Today

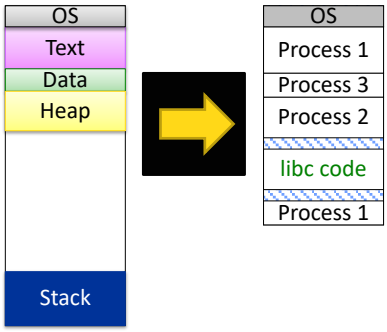
- Memory Management
  - Virtual Memory
  - Segmentation, Paging
- Project 5

Review

- What abstraction does virtual memory provide?
- What requirements do we have for the VM, from the various stakeholders, so far?

Aaron Bauer, University of Washington
"Understanding Human Problem Solving in Complex Digital Environments"
Talk at 4 p.m. (Reception at 3:45 p.m.)

Address Translation: Wish List



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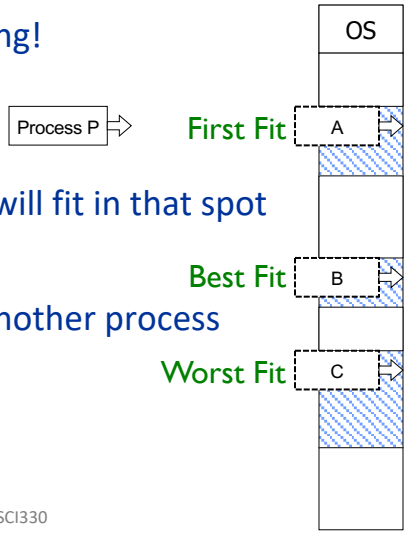
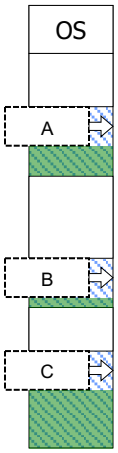
Review:
Where should process P be placed?

- First fit
  - Don't spend time searching!
- Best fit
  - It fits tightly!
  - Maybe no other process will fit in that spot
- Worst fit
  - Leaves lots of space for another process



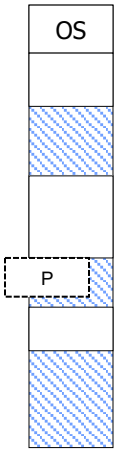
(External) Fragmentation

- No matter where it ends up, the remaining gaps get smaller
- Large gaps are probably still usable, small ones likely aren't
- Fragmentation: over time, we end up with small gaps that become more difficult to use (eventually, wasted)
- "External" because the gaps are *between allocated* pieces



(External) Fragmentation

- Suppose we put it here, and later, P asks for more memory?
- What if there isn't enough space…
  - Move P?
  - Move everybody to compact the address space?
- This seems bad. Lots of tough problems (placement, fragmentation) with no clear solutions.



Alternative Organization of PAS

- Divide PAS into *fixed*-size pieces
- Use memory translation to assign virtual addresses to physical locations
- Every physical location is an equally good choice!

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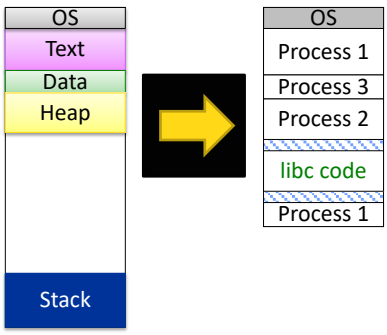

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- **Make it easier to perform placement in a way that reduces fragmentation**

OS Perspective

- Primary challenge: Which physical memory do we give to processes?
- Other important considerations:
  - **Protection**: OS is resource gatekeeper, must isolate itself (and processes)
  - **Performance**: OS should map memory for best performance, as long as it doesn't violate protection

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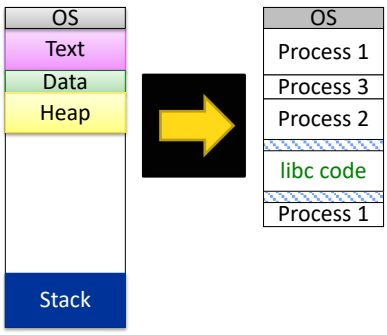

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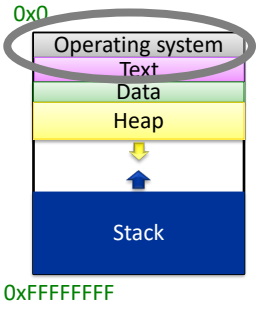
Recall: Context Switching Performance

- Even though it's fast, context switching is expensive:
  1. time spent is 100% overhead
  2. must invalidate other processes' resources (caches, memory mappings)
  3. kernel must execute – it must be accessible in memory
- Solution to #3:
  - keep kernel mapped in every process VAS
  - protect it to be inaccessible



Hardware

- Hardware and OS are symbiotic, often influence each other
  - Example: atomic instructions
- Memory management is another important area of collaboration
- Hardware goals:
  - Make translation fast
  - Give OS storage for and control over mappings

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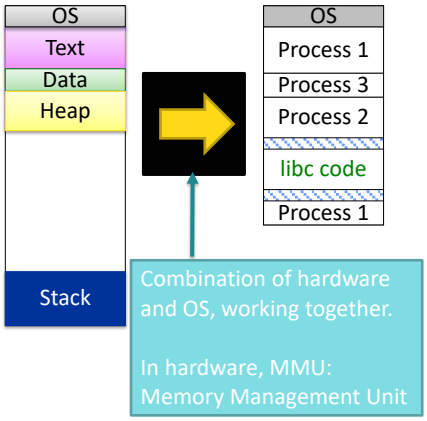

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- **Map addresses quickly with a little HW help**

How does each benefit from having a logical memory abstraction?

- The user
  - Memory size, protection
- The programmer
  - Shared libraries
- The compiler
  - Placement of data
- The OS / OS designer
  - Memory placement, fragmentation
- The hardware / hardware designer
  - Just makes it more complex BUT can help OS

Awkward transition

PROJECT 5

Project 5

- Combines processes and memory management
- proc.c
  - Implementations of process management and memory management

proc.h Data Structures: memoryMap

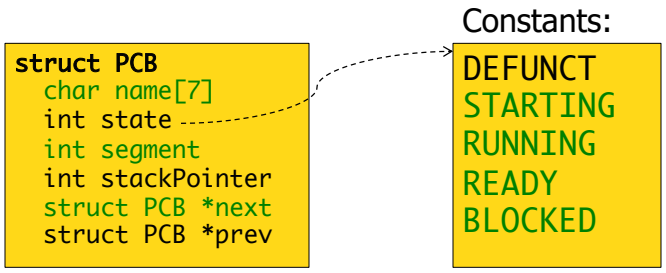
- Allow one process to be loaded into each segment
  - Valid Segments: 0x2000, … 0x9000
  - (0x0000 reserved for interrupt vector, 0x1000 reserved for kernel)
- Memory segment map:
  - Each index corresponds to one memory segment.
    - segment = (index+2)*0x1000
    - index = (segment/0x1000)-2
  - Marked as:
    - FREE or USED

memoryMap

0	USED
1	USED
2	FREE
3	FREE
4	USED
5	FREE
6	FREE
7	FREE

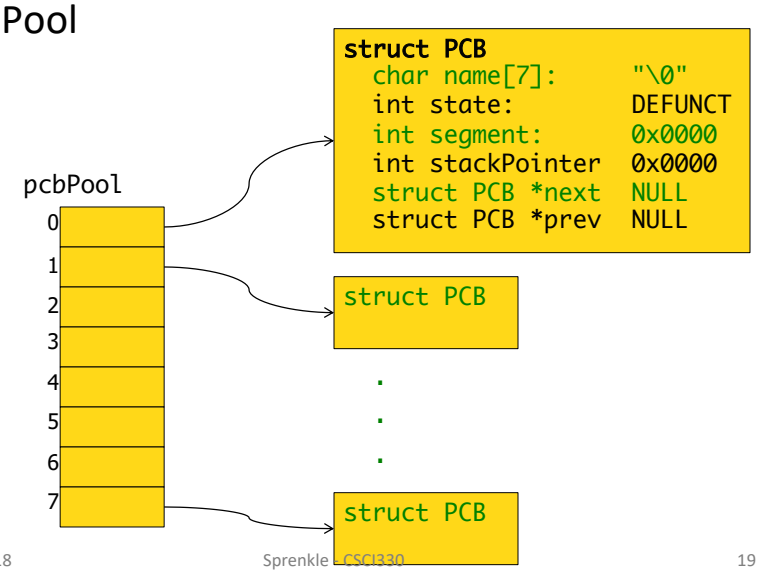
proc.h Data Structures: PCB

- Process Control Block:



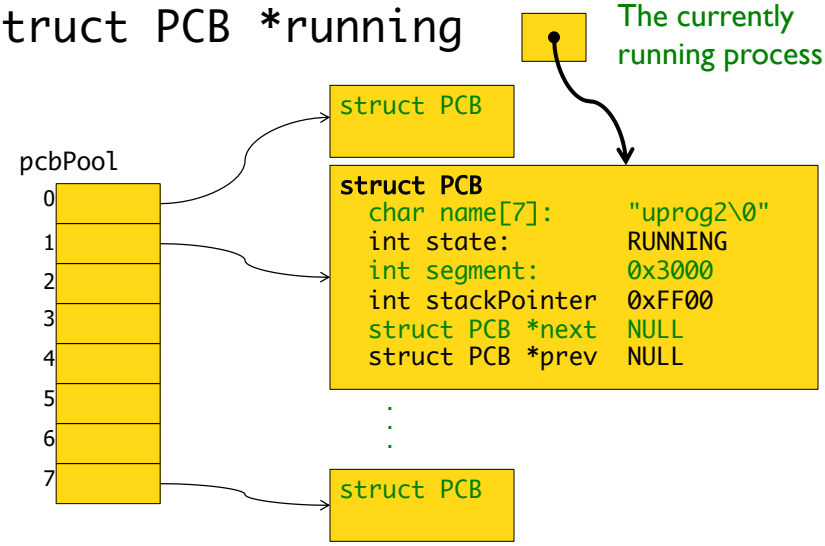
proc.h Data Structures: pcbPool

- PCB Pool



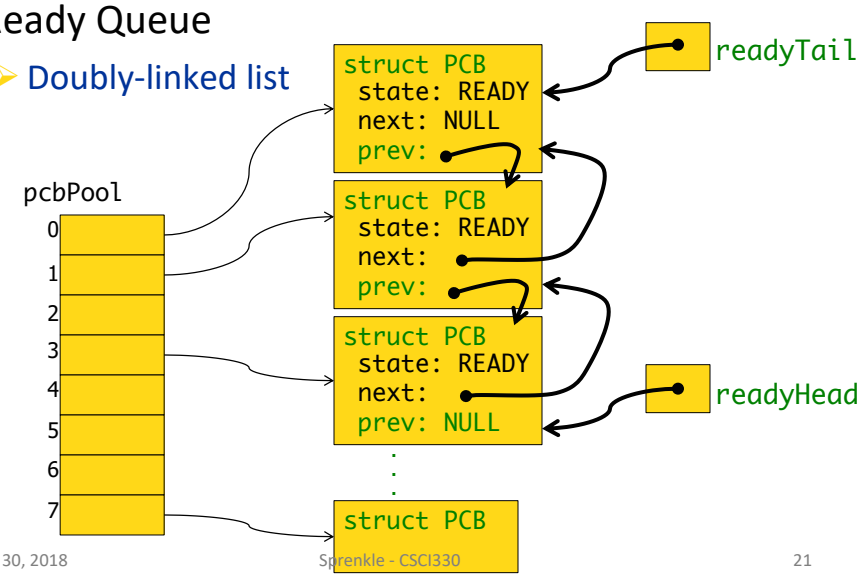
proc.h Data Structures

- struct PCB *running



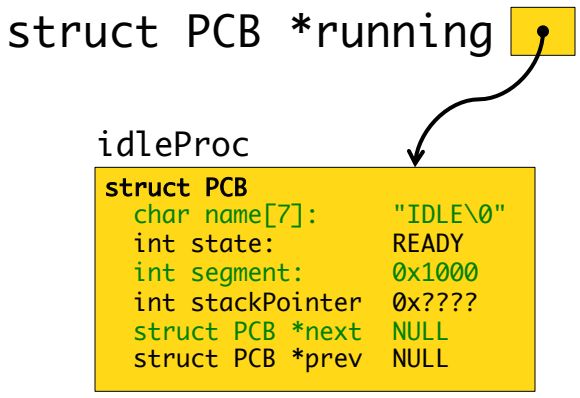
proc.h Data Structures

- Ready Queue
  - Doubly-linked list



proc.h Data Structures: running

- Initially the running process will be the **idle** process

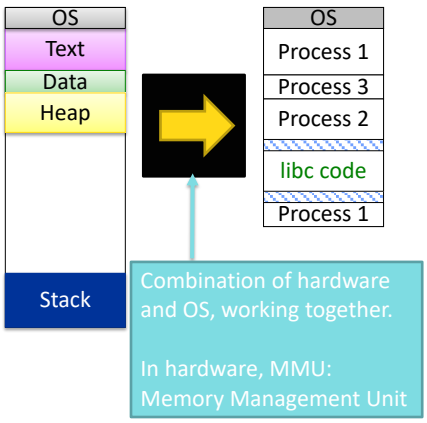


If no processes in the ready queue, run idle process

Equally awkward translation back

VM→PHYSICAL ADDRESS TRANSLATION

Address Translation: Wish List



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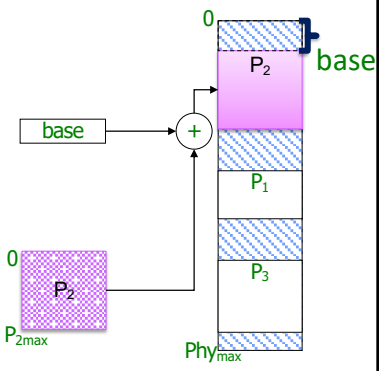
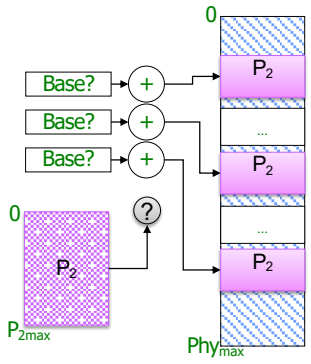
Simple (Unrealistic) Translation Example

- Process P_2's virtual addresses don't align with physical memory's addresses
- Consider: P_2 wants to access address 0x1000
- Determine offset from *physical address* 0 to start of P_2
  - store in *base*



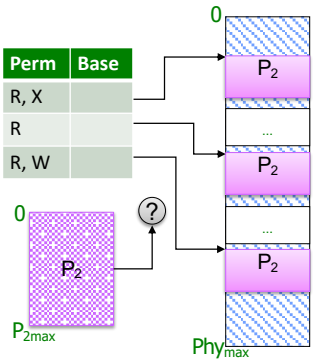
Generalizing

- Problem: process may not fit in one contiguous region



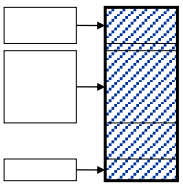
Generalizing

- Problem: process may not fit in one contiguous region
- Solution: keep a table (one per process)
  - Keep details for each region in a row
  - Store additional metadata (ex. permissions)
- Questions:
  - How many regions should there be (and what size)?
  - How to determine which table entry we should use?

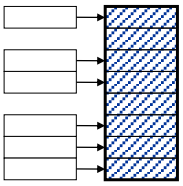


Defining Regions - Two Approaches

- Segmentation:
  - Partition address space and memory into logical segments
  - Segments have *varying* sizes



- Paging:
  - Partition address space and memory into pages
  - Pages are a constant, *fixed* size



Why would you use each approach? Pros/Cons

- Segmentation:
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  - Segments have *varying* sizes
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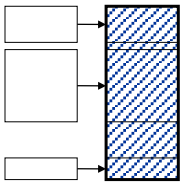
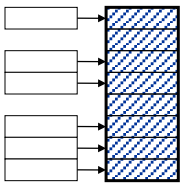


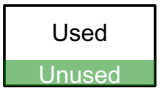


Consider how memory would be requested and used
Do the pros/cons change based on whose perspective?

Fragmentation

Internal

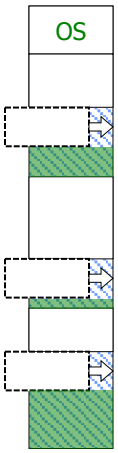
- Process asks for memory, doesn't use it all
- Possible reasons:
  - Process was wrong about needs
  - OS gave it more than it asked for
- ***internal***: within an allocation



Memory allocated to process

External

- Over time, we end up with small gaps that become more difficult to use
  - eventually, wasted
- ***external***: unused memory between allocations



Which scheme is better for *reducing* internal and external fragmentation?

A. Segmentation is better than paging for both forms of fragmentation.

B. Segmentation is better for *internal* fragmentation, while paging is better for *external* fragmentation.

C. Paging is better for *internal* fragmentation, while segmentation is better for *external* fragmentation.

D. Paging is better than segmentation for both forms of fragmentation.

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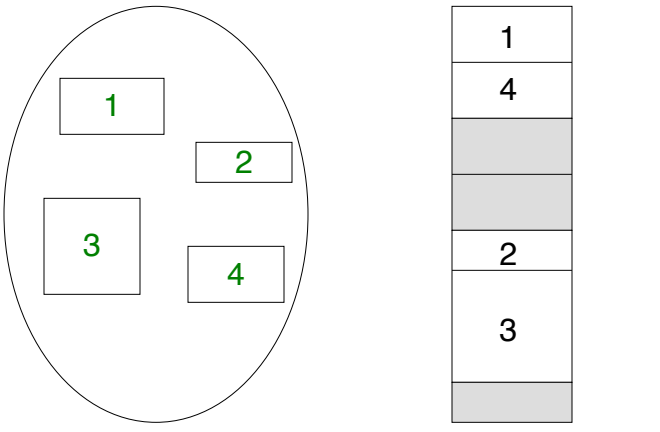
Segmentation vs. Paging

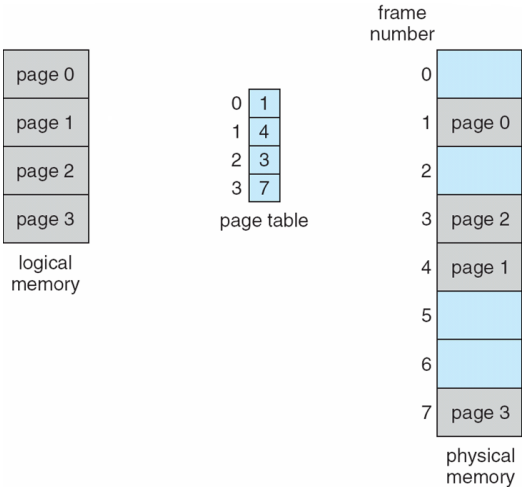
- A ***segment*** is good ***logical*** unit of information
  - Can be sized to fit any contents
  - Easy to share large regions (e.g., code, data)
  - Protection requirements correspond to logical data segment
- A ***page*** is good ***physical*** unit of information
  - Simple physical memory placement
  - No external fragmentation
  - Constant sizes make it easier for hardware to help

Logical View of Segmentation



Since segments vary in length,
memory allocation is a dynamic storage allocation problem

Paging Model of Logical and Physical Memory



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- Solution: keep a table (one per process)
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- Interesting questions:
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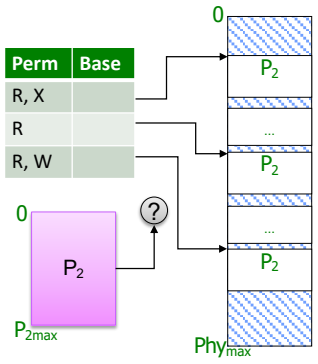
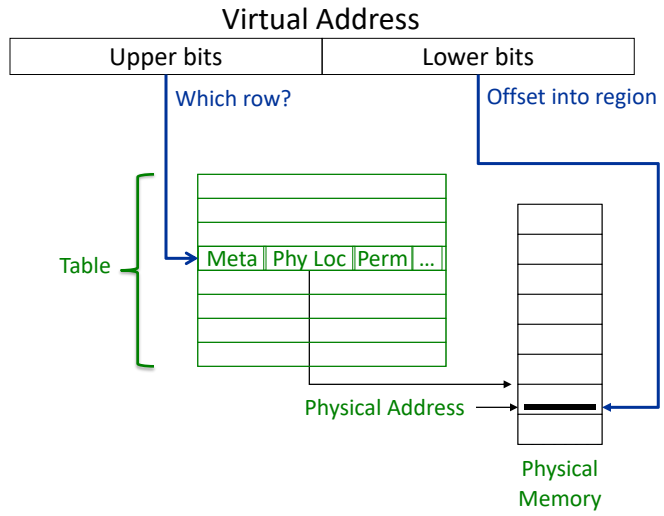


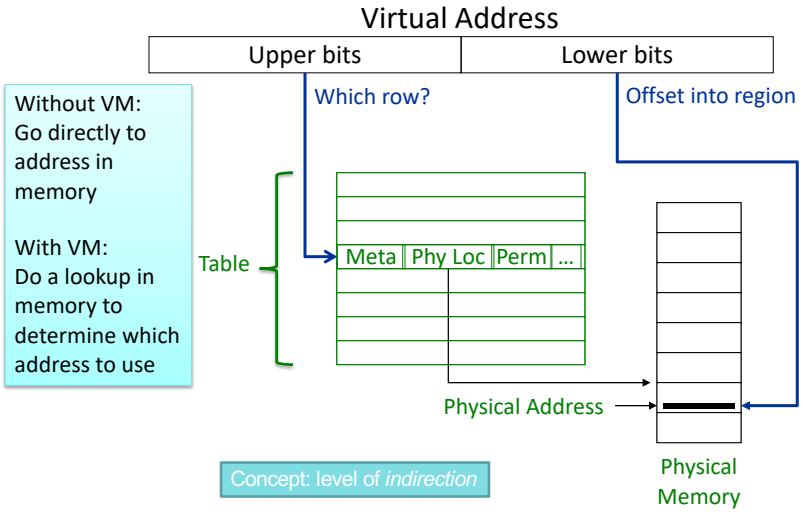
For **Both** Segmentation and Paging…

- Each process has a table to track memory address translations
- When a process attempts to read/write to memory:
  - use *high order* bits of virtual address to determine which row to look at in the table
  - use *low order* bits of virtual address to determine an offset within the physical region

Address Translation



Performance Implications



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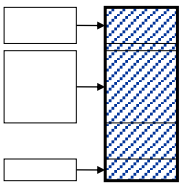

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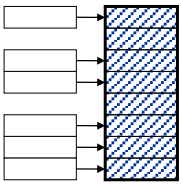
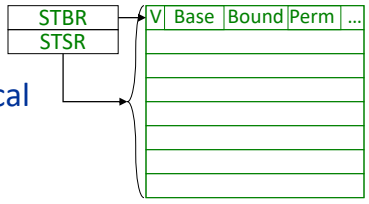
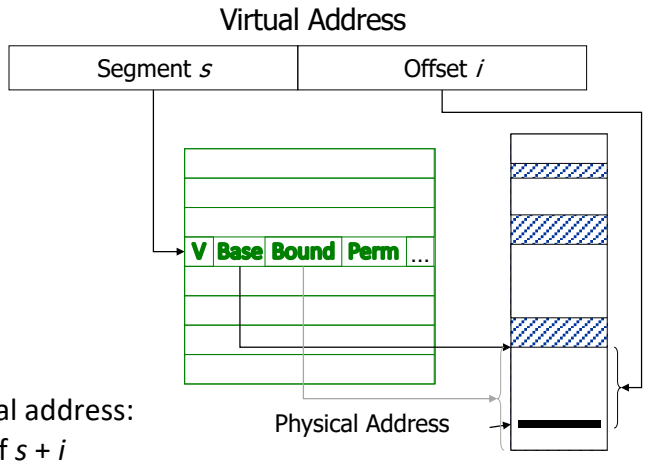


Segment Table

- One table per process
- Where is the *table* located in memory?
  - Segment table base register (STBR)
  - Segment table size register (STSR)
- Table entries: Segment metadata
  - V: valid bit
    - does it contain a mapping?
  - Base: segment location in physical memory
  - Bound: segment size in physical memory
  - Permissions

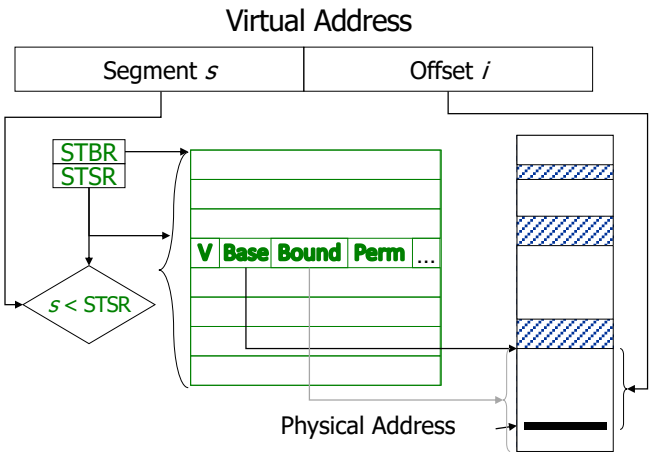


Segment Address Translation

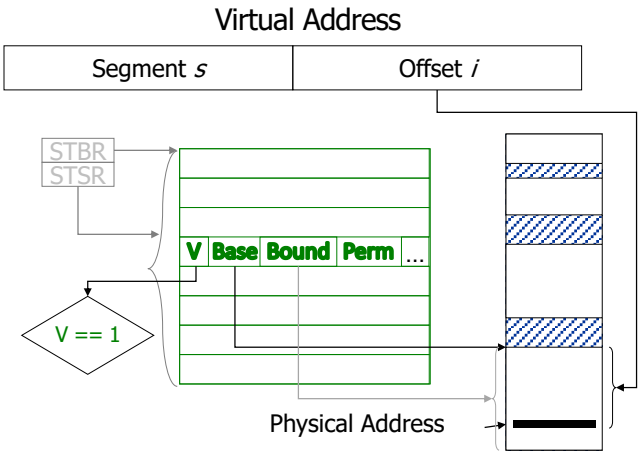


- Physical address: base of *s* + *i*

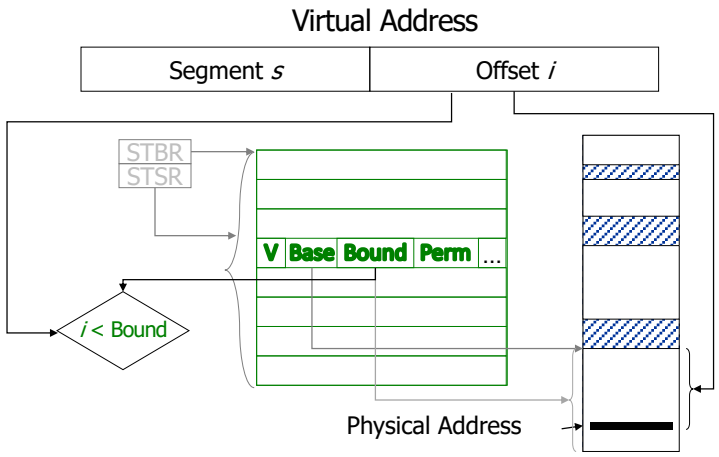
Check if Segment *s* is within Range



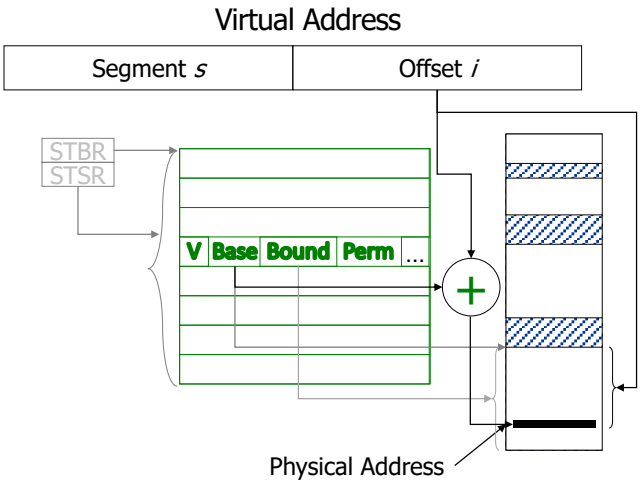
Check if Segment Entry *s* is Valid



Check if Offset *i* is within Bounds



Translate Address



Pros and Cons of Segmentation

Pros

- Each segment can be
  - located independently
  - separately protected
  - grown/shrunk independently
- Small segment table size
  - ~256 Bytes → 1GB memory

Cons

- Variable-size allocation
  - Difficult to find holes in physical memory
  - External fragmentation

Looking Ahead

- Project 5 due next Friday