CS 370: OPERATING SYSTEMS

[MEMORY MANAGEMENT]

Computer Science
Colorado State University

Instructor: Louis-Noel Pouchet
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** Lecture slides created by: SHRIDEEP PALLICKARA

Topics covered in this lecture

- Address binding
- Address spaces
- Swapping
- Contiguous memory allocations

Memory is an important resource that must be managed carefully

- Memory capacities have been increasing
  - But programs are getting bigger faster

- **Parkinson's Law**

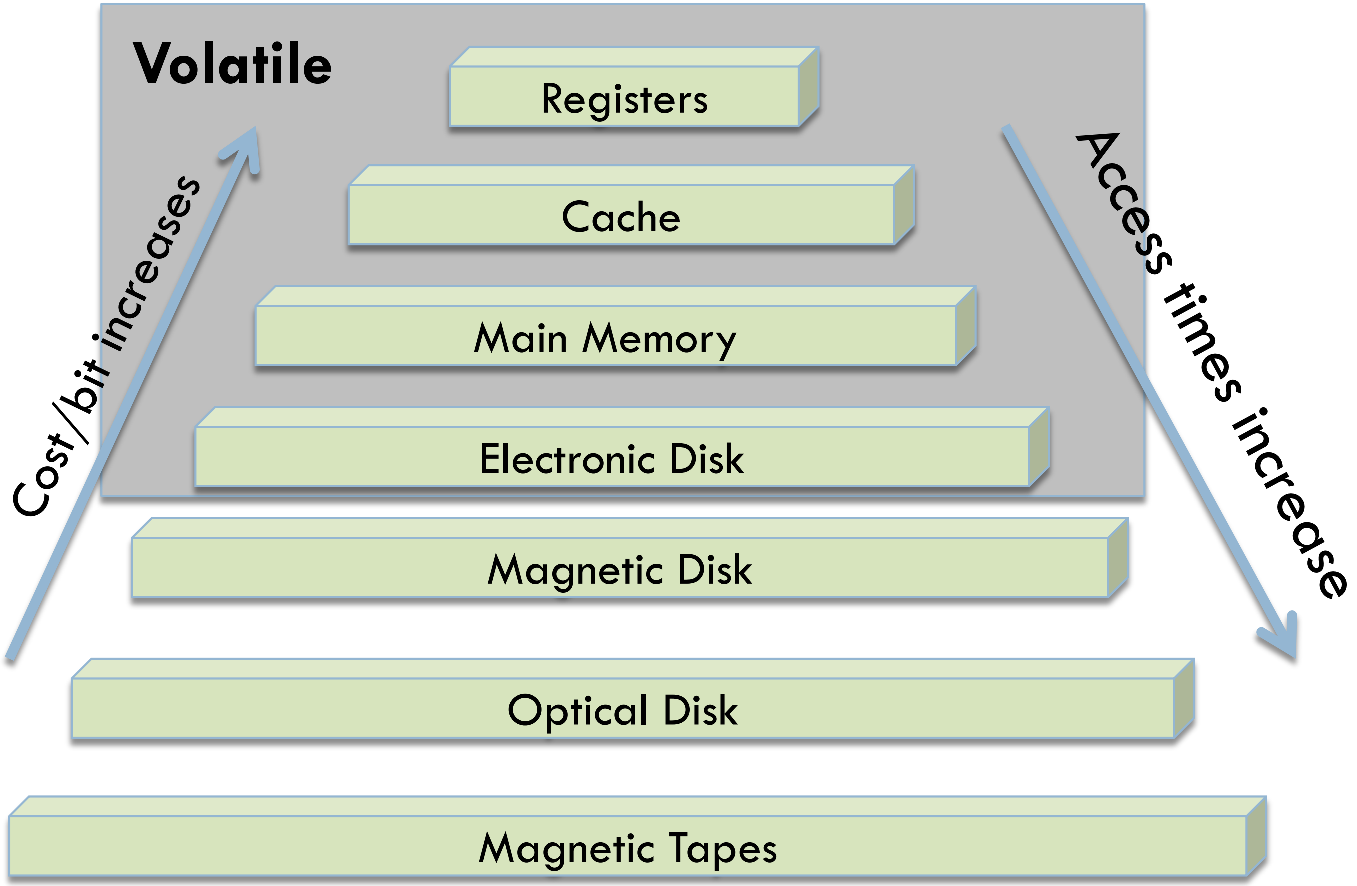
  Programs expand to fill the memory available to hold them

What every programmer would like

- Memory that is
  - Private, infinitely large, infinitely fast
  - Non-volatile
  - Inexpensive too

- Unfortunately, no such memory exists as of now

The second choice is to manage a hierarchy of memory



Memory Management

Memory Management: Why?

- Main objective of system is to execute programs
- Programs and data must be **in memory** (*at least partially*) during execution
- To improve CPU utilization and response times
  - **Several** processes need to be memory resident
  - Memory needs to be **shared**

Memory

- Large array of words or bytes
  - Each word/byte has its own address

- Typical execution cycle:
  1. Fetch instruction from memory where program is stored
  2. Decode
  3. Execute. Operands may be fetched from memory
  4. Result of execution may be stored back to memory

Memory Unit

- Sees only a **stream** of memory addresses

- Oblivious to
  - ***How*** these addresses are generated
    - Instruction counter, indexing, indirection, etc.
  - ***What*** they are for
    - Instructions or data

Why processes must be memory resident

- Storage that the CPU can access **directly**
  1. Registers in the processor
  2. Main memory
- Machine instructions take memory addresses as arguments
  - <u>None operate on disk addresses</u>
- Any instructions in execution *plus* needed data
  - Must be in memory

Overheads in direct-access storage devices

- CPUs can decode instructions and perform simple operations on register contents
  - 1 or more per clock cycle
- Registers accessible in 1 clock cycle
- Main memory access is a *transaction* on the memory bus
  - Takes several cycles to complete

Coping with the speed differential

- Introduce fast memory between CPU and main memory for reused data
  - Cache (data)
  - Cache (instructions!)
  - Cache (translation!)
  - Cache …

Besides coping with the speed differential, **correct** operation needed

- OS must be protected from accesses by user processes

- User processes must be protected from one another

Protection: Making sure each process has separate memory spaces

- Determine **range** of legal addresses for process
- **Ensure** that process can access only those

Providing protection with registers

- Base
  - **Smallest** legal physical address

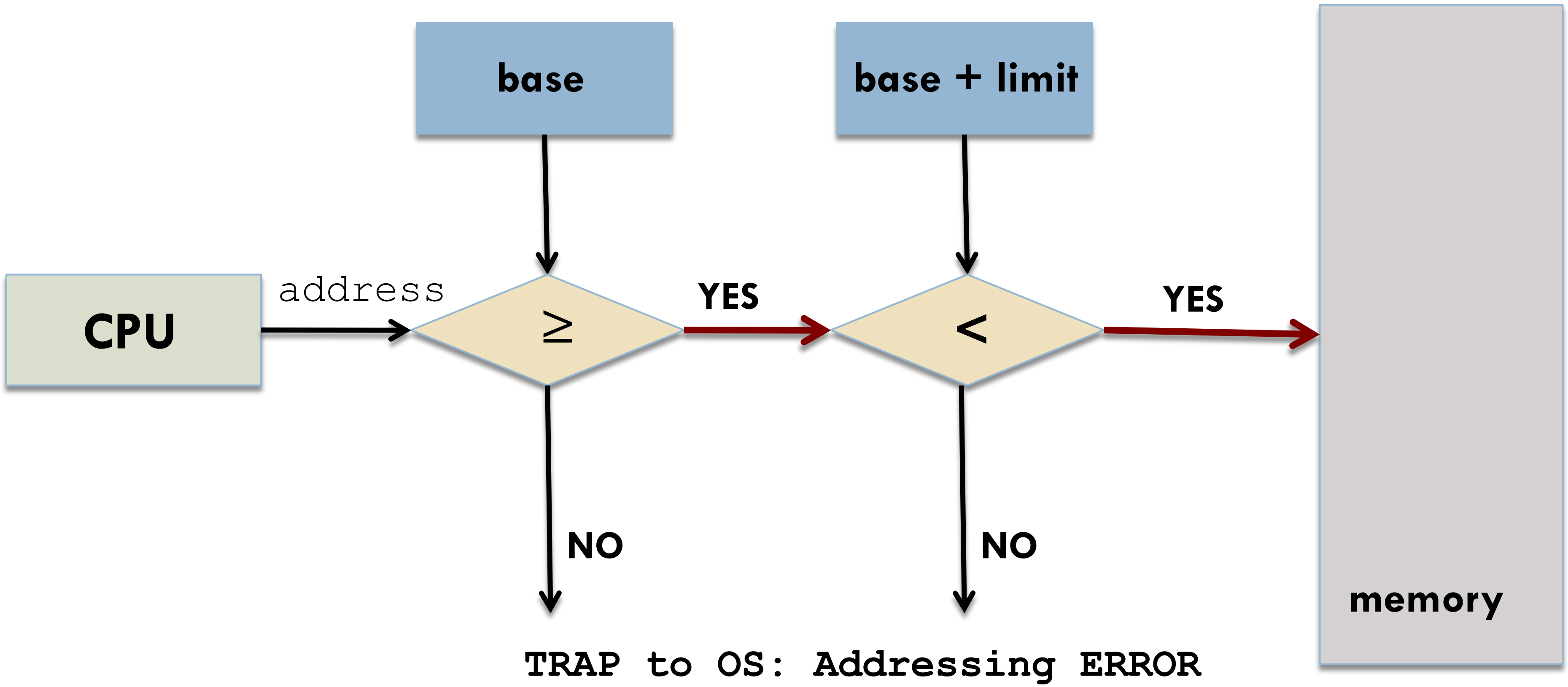
- Limit
  - Size of the **range** of physical address

- Eg: Base = 300040 and limit = 120900
  - Legal: 300040 ←→ (300040 + 120900 -1) = 420939

Base and limit registers loaded only by the OS

- **Privileged** instructions needed to load registers
  - Executed ONLY in kernel mode
- User programs cannot change these registers' contents
- OS is given unrestricted access to OS and user's memory

CPU hardware compares every address generated in user mode



Processes and memory

- To execute, a program needs to be **placed** inside a process
- Process **executes**
  - Access instructions and data from memory
- Process **terminates**
  - Memory reclaimed and declared available

Binding is a mapping from one address space to the next

- Processes can reside in **any part** of the physical memory
  - First address of process need not be x0000
- Addresses in source program are **symbolic**
- Compiler binds symbolic addresses to **relocatable** addresses
- Loader binds relocatable addresses to **absolute** addresses

Binding can be done at … [1/2]

- Compile time
  - Known that the process will reside at location **R**
    - If location changes: recompile
  - MS-DOS .COM programs were bound this way

- Load time
  - Based on compiler generated relocatable code

Binding can be done at … [2/2]: Execution-time

- Process can be moved around during execution
  - Binding *delayed* until run time
  - Special hardware needed
  - Supported by most OS

ADDRESS SPACES

Address spaces

- **Logical**
  - Addresses *generated* by the program running on CPU
- **Physical**
  - Addresses *seen* by the memory unit
- Logical address space
  - Set of logical addresses generated by program
- Physical address space
  - Set of physical addresses corresponding to the logical address space

Generation of physical and logical addresses

- Compile-time and load-time
  - *Identical* logical and physical addresses

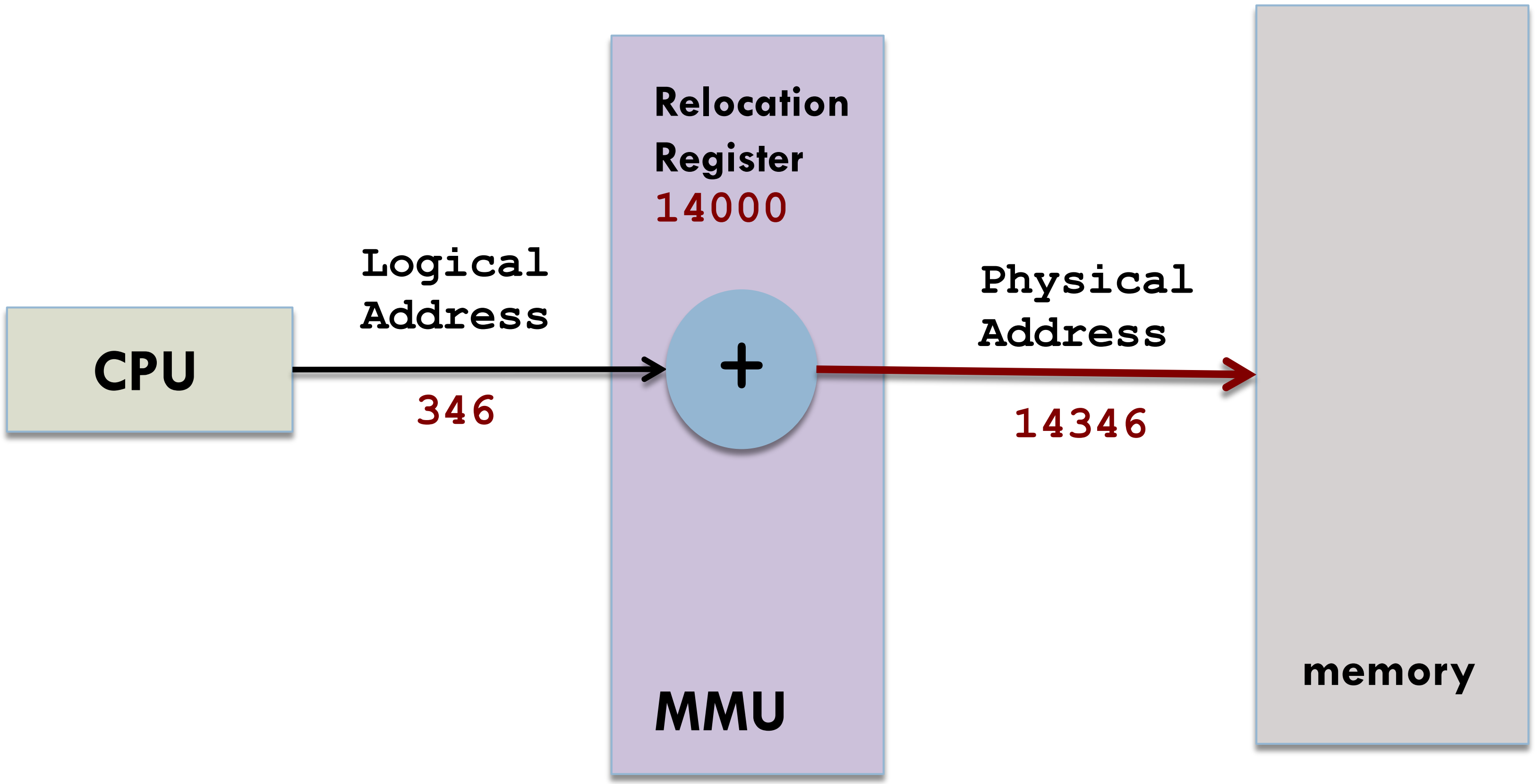
- Execution time
  - Logical addresses *differ* from physical addresses
  - Logical address referred to as **virtual** address

- Runtime mapping performed in hardware
  - Memory management unit (**MMU**)

Memory management unit

- Mapping converts logical to physical addresses
- User program ***never sees*** real physical address
  - Create pointer to location
  - Store in memory, manipulate and compare
- When used as a **memory address** (load/store)
  - Relocated to physical memory

Dynamic relocation using a relocation register



User program **never sees** the real physical addresses

But …

- Do we need to load the entire program in memory?

In dynamic loading an unused routine is never loaded into memory

- Routine is not loaded until it is called
  - Kept on disk in relocatable load format
- When routine calls another one
  - If routine not present?
    - Load routine and update address tables
- Does not require special support from OS
  - Design programs appropriately

Contrasting Loading and Linking

- Loading
  - Load executable into memory prior to execution

- Linking
  - Takes some smaller executables and joins them together as a single larger executable.

Static linking

- Language libraries treated as other modules
  - Combined by loader into program image

- Each program **includes a copy** of library functions called in executable image
  - Wastes disk / memory space, but make the binary self-contained

Dynamic linking is similar to dynamic loading

- **Stub** included for each library reference
  - Locate memory resident routine
  - How to load routine if not in memory

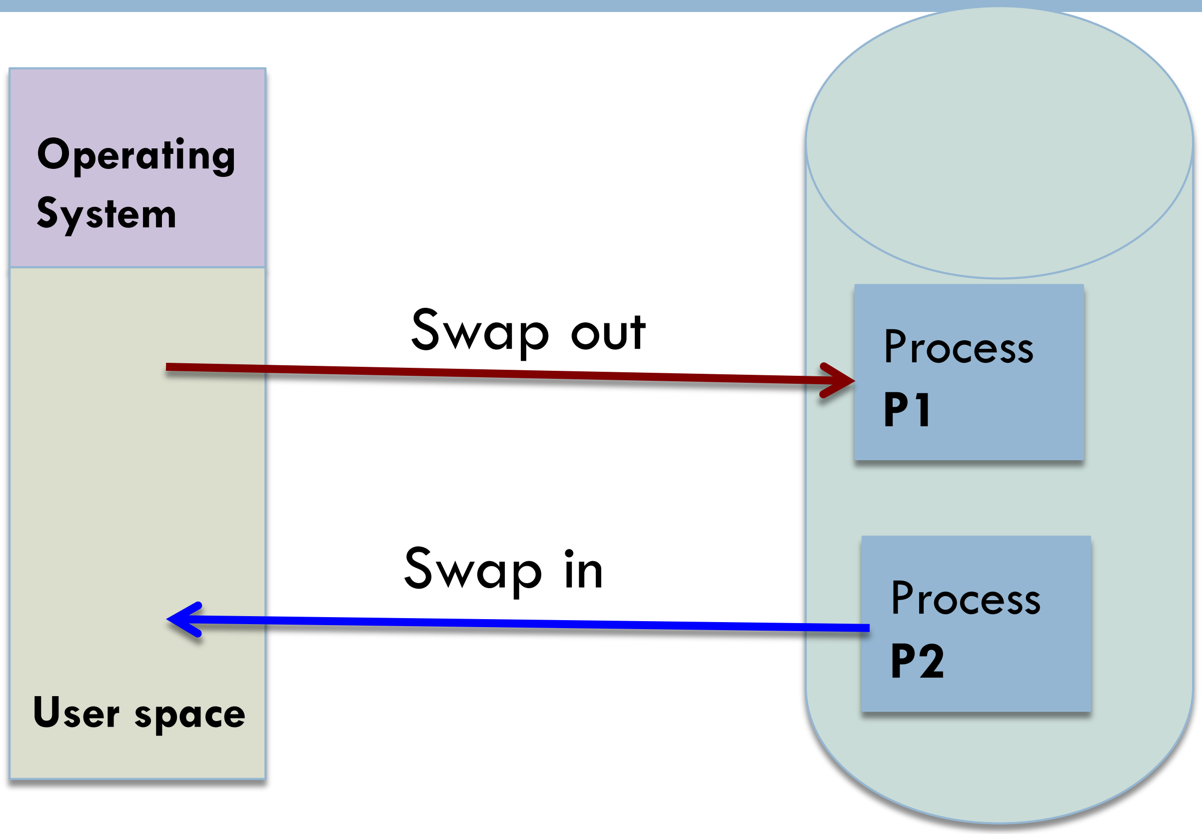
- After routine is loaded, stub replaces itself with address of routine
  - Subsequent accesses to code-segment do not incur dynamic linking costs

Unlike dynamic loading, dynamic linking needs support from the OS

- Only the OS **can allow** multiple processes to access the same memory region
  - Shared Pages

SWAPPING

Swapping: Temporarily moving a process out of memory into a backing store



Swapping and memory space restrictions: Effects of binding

- Process may or may not be swapped back into the same space that it occupied
- Binding at compile or load time?
  - Difficult to relocate
- Execution-time binding
  - Process can be swapped into different memory space
  - Physical addresses computed at run-time

When a CPU scheduler decides to execute a process, it calls the dispatcher

- Check whether the next process is in memory

- If it is not & there is no free memory?
  - *Swap out* a process that is memory resident
  - *Swap in* the desired process

Overheads in swapping: Context switch time

- User process size: 100 MB
- Transfer rate: 50 MB/sec
- Transfer time = 2 seconds
- Average latency: 8 milliseconds
- Swap out = transfer time + latency
  - 2000 + 8 = 2008 milliseconds
- Total swap time = swap in + swap out
  - 4016 milliseconds

Factors constraining swapping besides swap time

- Process must be completely **idle**
  - No pending I/O

- Device is busy so I/O is *queued*
  - Swap out P_1 and swap in P_2
  - I/O operation may attempt to use P_2's memory
    - Solution 1: Never swap process with pending I/O
    - Solution 2: Execute I/O operations into OS buffers

Swapping is not a reasonable memory management solution

- Too much swapping time; too little execution time

- Modification of swapping exists in many versions of UNIX
  - Swapping is normally disabled
  - Starts if many processes are running, and a set *threshold is breached*
  - Halted when system load reduces

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

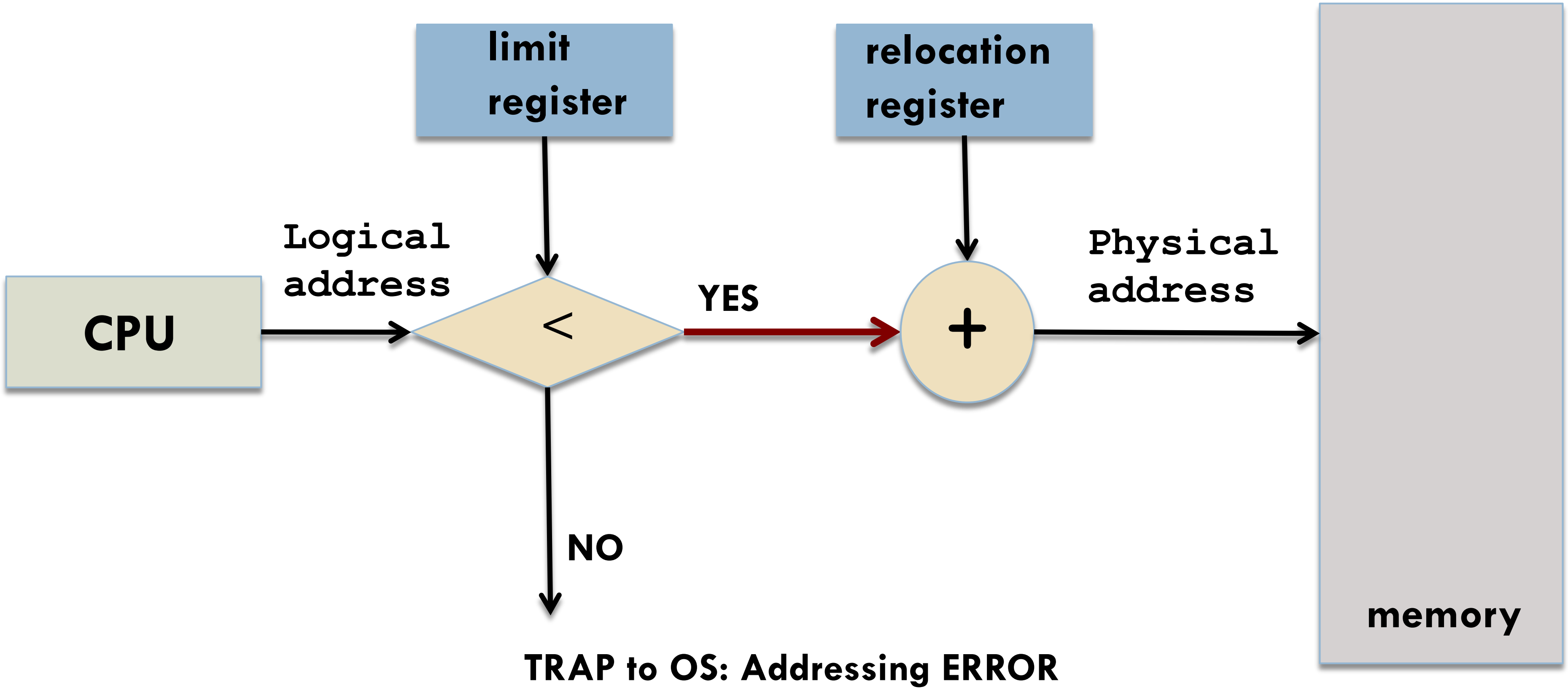
Memory Mapping and Protection

- Relocation register
  - Smallest physical address
- Limit register
  - Range of logical addresses

Memory Mapping and Protection

- When CPU scheduler selects a process for execution
  - Relocation 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.: 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 hole**
  - Eventually *many* memory holes will exist

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

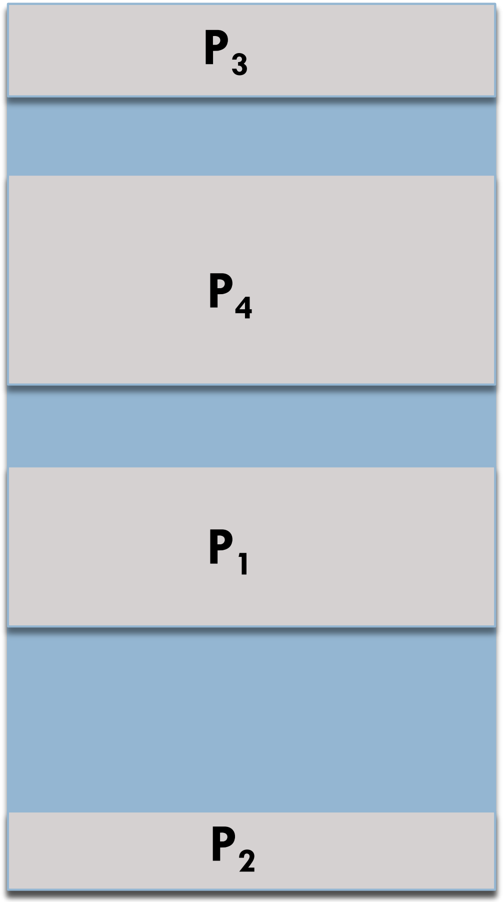
- OS orders processes according to the scheduling algorithm
- Memory allocated to processes until requirements of the next process cannot be met
  - *Wait* till a larger block is available
  - *Check* if smaller requirements of other processes can be met

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 holes*
    - **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-hole that is big enough

- Hole is broken up into two pieces
  - One for the process
  - The other is unused memory

Best Fit

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

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 holes

Worst fit

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

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]*