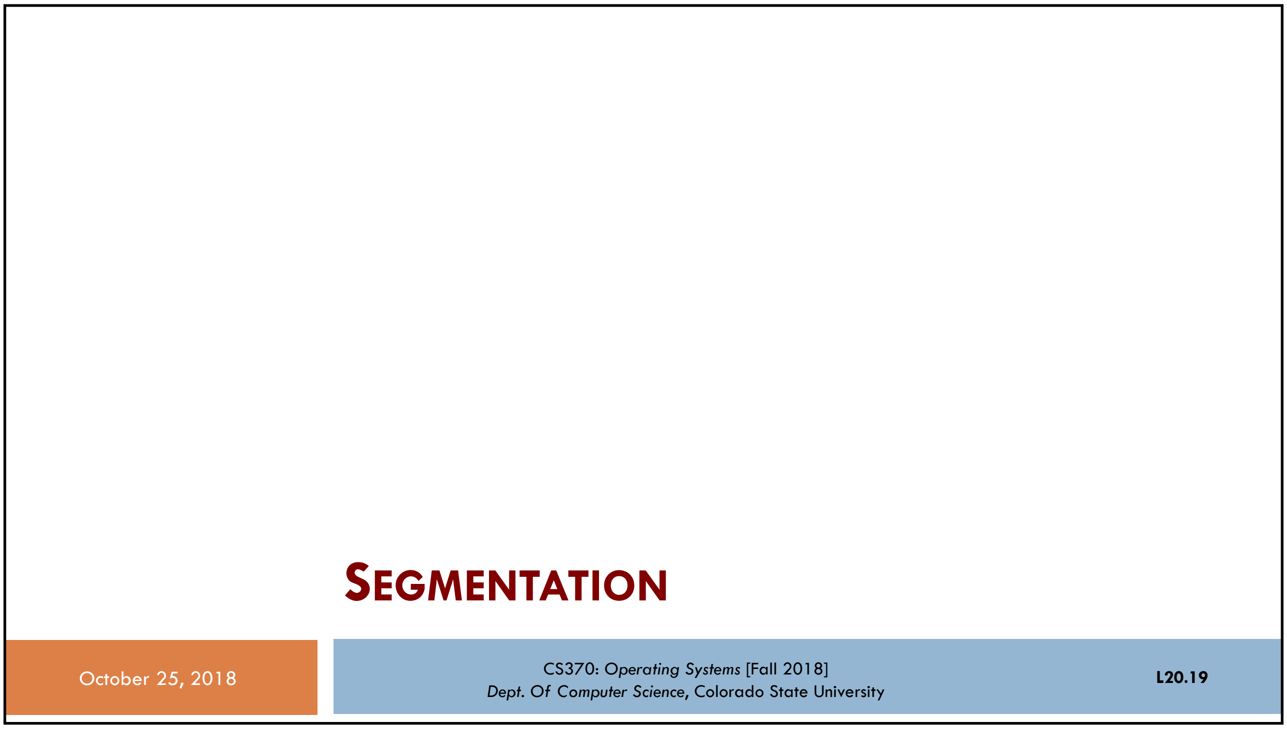
Comparing Best Fit and First Fit

- Best fit is **slower** than first fit
- Surprisingly, it also results in more **wasted memory** than first fit
  - Tends to fill up memory with tiny, useless gaps

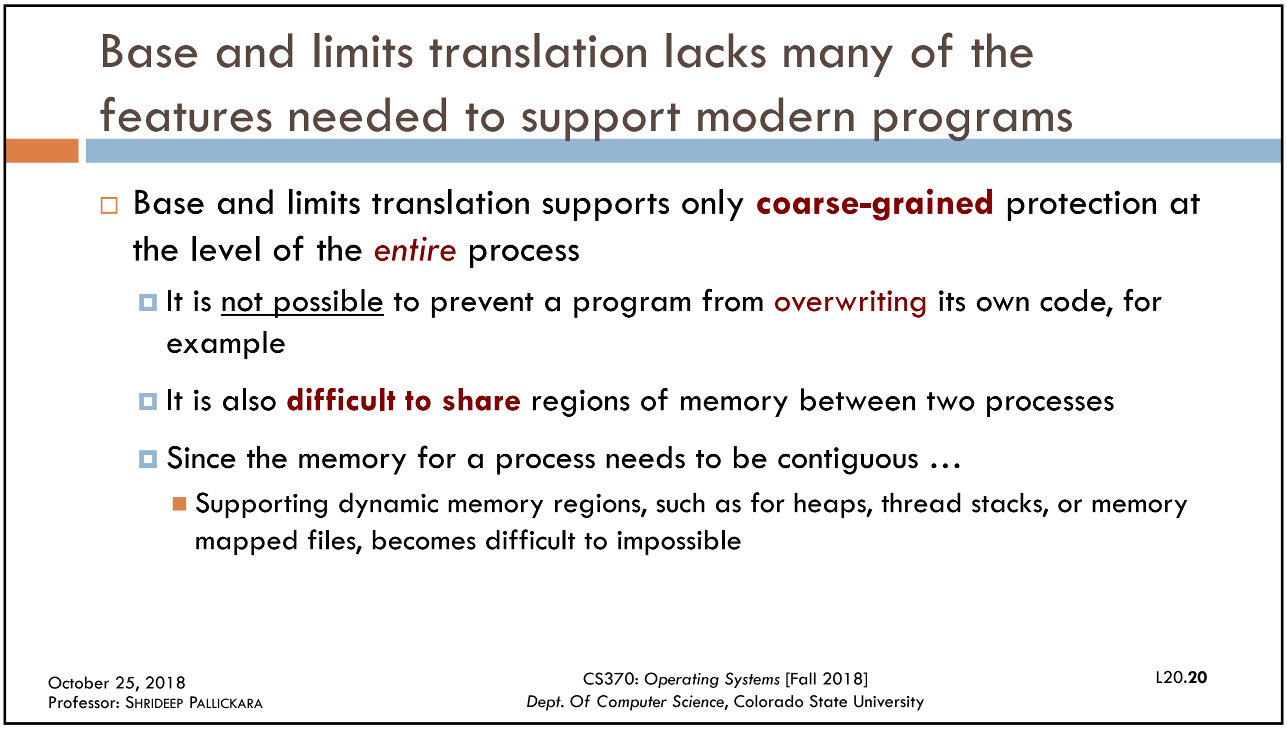


Worst fit

- How about going to the other extreme?
  - Always take the largest available memory-gap
  - Perhaps, the new memory-gap would be useful
- Simulations have shown that worst fit is not a good idea either



SEGMENTATION



Base and limits translation lacks many of the features needed to support modern programs

- Base and limits translation supports only **coarse-grained** protection at the level of the *entire* process
  - It is not possible to prevent a program from overwriting its own code, for example
  - It is also **difficult to share** regions of memory between two processes
  - Since the memory for a process needs to be contiguous …
    - Supporting dynamic memory regions, such as for heaps, thread stacks, or memory mapped files, becomes difficult to impossible

In our discussions so far …

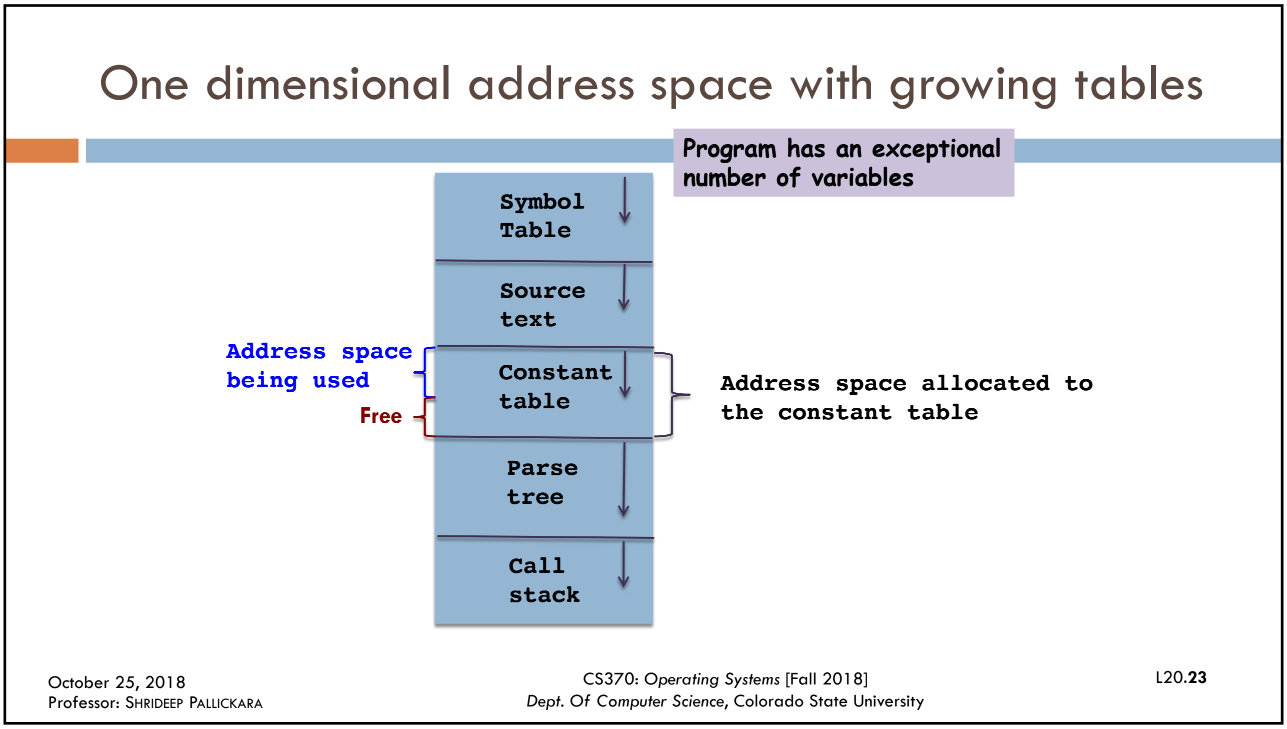
- □ Logical/virtual memory is **one-dimensional**
  - Logical addresses go from `0` to some `max` value
- □ Many problems can benefit from having two or more **separate** logical address spaces

A compiler has many tables that are built up as compilation proceeds

- □ Source Text
- □ Symbol table
  - Names and attributes of variables
- □ Constants Table
  - Integer and floating point constants
- □ Parse tree
  - Syntactic analysis of program
- □ Stack
  - Procedure calls within the compiler

Grows continuously as compilation proceeds

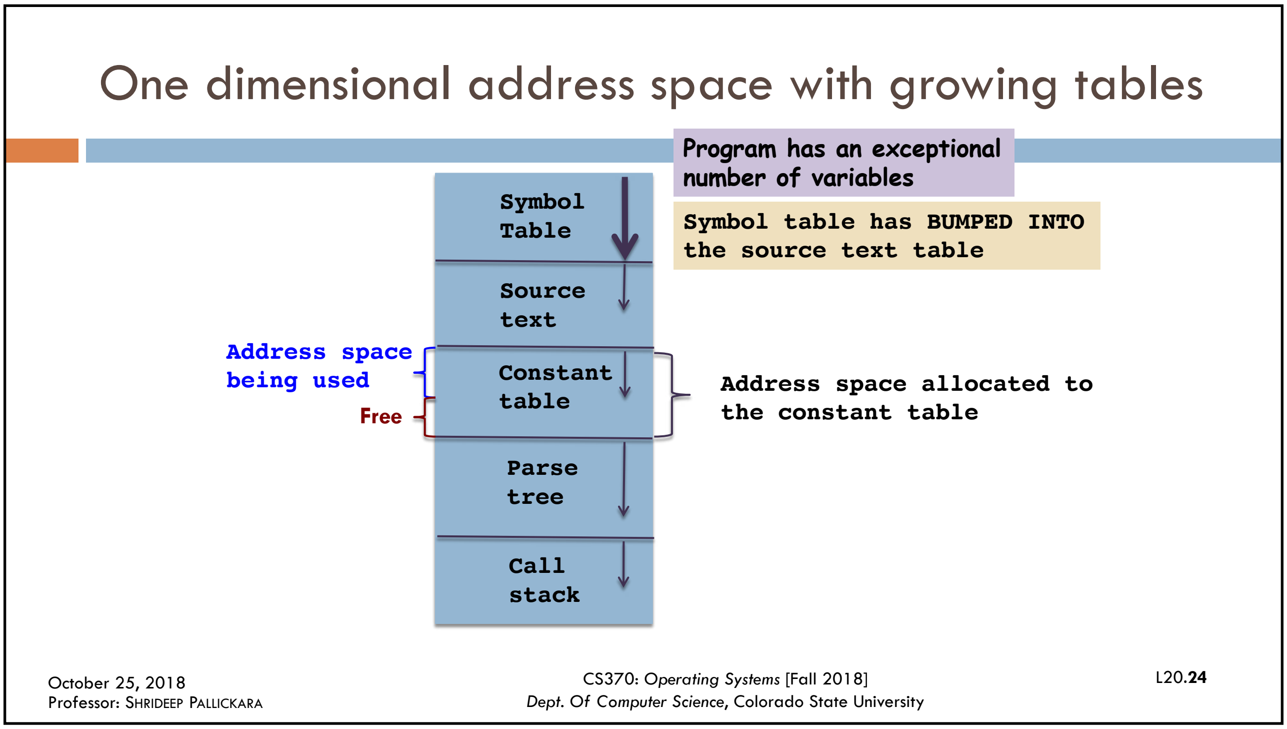
Grows and shrinks in unpredictable ways during compilation



One dimensional address space with growing tables

Program has an exceptional number of variables

Address space allocated to the constant table

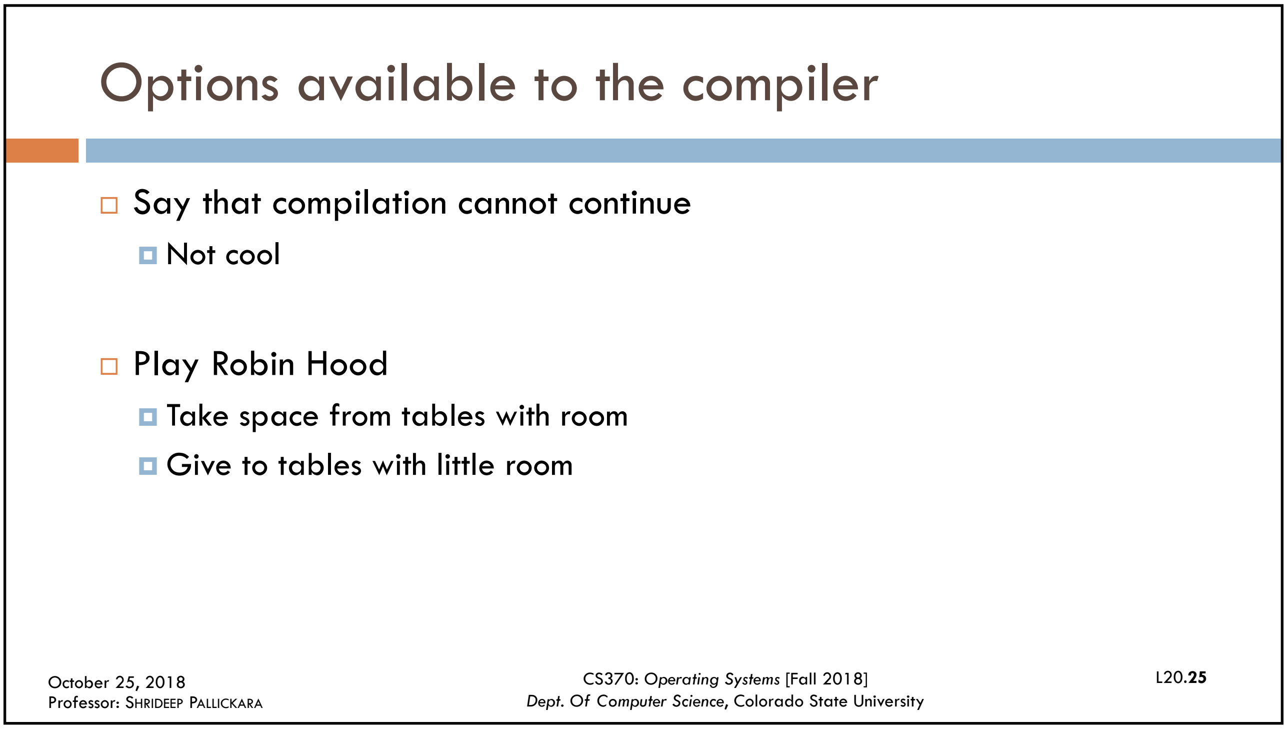


One dimensional address space with growing tables

Program has an exceptional number of variables

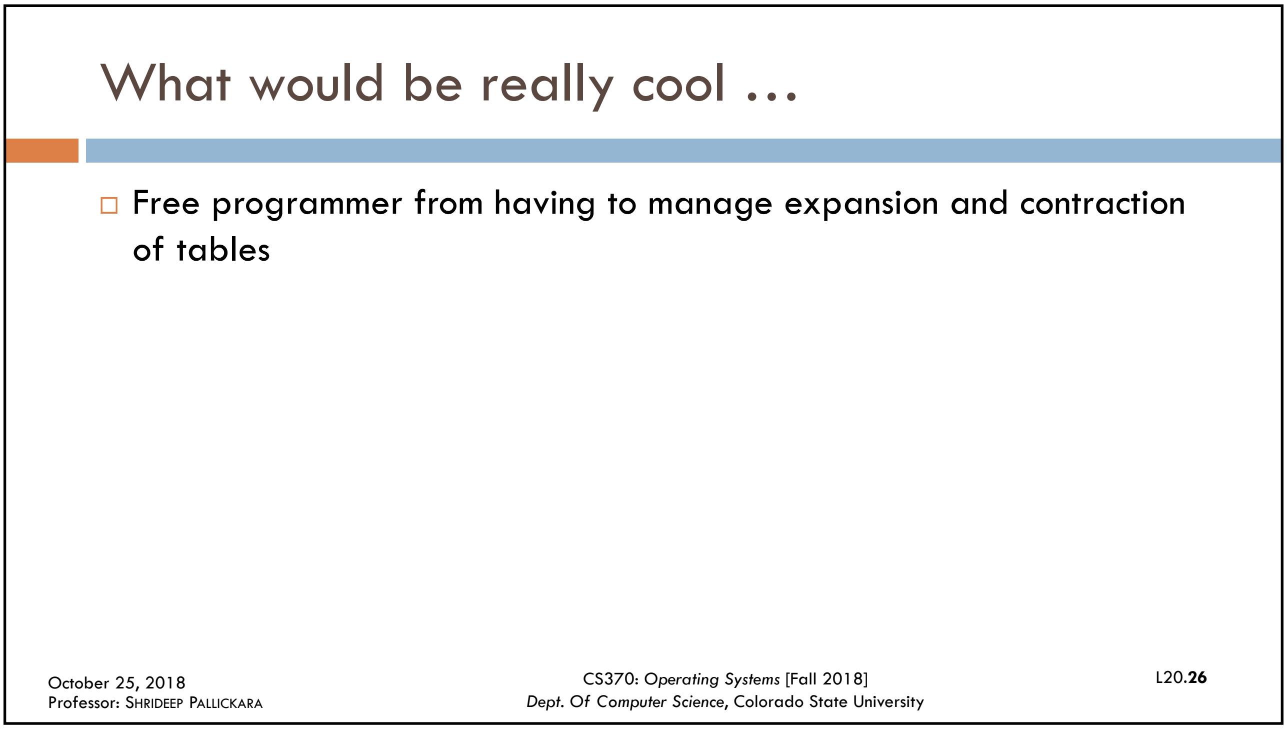
Symbol table has BUMPED INTO the source text table

Address space allocated to the constant table



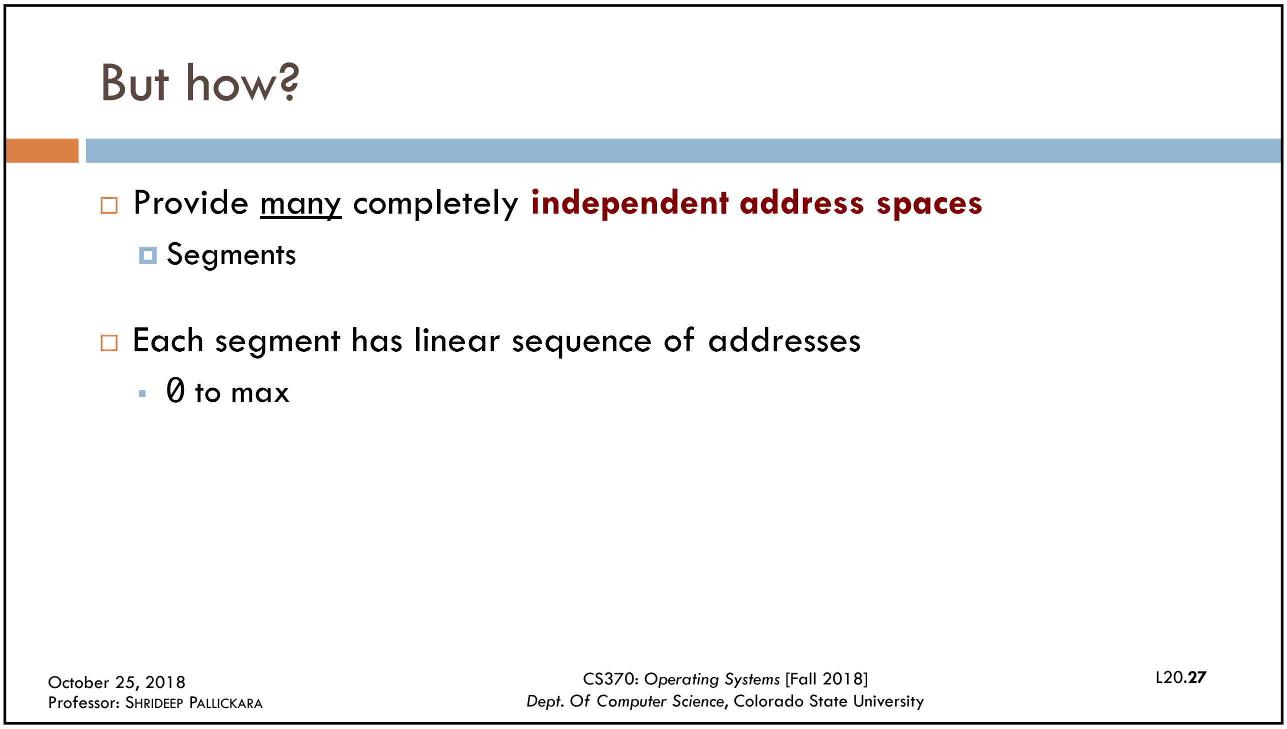
Options available to the compiler

- Say that compilation cannot continue
  - Not cool
- Play Robin Hood
  - Take space from tables with room
  - Give to tables with little room



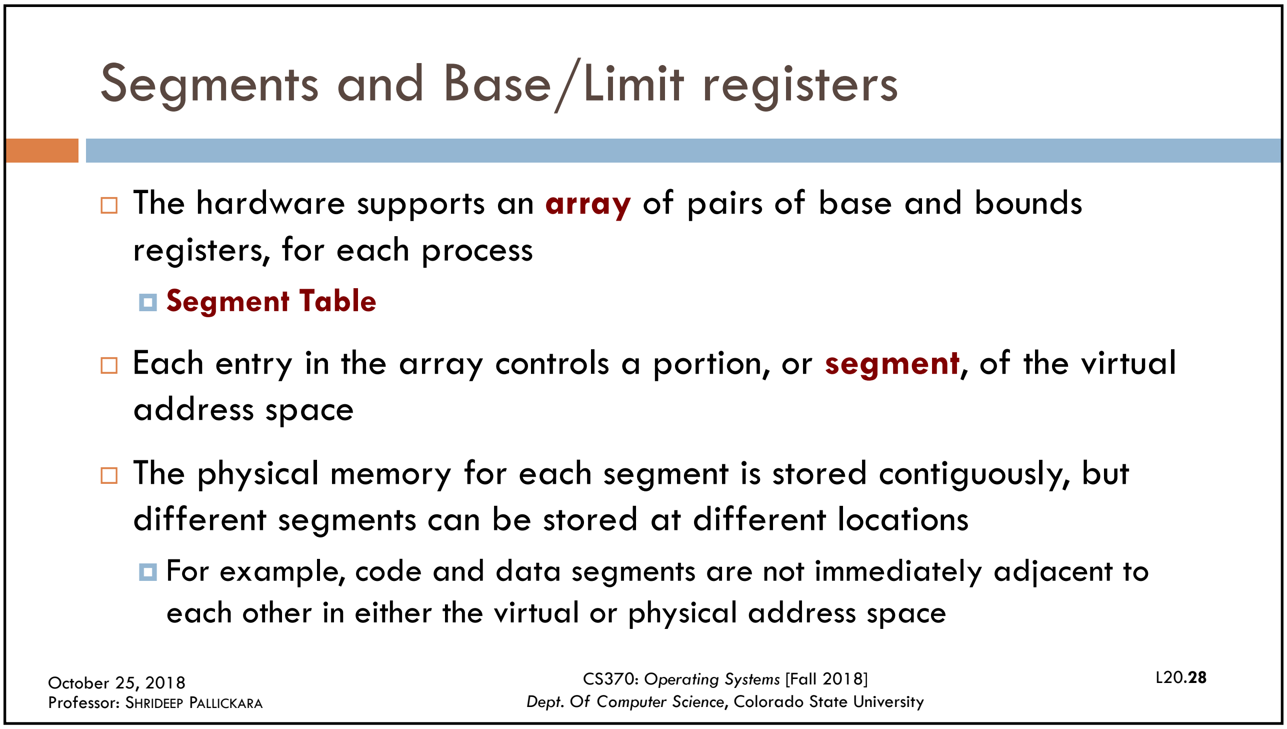
What would be really cool …

- Free programmer from having to manage expansion and contraction of tables



But how?

- Provide many completely **independent address spaces**
  - Segments
- Each segment has linear sequence of addresses
  - 0 to max



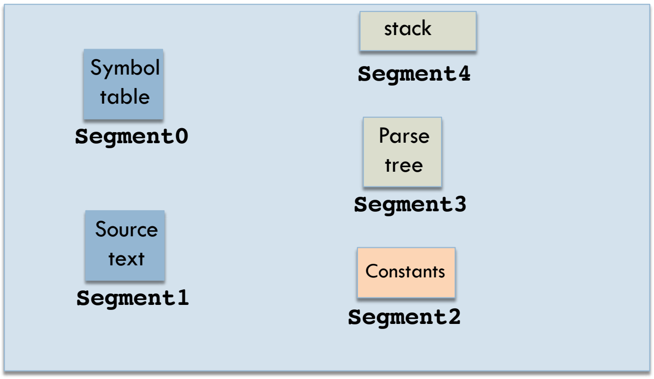
Segments and Base/Limit registers

- The hardware supports an **array** of pairs of base and bounds registers, for each process
  - **Segment Table**
- Each entry in the array controls a portion, or **segment**, of the virtual address space
- The physical memory for each segment is stored contiguously, but different segments can be stored at different locations
  - For example, code and data segments are not immediately adjacent to each other in either the virtual or physical address space

Other things about segments

- Different segments can and do have different lengths
- Segments grow and shrink independently without affecting each other. For example, consider a segment for the stack
  - Size increase: something pushed on stack segment
  - Size decrease: something popped off of stack segment

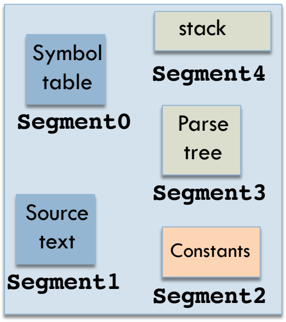
Users view memory as a collection of variable-sized segments



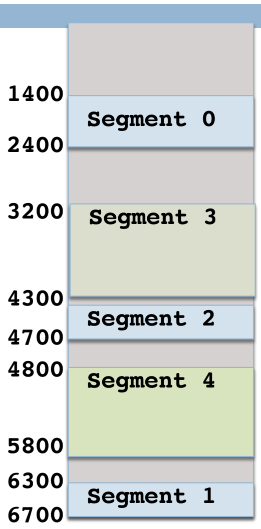
Segmentation

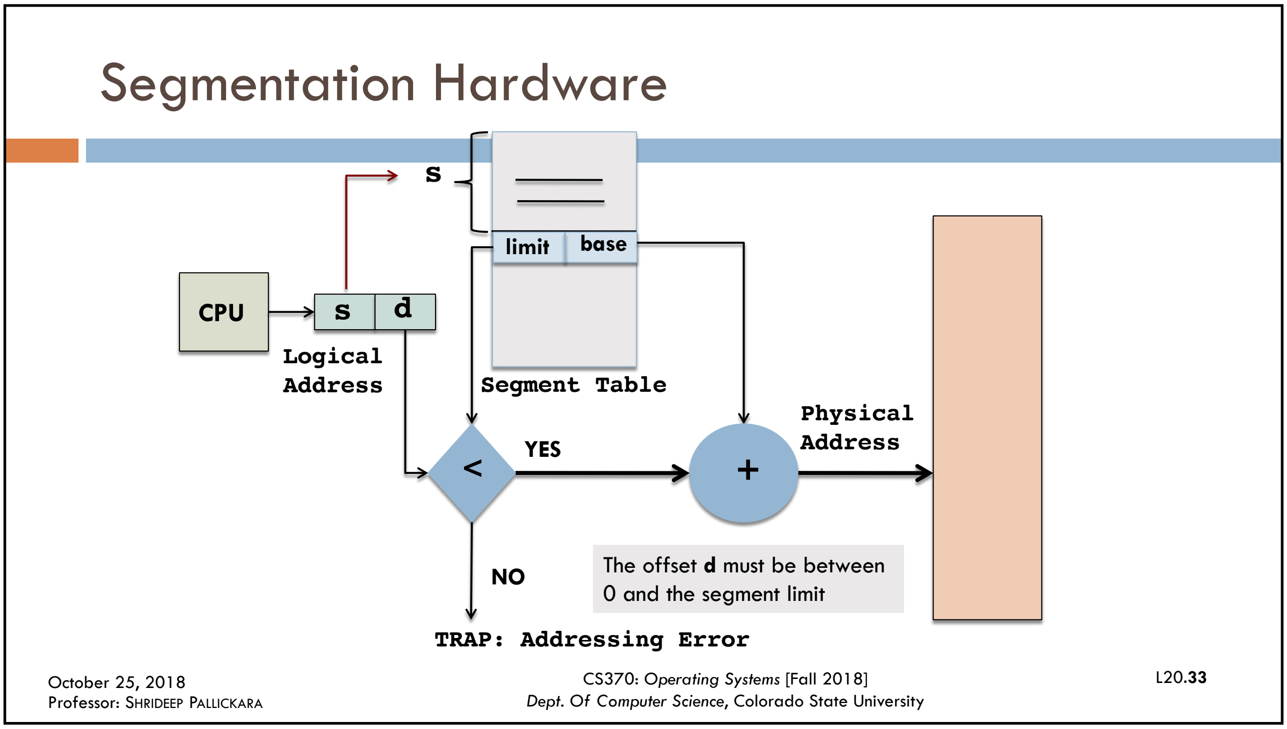
- □ Logical address space is a collection of segments
- □ Segments have name and length
- □ Addresses specify
  - Segment name
  - Offset within the segment
- □ Tuple: **`<segment-number, offset>`**

Segmentation Addressing Example



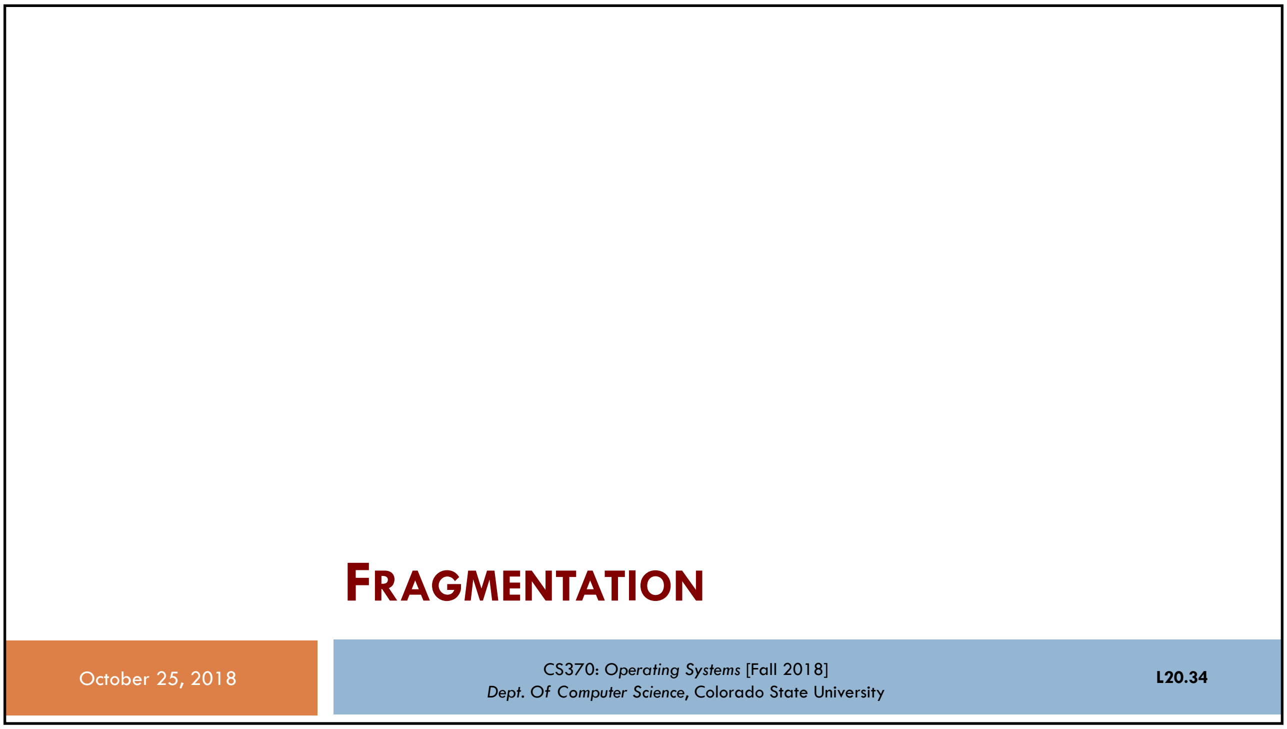
	Limit	Base
0	1000	1400
1	400	6300
2	400	4300
3	1000	3200
4	1000	4800





Segmentation Hardware

The offset **d** must be between 0 and the segment limit



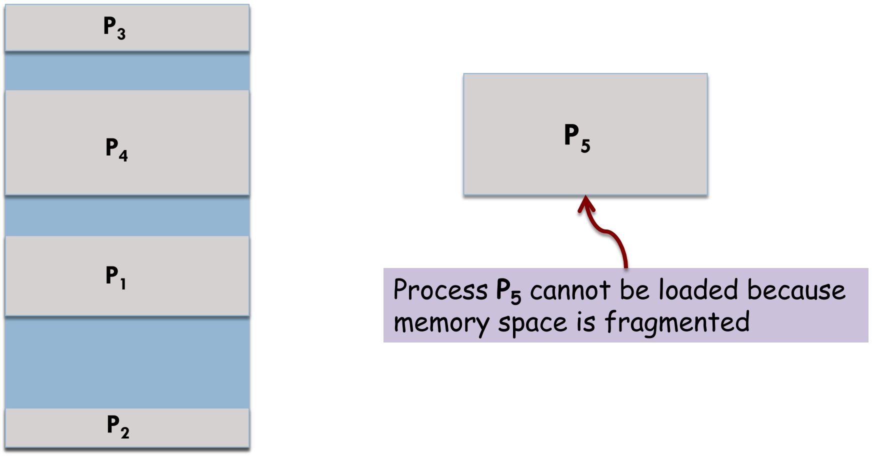
Fragmentation

Contiguous Memory Allocation: Fragmentation

- As processes (and segments) are loaded/removed from memory
  - Free memory space is **broken** into small pieces

- **External fragmentation**
  - Enough space to satisfy request; BUT
  - Available spaces are *not contiguous*

Fragmentation: Example



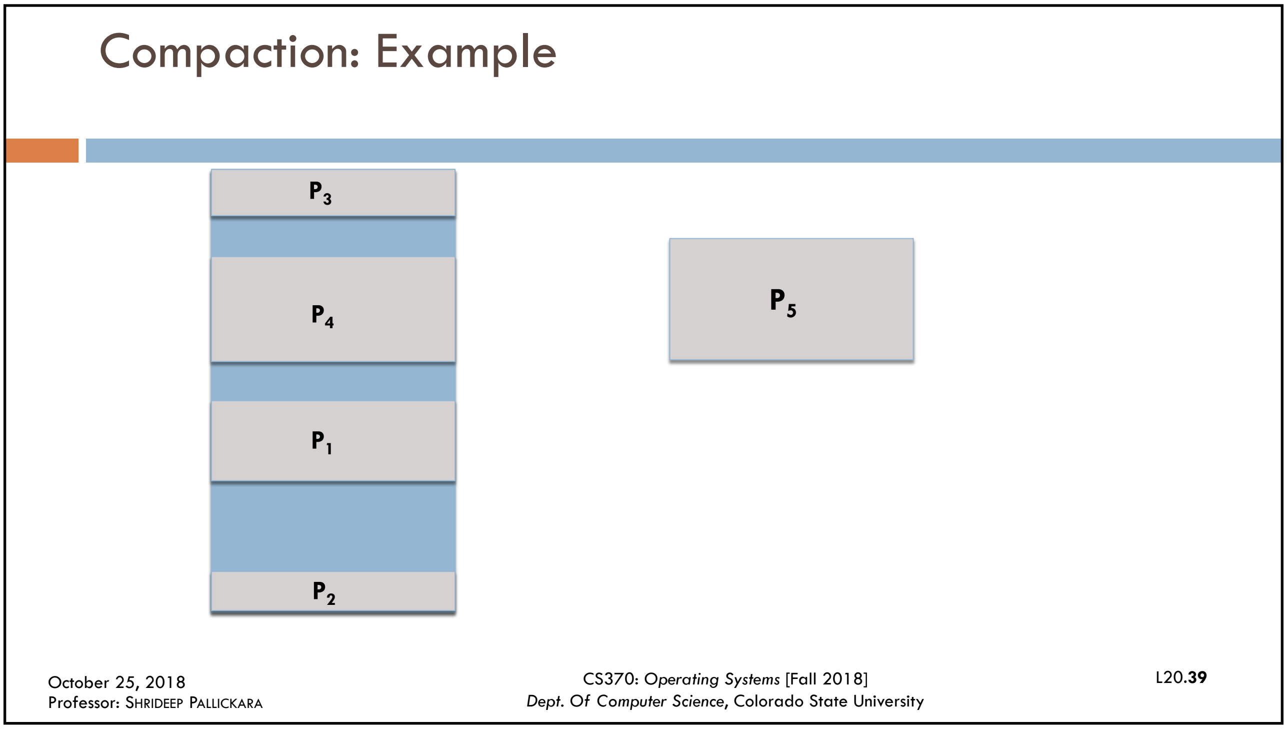
Process P_5 cannot be loaded because memory space is fragmented

Fragmentation can be internal as well

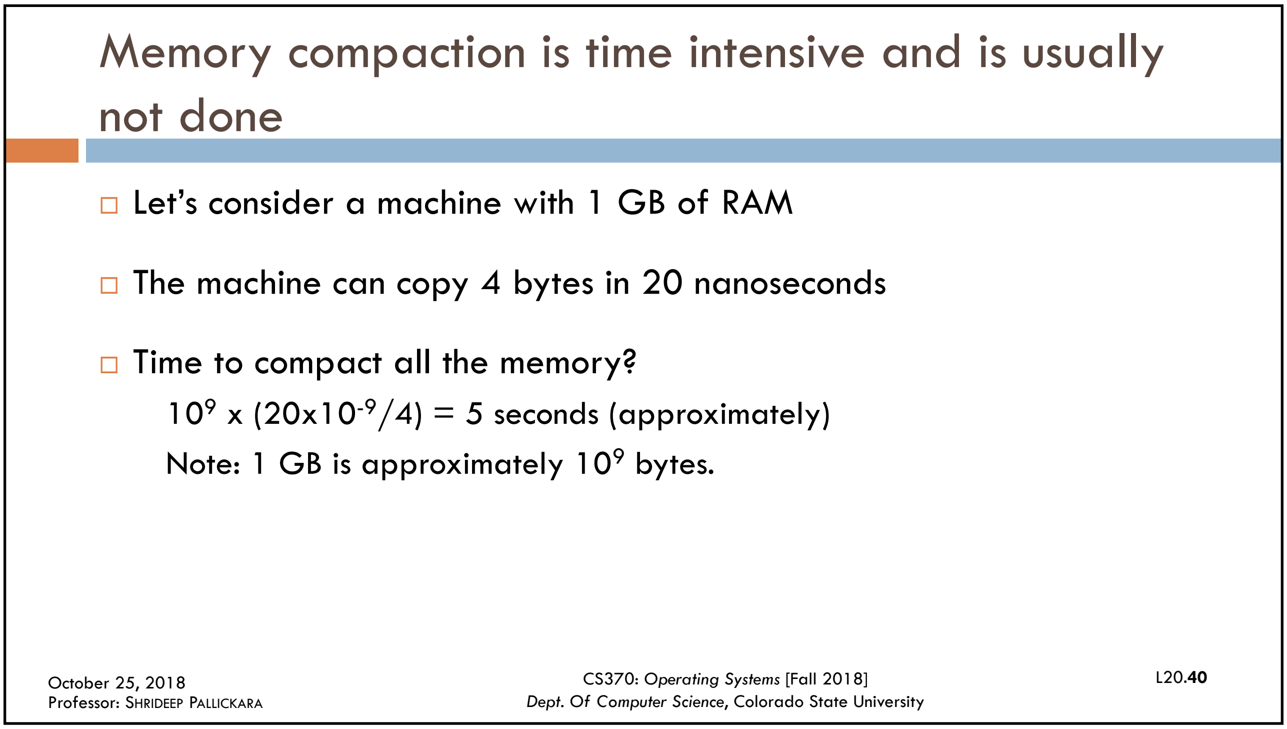
- Memory allocated to process may be *slightly larger* than requested
- **Internal fragmentation**
  - Unused memory is internal to blocks

Compaction: Solution to external fragmentation

- **Shuffle** memory contents
  - Objective: Place free memory into large block
- Not possible if relocation is static
  - Load time
- Approach involves moving:
  1. Processes towards one end
  2. Gaps towards the other end



Compaction: Example



Memory compaction is time intensive and is usually not done

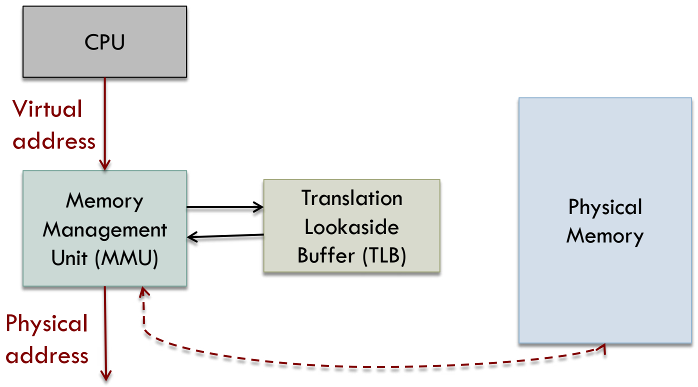
- Let's consider a machine with 1 GB of RAM
- The machine can copy 4 bytes in 20 nanoseconds
- Time to compact all the memory?

  10^9 x $(20\text{x}10^{-9}/4) = 5$ seconds (approximately)

  Note: 1 GB is approximately 10^9 bytes.

PAGING:
OVERVIEW OF THE MAPPING PROCESS

Overview of how mapping of logical and physical addresses is performed



CPU

Virtual address

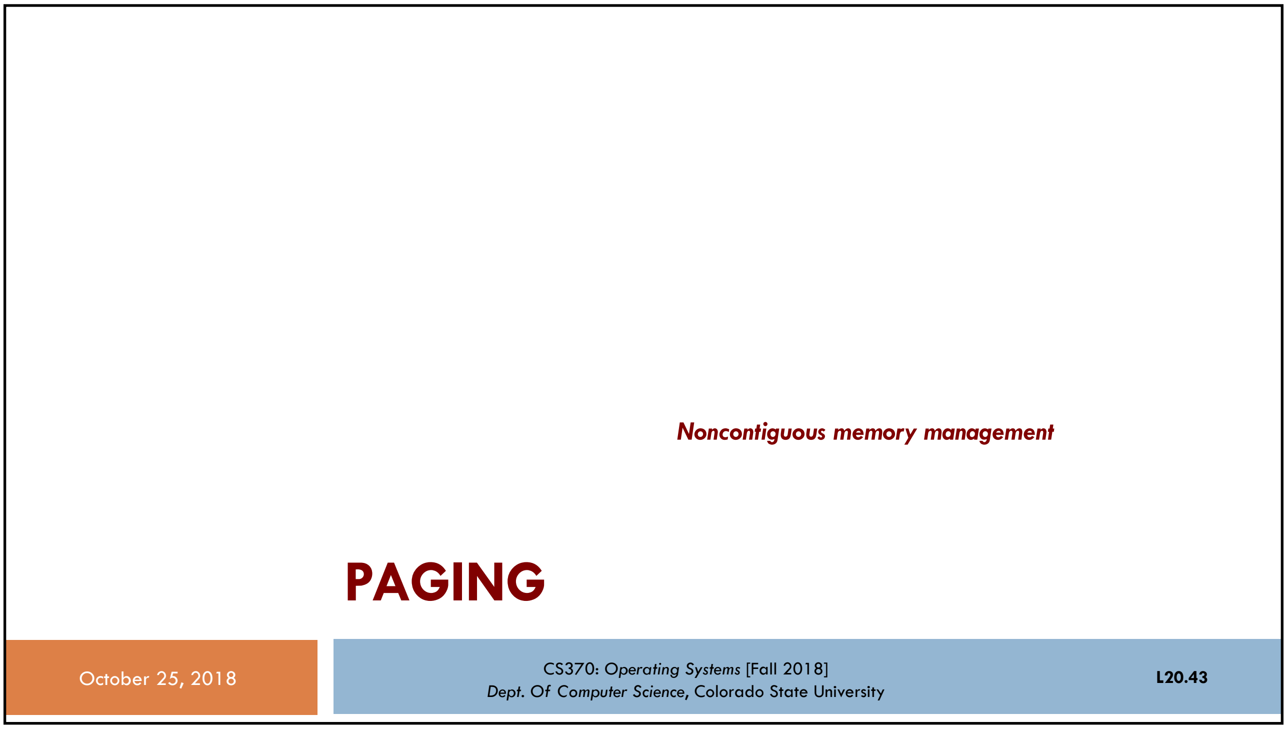
Memory Management Unit (MMU)

Translation Lookaside Buffer (TLB)

Physical Memory

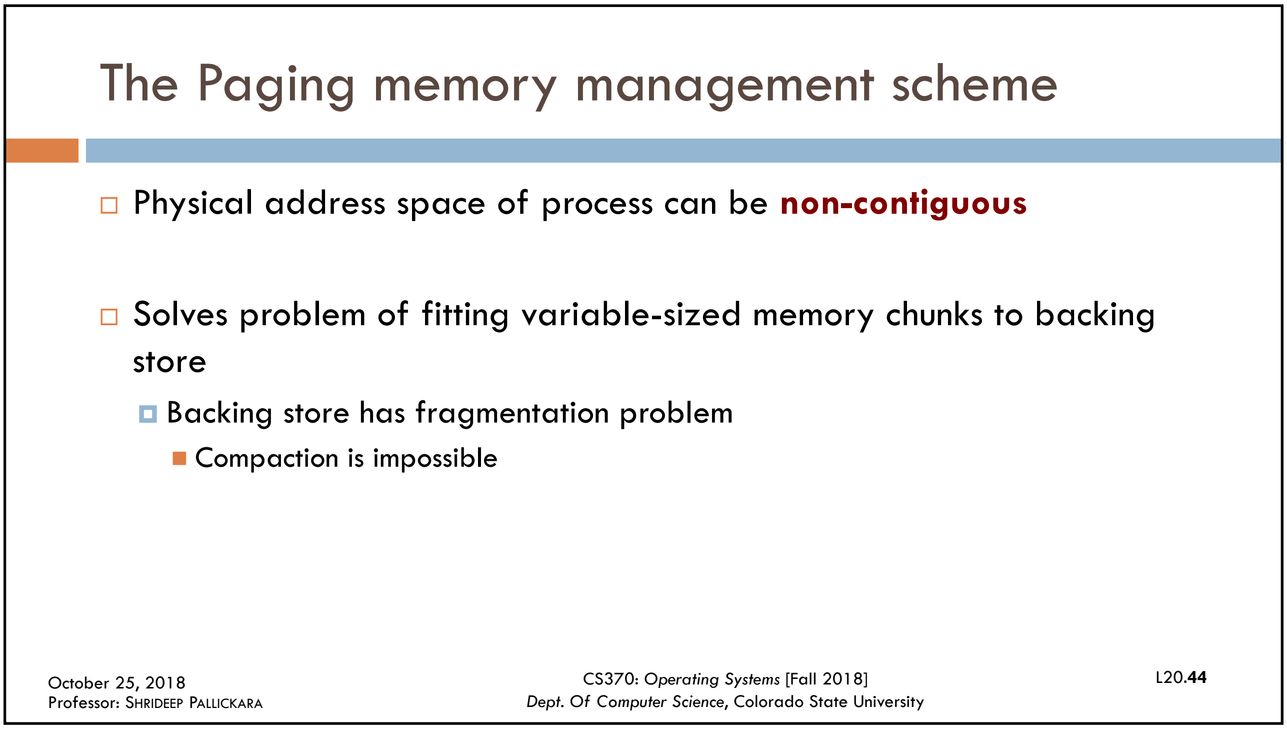
Physical address

MMU may access Physical Memory to perform translations
{PageTable may be stored there}



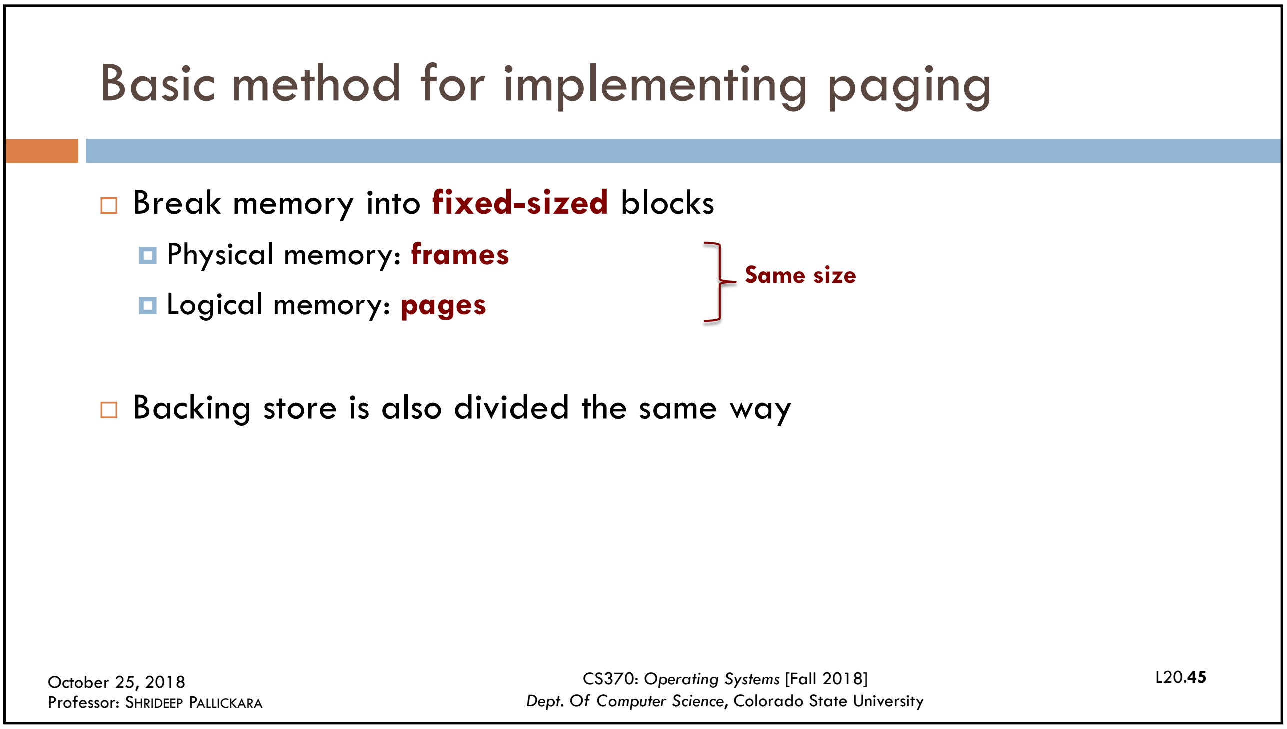
Noncontiguous memory management

PAGING



The Paging memory management scheme

- Physical address space of process can be **non-contiguous**
- Solves problem of fitting variable-sized memory chunks to backing store
  - Backing store has fragmentation problem
    - Compaction is impossible

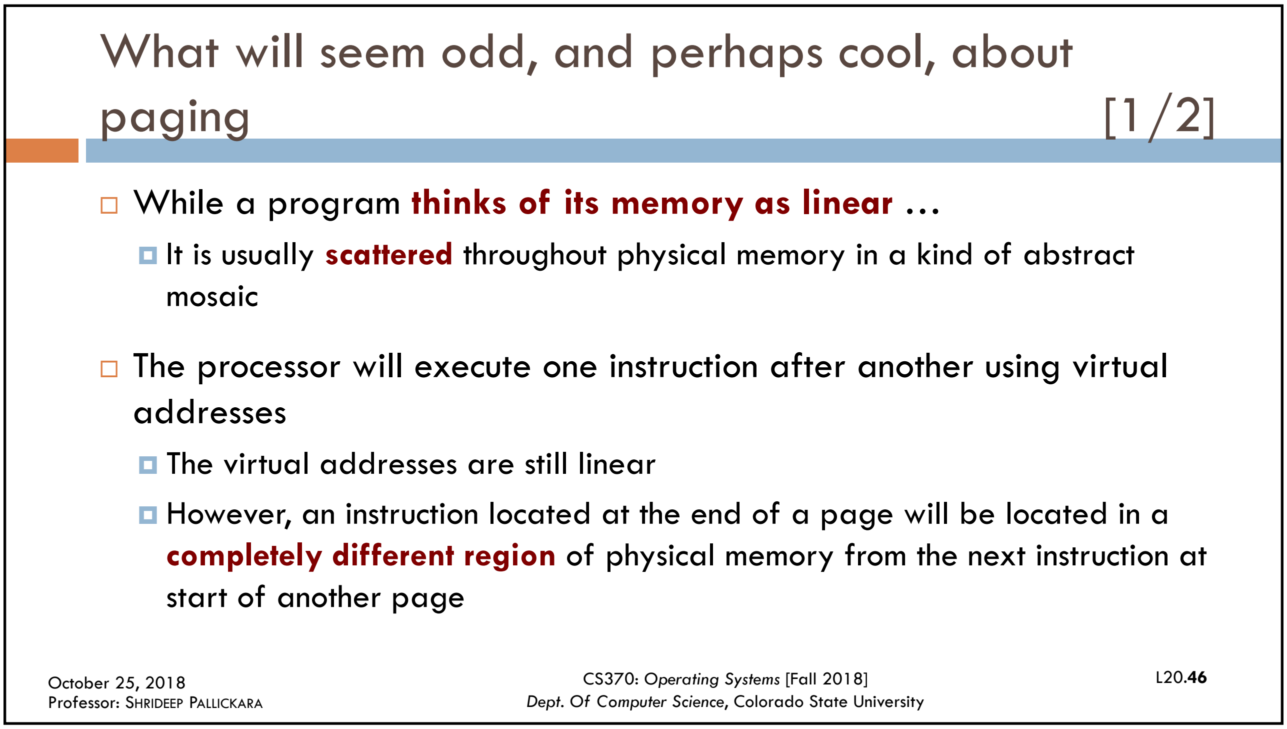


Basic method for implementing paging

- Break memory into **fixed-sized** blocks
  - Physical memory: **frames**
  - Logical memory: **pages**

Same size

- Backing store is also divided the same way



What will seem odd, and perhaps cool, about paging [1/2]

- While a program **thinks of its memory as linear** …
  - It is usually **scattered** throughout physical memory in a kind of abstract mosaic
- The processor will execute one instruction after another using virtual addresses
  - The virtual addresses are still linear
  - However, an instruction located at the end of a page will be located in a **completely different region** of physical memory from the next instruction at start of another page

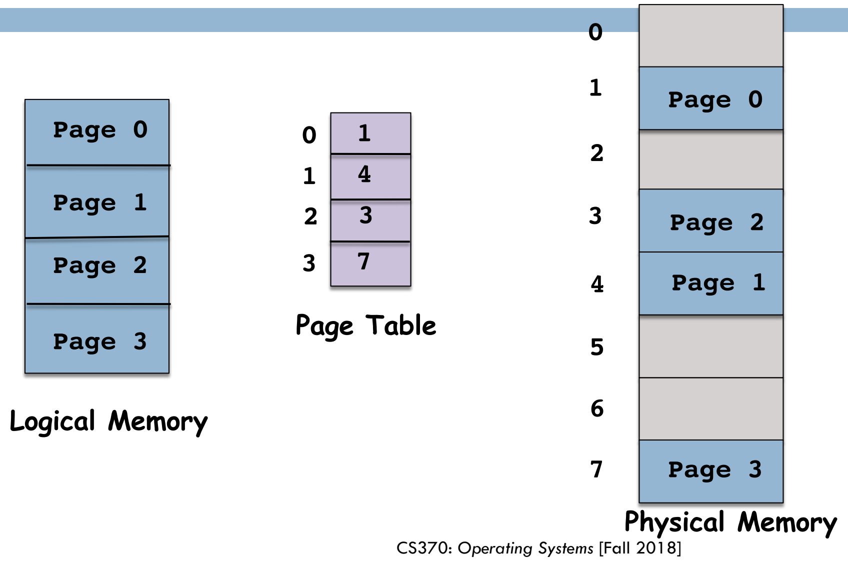
What will seem odd, and perhaps cool, about paging [2/2]

- Data structures appear to be contiguous using virtual addresses
  - But a large matrix is scattered across many physical page frames

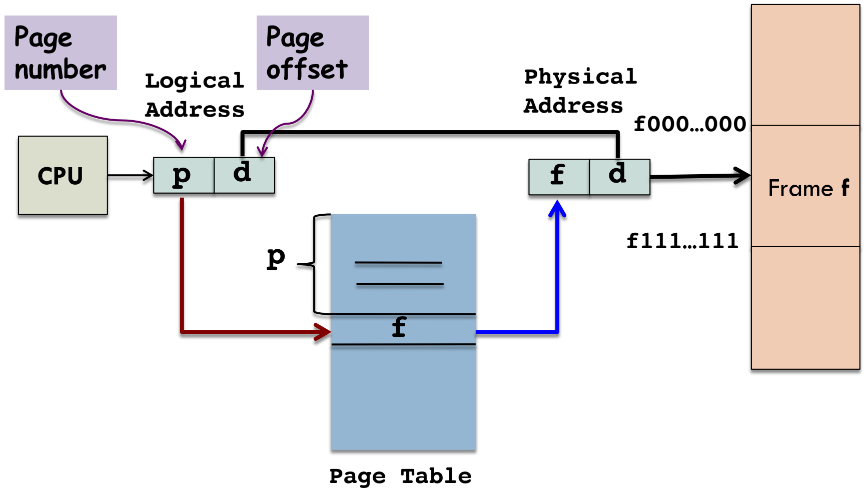
Paging: Analogy

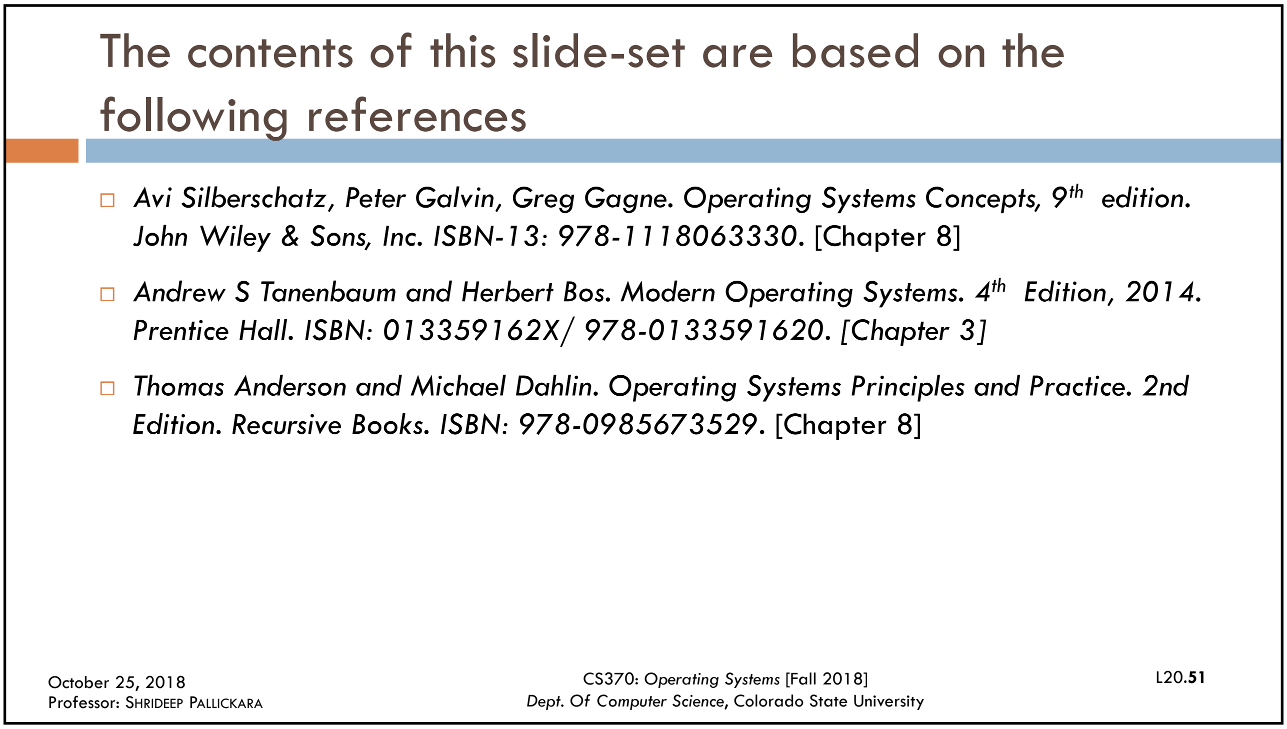
- Shuffling several decks of cards together
- A single process in its virtual address page sees the cards of a single deck in order
  - A different process sees a completely different deck, but it will also be in order
- In physical memory, however, the **decks of all processes** currently running will be **shuffled** together, apparently at random
- Page tables are the magician's assistant in locating cards from the shuffled decks

Paging: Logical and Physical Memory



Paging Hardware: Performing address translation





The contents of this slide-set are based on the following references

- *Avi Silberschatz, Peter Galvin, Greg Gagne. Operating Systems Concepts, 9th edition. John Wiley & Sons, Inc. ISBN-13: 978-1118063330.* [Chapter 8]
- *Andrew S Tanenbaum and Herbert Bos. Modern Operating Systems. 4th Edition, 2014. Prentice Hall. ISBN: 013359162X/ 978-0133591620. [Chapter 3]*
- *Thomas Anderson and Michael Dahlin. Operating Systems Principles and Practice. 2nd Edition. Recursive Books. ISBN: 978-0985673529.* [Chapter 8]