CS 134:
Operating Systems

More Memory Management

2013-05-19

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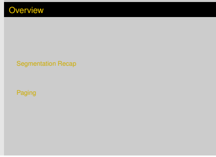
Overview



Overview

Segmentation Recap

Paging

Segmentation (Recap)

Logical address consists of the pair

<segment-number, offset>

Example

Use 32-bit logical address

- High-order 8 bits are segment number
- Low-order 24 bits are offset within segment

256 segments, of max size 16,777,216 bytes (16MB)

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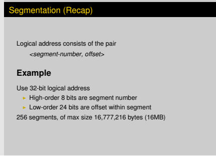
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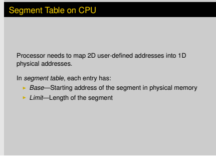
Segment Table on CPU

Processor needs to map 2D user-defined addresses into 1D physical addresses.

In *segment table*, each entry has:

- *Base*—Starting address of the segment in physical memory
- *Limit*—Length of the segment



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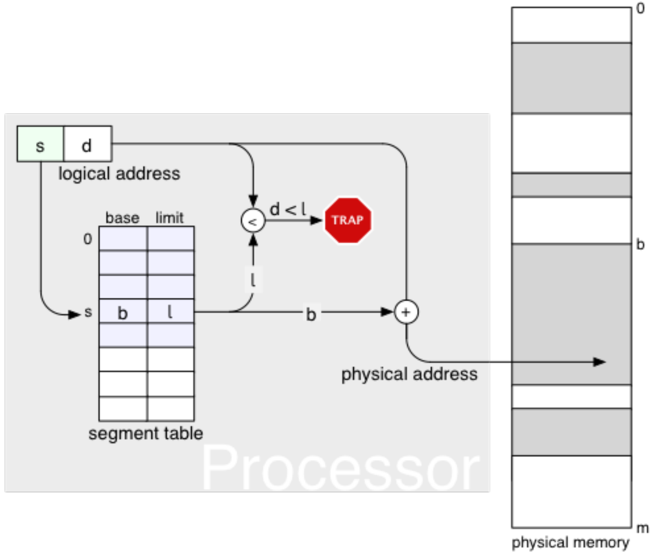

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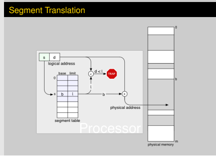

Segmentation Architecture

- Relocation
  - Dynamic
  - By segment table
- Sharing
  - Shared segments
  - Same segment number
- Allocation
  - First fit/best fit
  - External fragmentation

Class Exercise

Do shared segments *need* to have the same segment number.

- If so, why?
- If not, why? (Why might we give them the same segment number anyway?)

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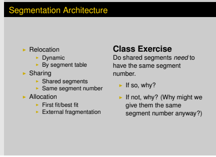
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Does our segmentation scheme capture the *difference* between code and data segments?

- If not, what would we need to fix it?

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What if a program wants more contiguous data space than a segment can hold? Is this a problem?

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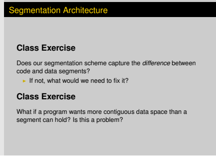
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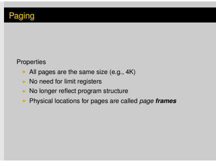
- All pages are the same size (e.g., 4K)
- No need for limit registers
- No longer reflect program structure
- Physical locations for pages are called *page* ***frames***



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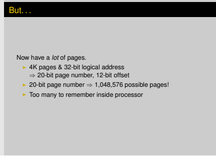
But. . .

Now have a *lot* of pages.

- 4K pages & 32-bit logical address
  $\Rightarrow$ 20-bit page number, 12-bit offset
- 20-bit page number $\Rightarrow$ 1,048,576 possible pages!
- Too many to remember inside processor



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Sparsely Filled Address Spaces

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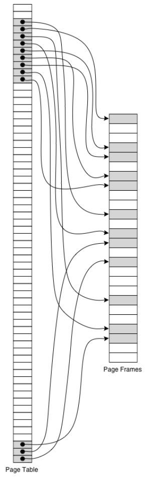
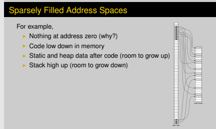
- Nothing at address zero (why?)
- Code low down in memory
- Static and heap data after code (room to grow up)
- Stack high up (room to grow down)

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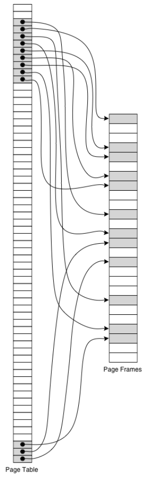

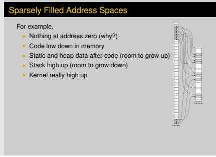
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Two-level (or three-level) page tables

- 10-bit upper page number (0-1023)
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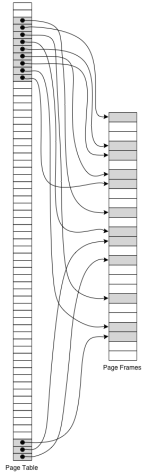
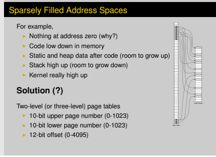
- 12-bit offset (0-4095)

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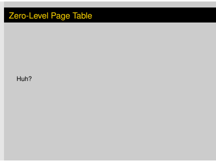
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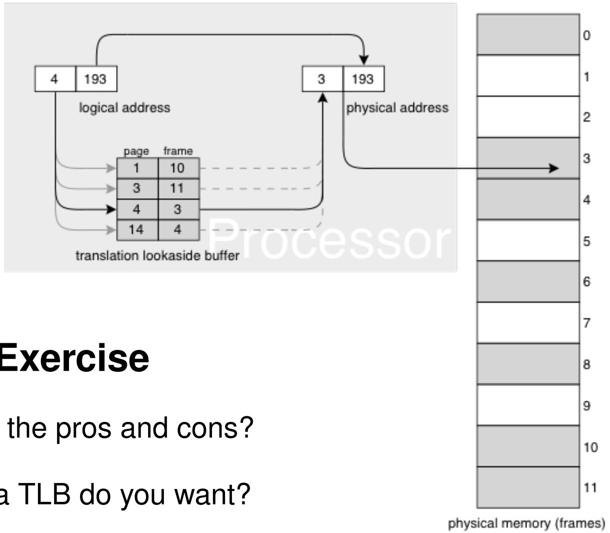

Class Exercise

What are the pros and cons?

How big a TLB do you want?

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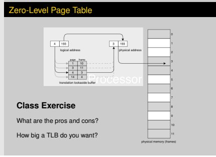
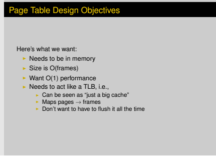


Page Table Design Objectives

Here's what we want:

- Needs to be in memory
- Size is O(frames)
- Want O(1) performance
- Needs to act like a TLB, i.e.,
    - Can be seen as "just a big cache"
    - Maps pages $\rightarrow$ frames
    - Don't want to have to flush it all the time



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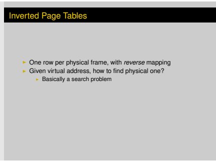
Inverted Page Tables

- One row per physical frame, with *reverse* mapping
- Given virtual address, how to find physical one?
  - Basically a search problem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Question: Is the hash table bigger than the number of frames?

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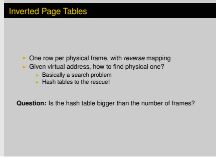

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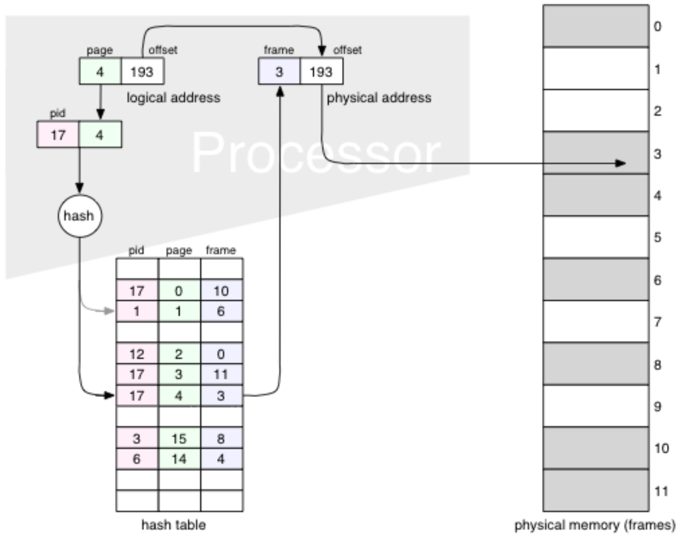
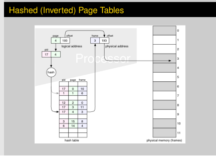
Hashed (Inverted) Page Tables





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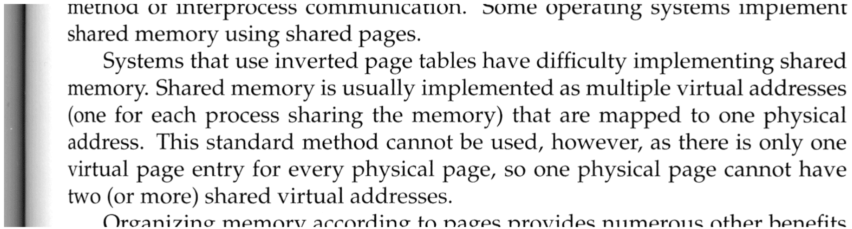


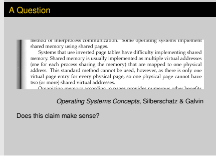
method of interprocess communication. Some operating systems implement shared memory using shared pages.

Systems that use inverted page tables have difficulty implementing shared memory. Shared memory is usually implemented as multiple virtual addresses (one for each process sharing the memory) that are mapped to one physical address. This standard method cannot be used, however, as there is only one virtual page entry for every physical page, so one physical page cannot have two (or more) shared virtual addresses.

Organizing memory according to pages provides numerous other benefits

Operating Systems Concepts, Silberschatz & Galvin

Does this claim make sense?



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	Physical addrs	Virtual addrs	TLB Size	Segments	Pages	Hashed page tables
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Opteron	40-bit	48-bit	1088	varied	4k, 4M	—
Itanium 2	50-bit	64-bit	4×32	—	4k. . . 4G	—
PowerPC 604	32-bit	52-bit	256	< 256MB	4k	Yes
PowerPC 970	42-bit	64-bit	1024	< 256MB	4k	Yes
UltraSparc	36-bit	64-bit	64	—	8k. . . 4M	Yes
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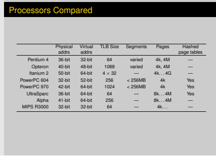
MIPS R3000	32-bit	32-bit	64	—	4k. . .	—



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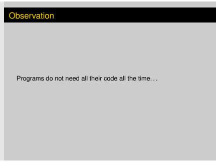

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- `handle = dlopen(filename, mode)`
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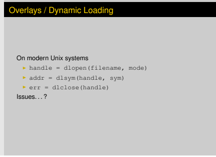
Issues. . . ?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`dlopen` maps a file into the address space and returns an opaque handle.

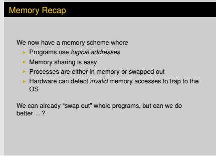
`dlsym` looks up a symbol in a dynamically loaded file.

Memory Recap

We now have a memory scheme where

- Programs use *logical addresses*
- Memory sharing is easy
- Processes are either in memory or swapped out
- Hardware can detect *invalid* memory accesses to trap to the OS

We can already “swap out” whole programs, but can we do better. . . ?



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Demand Paging

Need to

- Bring a page into memory only when it is needed.
  - Less I/O needed
  - Less memory needed
  - Faster response
  - More users & processes
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When program accesses an invalid page, two possibilities. . .

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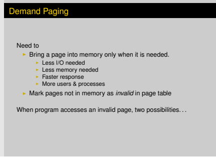
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Thus,

- Invalid accesses generate a trap
- Need to restart program after the trap
- Must seem like "nothing happened"

Example: The C-code for:

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--mystack = new_item;
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might be implemented as a single instruction:

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mov -(r6),r1
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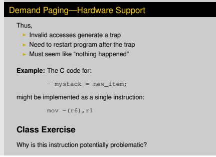
Why is this instruction potentially problematic?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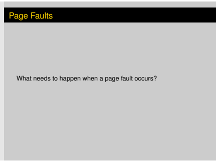
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What happens. . .

- User process accesses invalid memory—traps to OS
- OS saves process state
- OS checks access was actually legal
- Find a free frame
- Read from swap to free frame—I/O wait, process blocked
- Interrupt from disk (I/O complete)—process ready
- Scheduler restarts process—process running
- Adjust page table
- Restore process state
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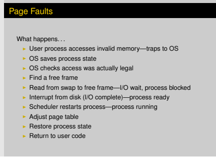
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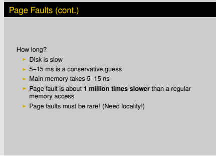
Page Faults (cont.)

How long?

- Disk is slow
- 5–15 ms is a conservative guess
- Main memory takes 5–15 ns
- Page fault is about **1 million times slower** than a regular memory access
- Page faults must be rare! (Need locality!)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A “Back of an Envelope Calculation”

How often are there page faults?

An example from a desktop machine:

- In 14 days
  - 378,110 page-ins
  - Average load < 4% $\rightarrow$ 12 hours actual compute time
  - 8.75 page faults per second *average*
- 1,000,000,000 memory accesses per second (a guess)
- 43,200,000,000,000 memory accesses in 12 hours
- 1 page-in every 114,252,466 memory accesses
- Using 5 ns for memory, 5 ms for disk:
  - $t_{\text{avg}} = (5,000,000 * 1 + 5 * 114,252,465)/114,252,466$
  - $t_{\text{avg}} = 5.04\text{ns}$

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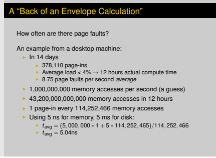
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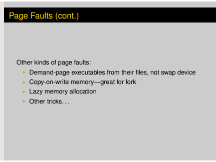
Page Faults (cont.)

Other kinds of page faults:

- Demand-page executables from their files, not swap device
- Copy-on-write memory—great for fork
- Lazy memory allocation
- Other tricks. . .


Page Faults (cont.)

Other kinds of page faults:

- Demand-page executables from their files, not swap device
- Copy-on-write memory—great for fork
- Lazy memory allocation
- Other tricks. . .

What kind of other tricks? Well, for example, debugging and tracing; VM translation; buffer overflow prevention.