Operating Systems
CS2006

Lecture 13

Memory Management

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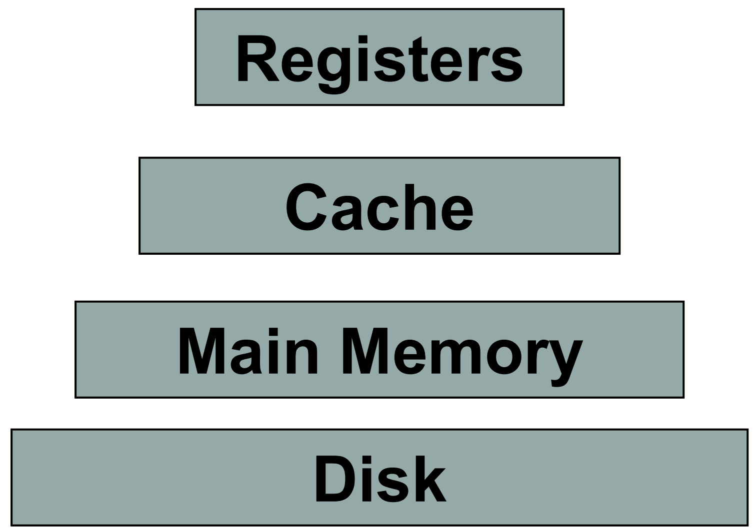
Background

- Program must be brought (from disk) into memory and placed within a process for it to be run

- A programmer will like to have memory
  - Infinitely large
  - Infinitely fast
  - Non volatile
- However, we have Memory Hierarchy:



Background

- Main memory and registers are only storage CPU can access directly
- Memory unit only sees a stream of addresses + read requests, or address + data and write requests
- Register access in one CPU clock (or less)
- Main memory can take many cycles, causing a **stall**
- **Cache** sits between main memory and CPU registers
- Protection of memory required to ensure correct operation

Memory Manager

- The part of the OS that manages the Memory Hierarchy
  - Which part of memory is in use and which is not in use
  - Allocate memory
  - De-allocate memory
  - Swapping between main memory and disks

Memory Management Requirements

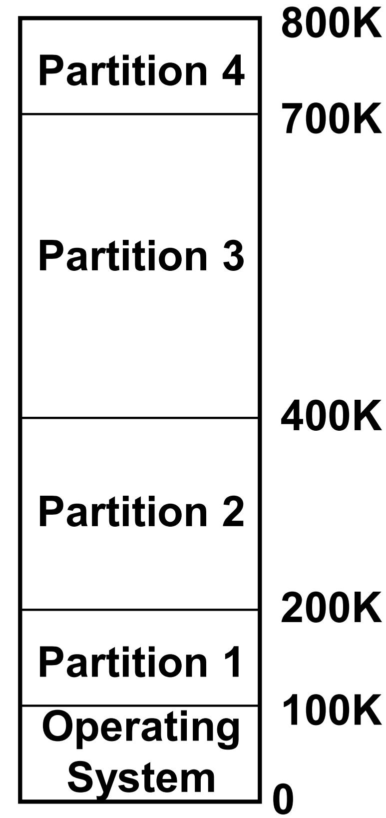
- Speed is not the only issue
  - Relocation
  - Protection
  - Sharing
  - Physical memory organization
  - ….

Requirements: Relocation

- The programmer does not know where the program will be placed in memory when it is executed,
  - it may be swapped to disk and return to main memory at a different location (relocated)
- Memory references must be translated to the actual physical memory address

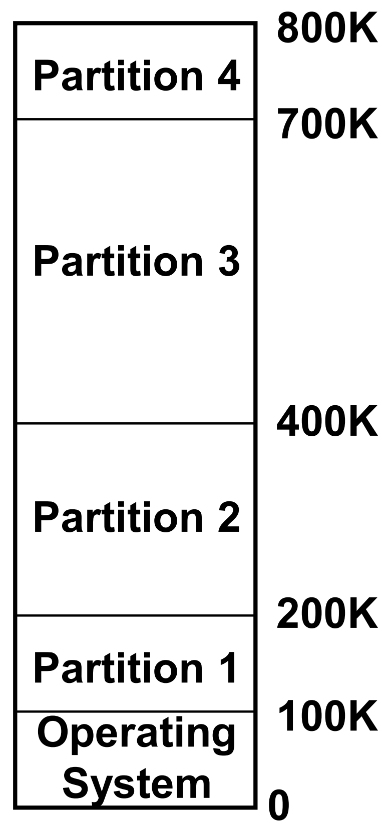
Relocation and Protection

- Different jobs will run at different addresses
- Suppose, the first instruction is
  - call a procedure at absolute address 10 within the binary file



This call will jump inside the Operating system

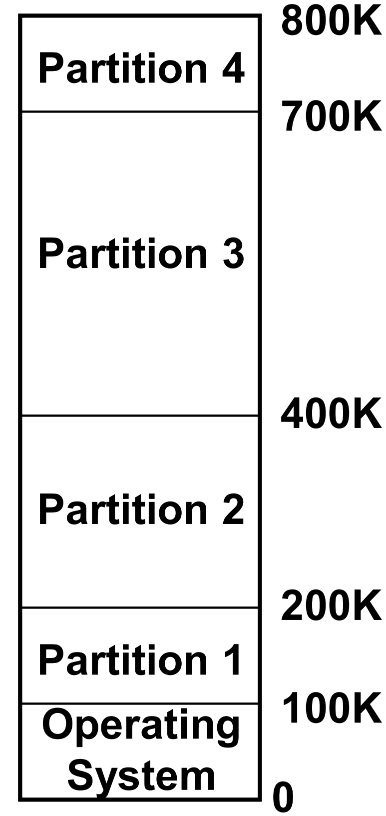
Relocation and Protection



- Solution:
- If the program is loaded in 1st partition, then
  - Call 100k + 10
- If the program is loaded in 2nd partition, then
  - Call 200k + 10
- So on…
- This is called ***Relocation*** problem

Relocation and Protection

- Solution:
  - Add an offset to each address in the program
  - The offset depends on the partition, e.g.,
    - if the Program is loaded in partition 1, add 100k to every address
    - if the Program is loaded in partition 2, add 200k to every address



•A program can still generate an address that jumps in the OS or other user's code

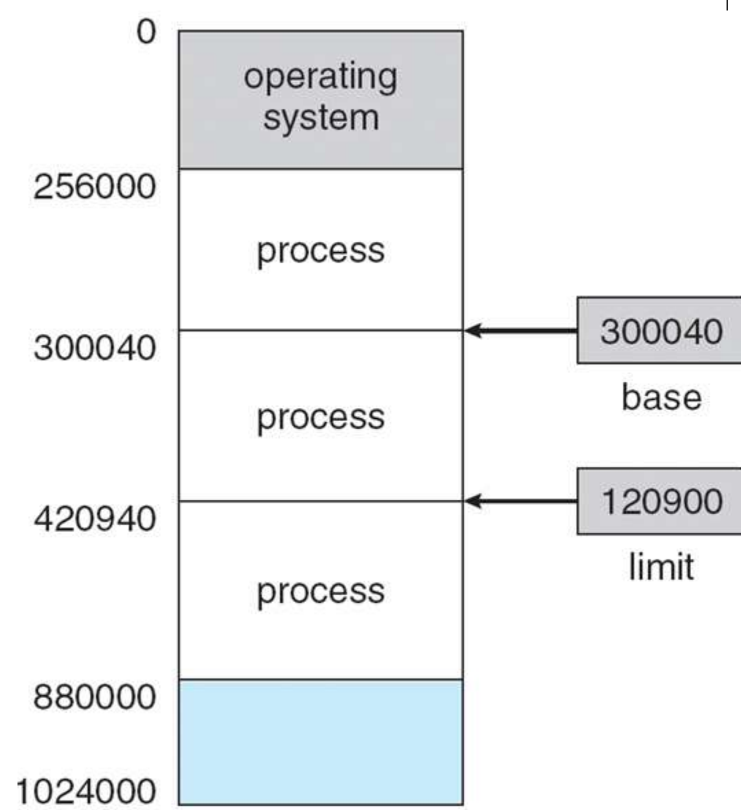
•We need to ***Protect*** the code

Requirements: Protection

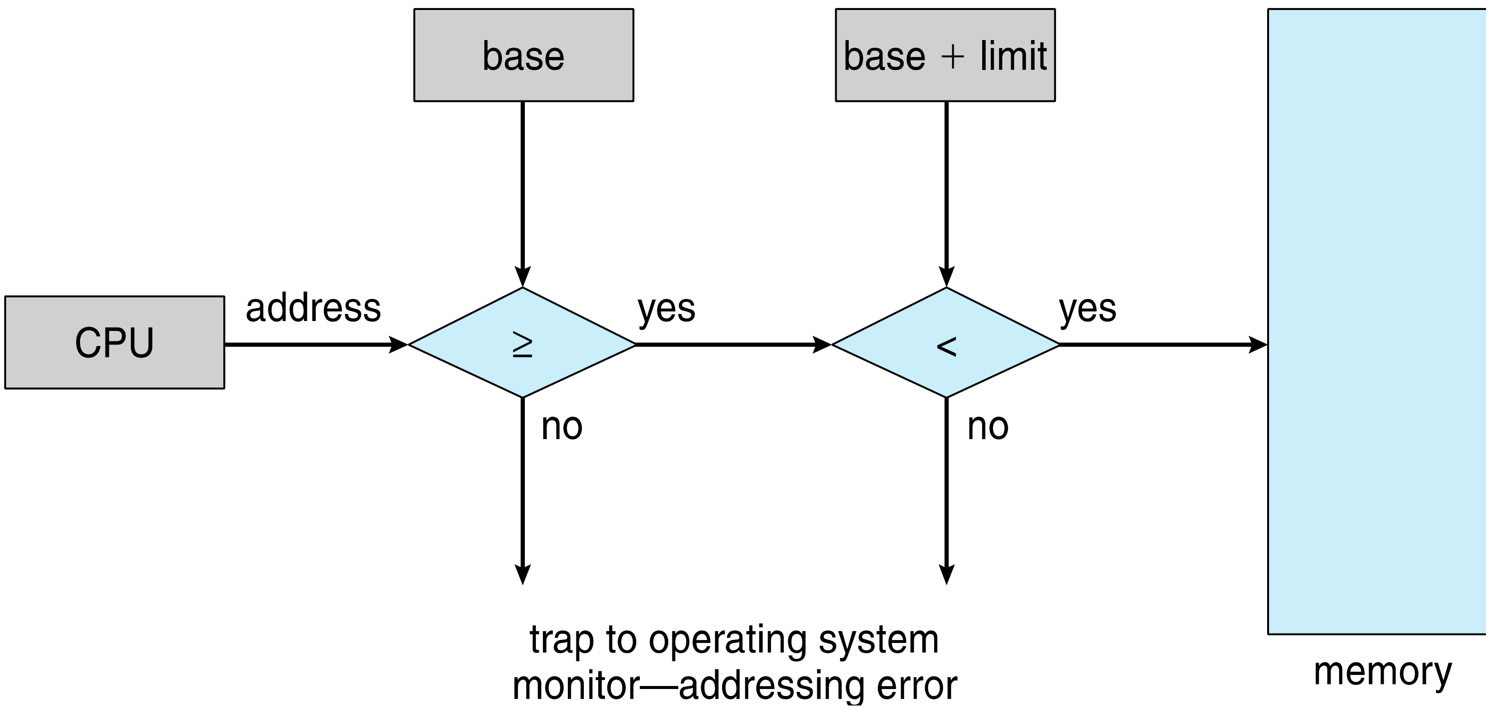
- Processes should not be able to reference memory locations in another process without permission
- Impossible to check absolute addresses at compile time
- Must be checked at run time

Relocation and Protection

- Solution:
  - Base and Limit Registers
- When a process is scheduled
  - Base Register is loaded with the starting address of the Partition
  - Limit Register is loaded with the length of the Partition
- Before referring to memory
  - Add the base register contents to generated memory address
  - Also check against the Limit register for protection

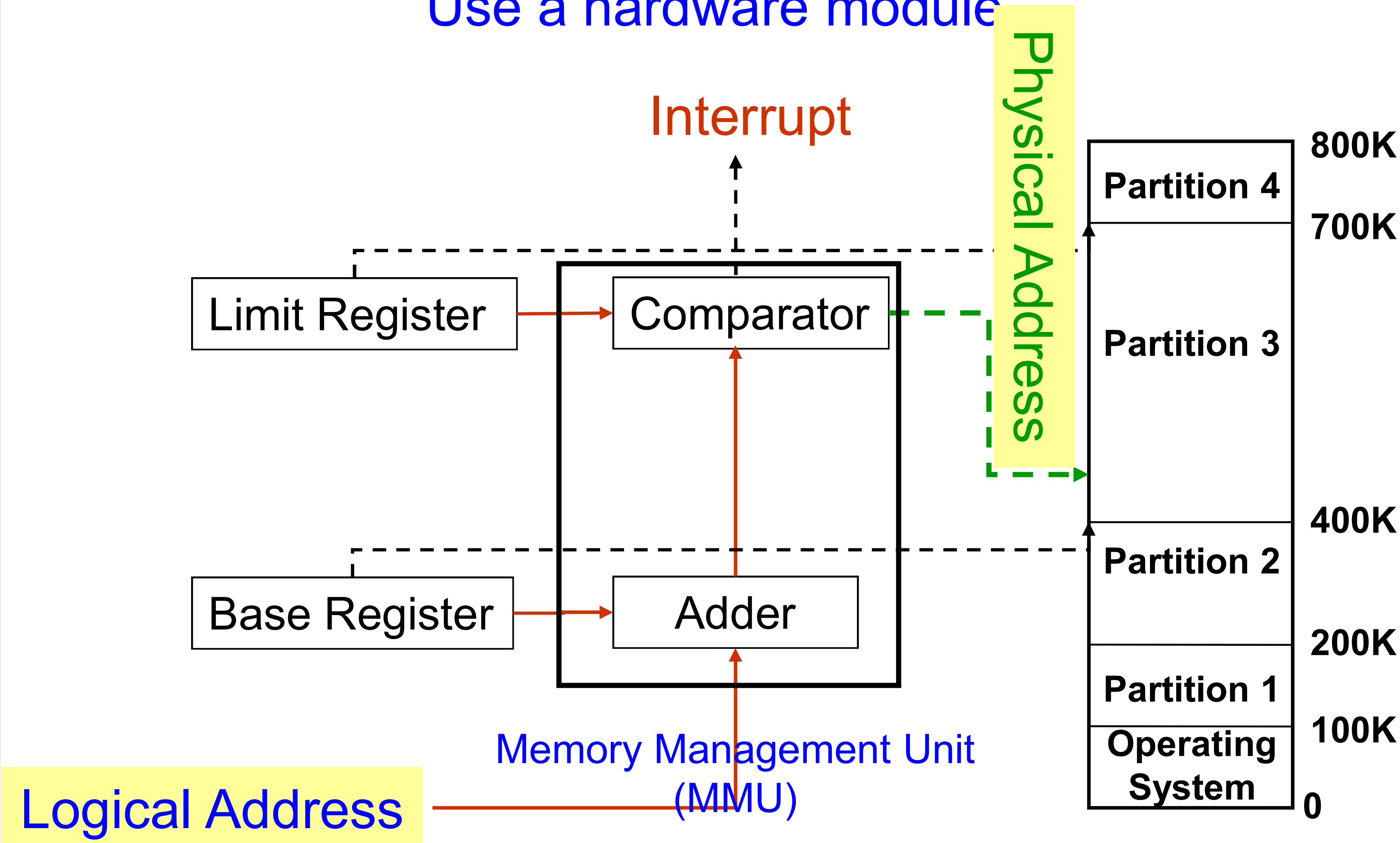


Hardware Address Protection



Relocation and Protection

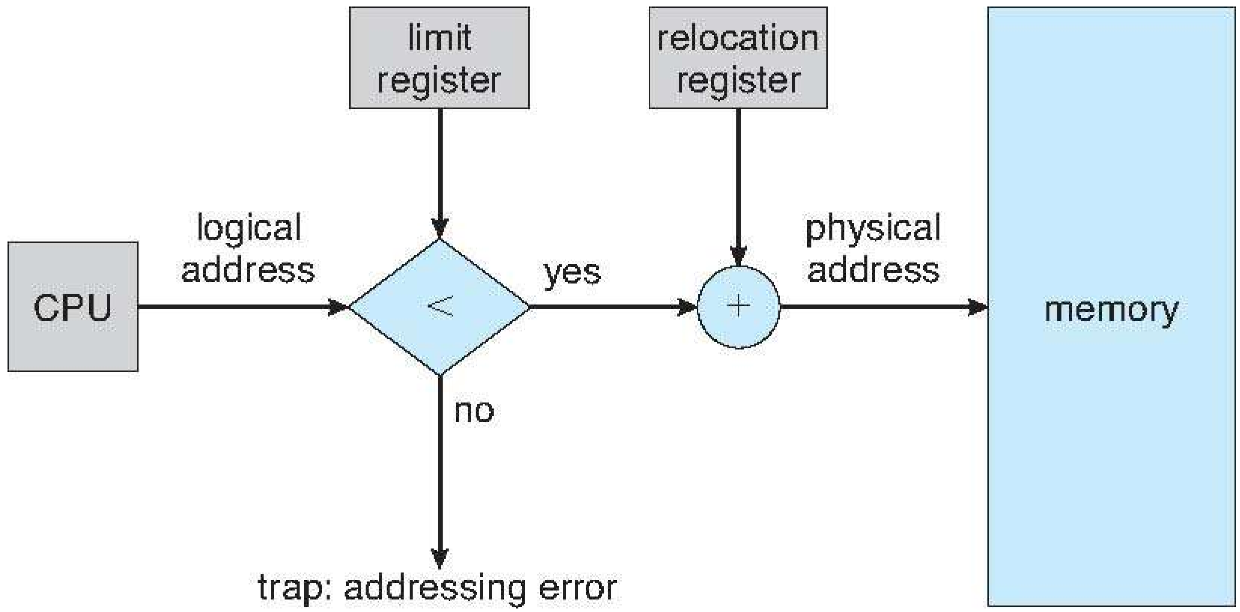
Addition and comparison has to be performed on every address
Use a hardware module



Memory-Management Unit (MMU)

- Hardware device that at run time maps virtual to physical address
- Many methods possible, covered in the rest of this chapter
- To start, consider simple scheme where the value in the relocation register is added to every address generated by a user process at the time it is sent to memory
  - Base register now called **relocation register**
  - MS-DOS on Intel 80x86 used 4 relocation registers
- The user program deals with *logical* addresses; it never sees the *real* physical addresses
  - Execution-time binding occurs when reference is made to location in memory
  - Logical address bound to physical addresses

Hardware Support for Relocation and Limit Registers



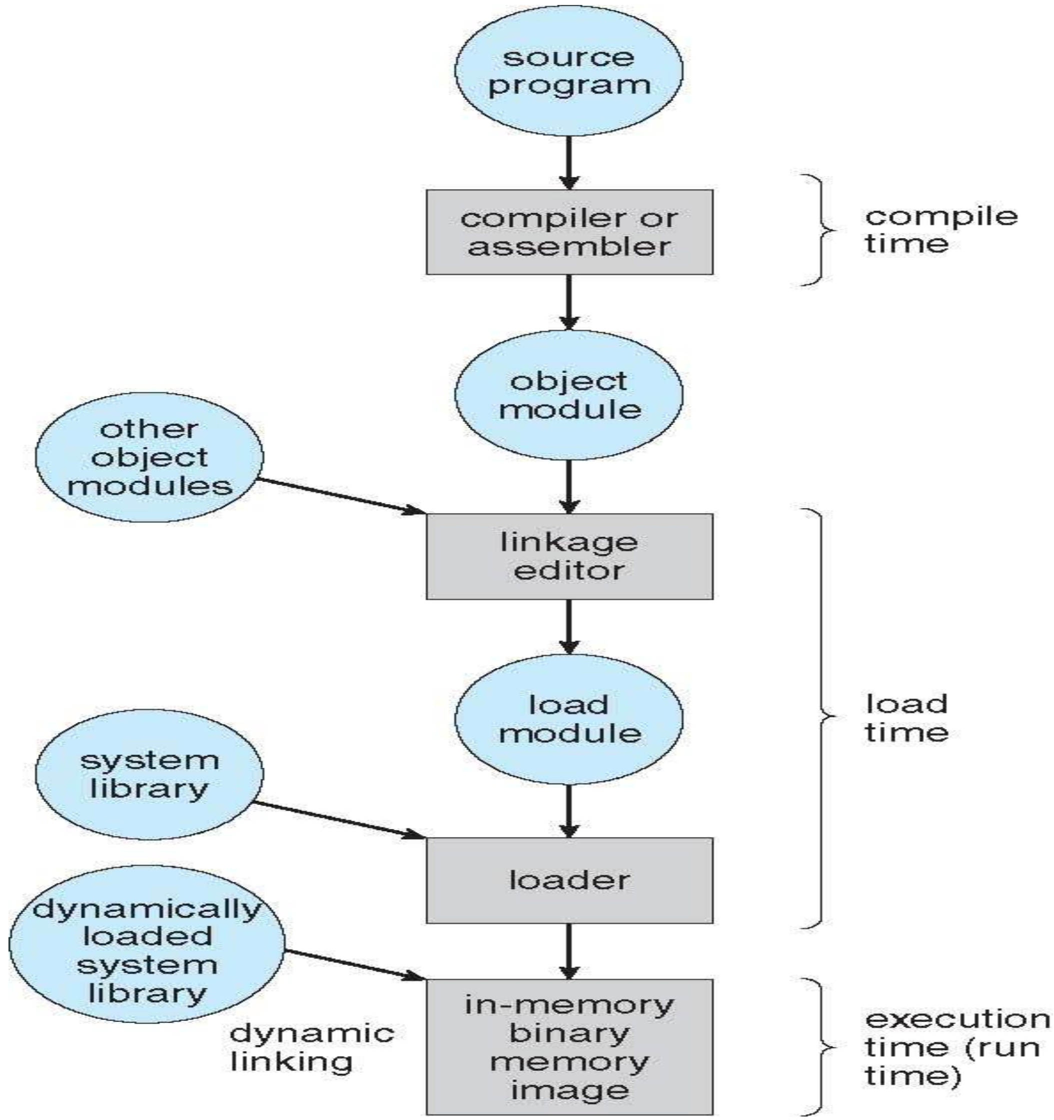
Logical vs. Physical Address Space

- The concept of a logical address space that is bound to a separate **physical address space** is central to proper memory management
  - **Logical address** – generated by the CPU; also referred to as **virtual address**
  - **Physical address** – address seen by the memory unit
- Logical and physical addresses are the same in compile-time and load-time address-binding schemes; logical (virtual) and physical addresses differ in execution-time address-binding scheme
- **Logical address space** is the set of all logical addresses generated by a program
- **Physical address space** is the set of all physical addresses corresponding to these logical addressess

Address Binding

- Programs on disk, ready to be brought into memory to execute form an **input queue**
  - Without support, must be loaded into address 0000
- Inconvenient to have first user process physical address always at 0000
  - How can it not be?
- Further, addresses represented in different ways at different stages of a program's life
  - Source code addresses usually symbolic
  - Compiled code addresses **bind** to relocatable addresses
    - i.e. "14 bytes from beginning of this module"
  - Linker or loader will bind relocatable addresses to absolute addresses
    - i.e. 74014
  - Each binding maps one address space to another

Multistep Processing of a User Program



Dynamic Loading

- Routine is not loaded until it is called
- Better memory-space utilization; unused routine is never loaded
- All routines kept on disk in relocatable load format
- Useful when large amounts of code are needed to handle infrequently occurring cases
- No special support from the operating system is required
  - Implemented through program design
  - OS can help by providing libraries to implement dynamic loading

Dynamic Linking

- **Static linking** – system libraries and program code combined by the loader into the binary program image
- Dynamic linking –linking postponed until execution time
- Small piece of code, **stub**, used to locate the appropriate memory-resident library routine
- Stub replaces itself with the address of the routine, and executes the routine
- Operating system checks if routine is in processes' memory address
  - If not in address space, add to address space
- Dynamic linking is particularly useful for libraries
- System also known as **shared libraries**
- Consider applicability to patching system libraries
  - Versioning may be needed

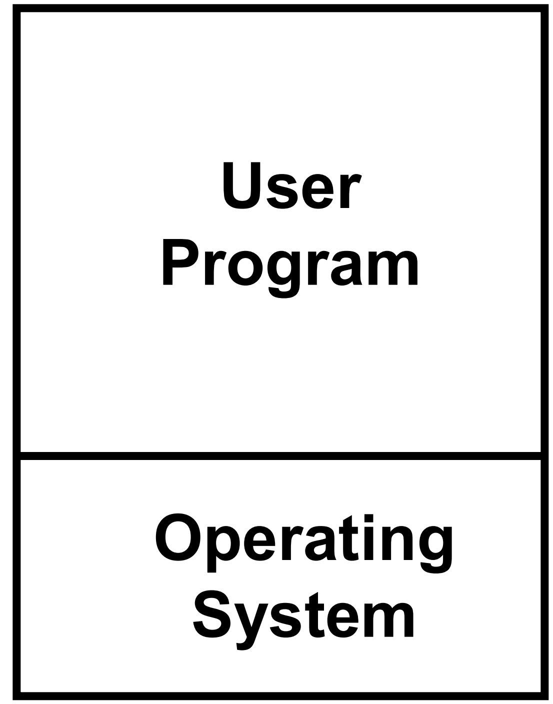
Memory Management/Organization

- In good old days, memory management was trivial as there was only one program
  - No OS, eveything is responsibility of user program

- For the later uniprogramming systems, memory was shared between
  - A User program
  - Operating system

Uni-programming

- Run just one program at a time
- Memory is shared between
  - A User program
  - Operating system



- The user types a command on the prompt
- The OS
  - Copies the program from the disk to memory
  - Executes the program
  - After execution, prompt is available again
- The new program is copied into RAM, overwriting the previous one

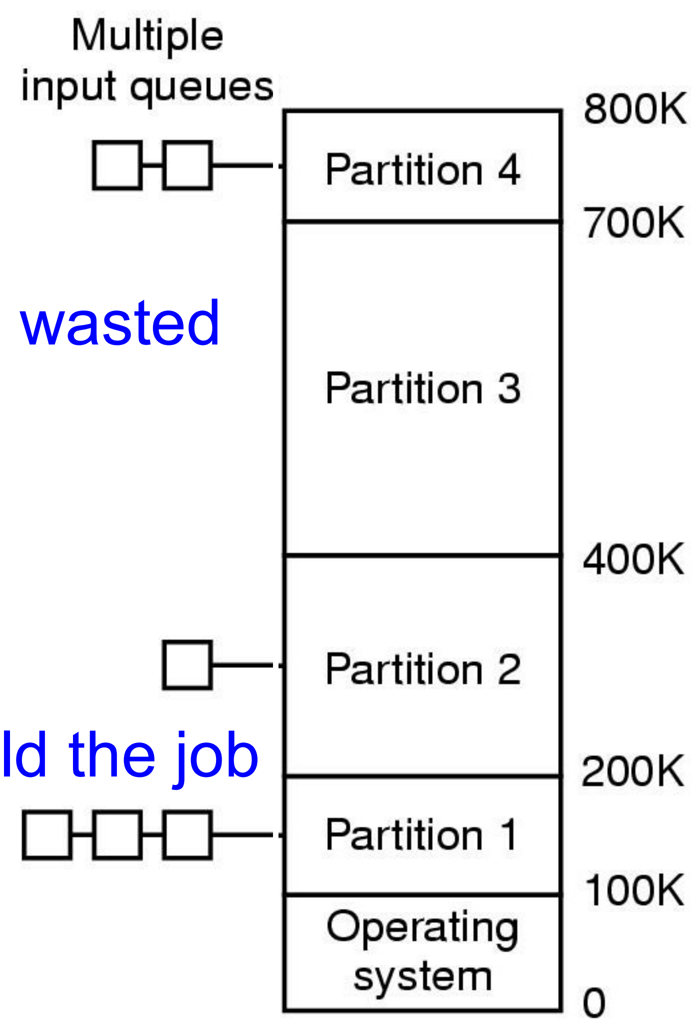
Multi-programming systems

- Keep more than one process in memory
  - Benefits?
- How to organize memory to achieve this?
- One basic approach is to divide memory into n partitions

Memory Allocation Mechanisms

- Contiguous Memory Allocation
  - Fixed or Static Partitioning
  - Variable or Dynamic Partitioning
- Non-Contiguous Memory Allocation
  - Fixed or Static Partitioning (Paging)
  - Variable or Dynamic Partitioning (Segmentations)

Multiprogramming with Fixed Partitions

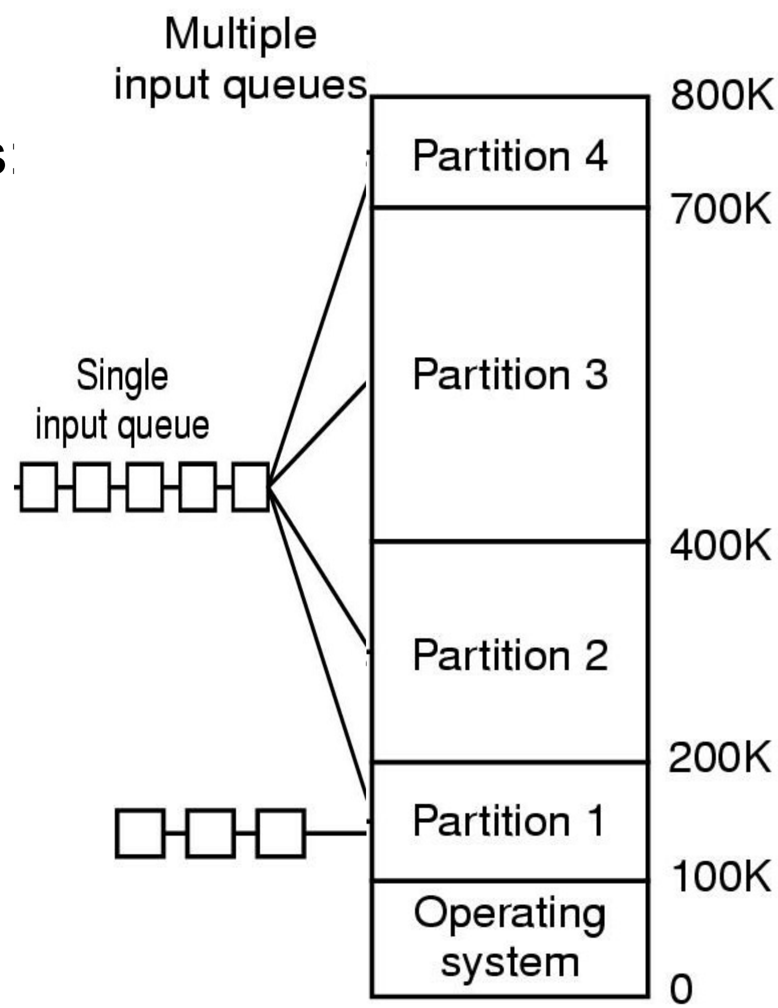


- If the job size < Partition size, memory is wasted
- When a job arrives
  - its put into the input queue of

The *smallest partition* *large enough* to hold the job

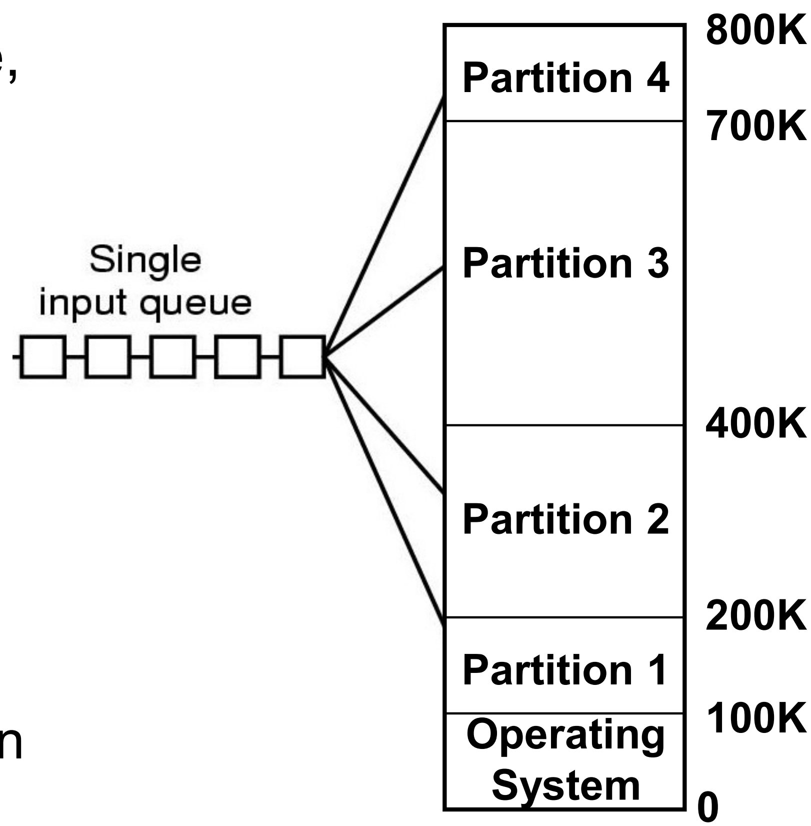
Multiprogramming with Fixed Partitions

- Disadvantage of Multiple Queues:
  - When a large partition is empty
  - And queues for small partition is full
  - Small jobs have to wait, even though plenty of memory is free
- Alternative: Maintain a single Queue



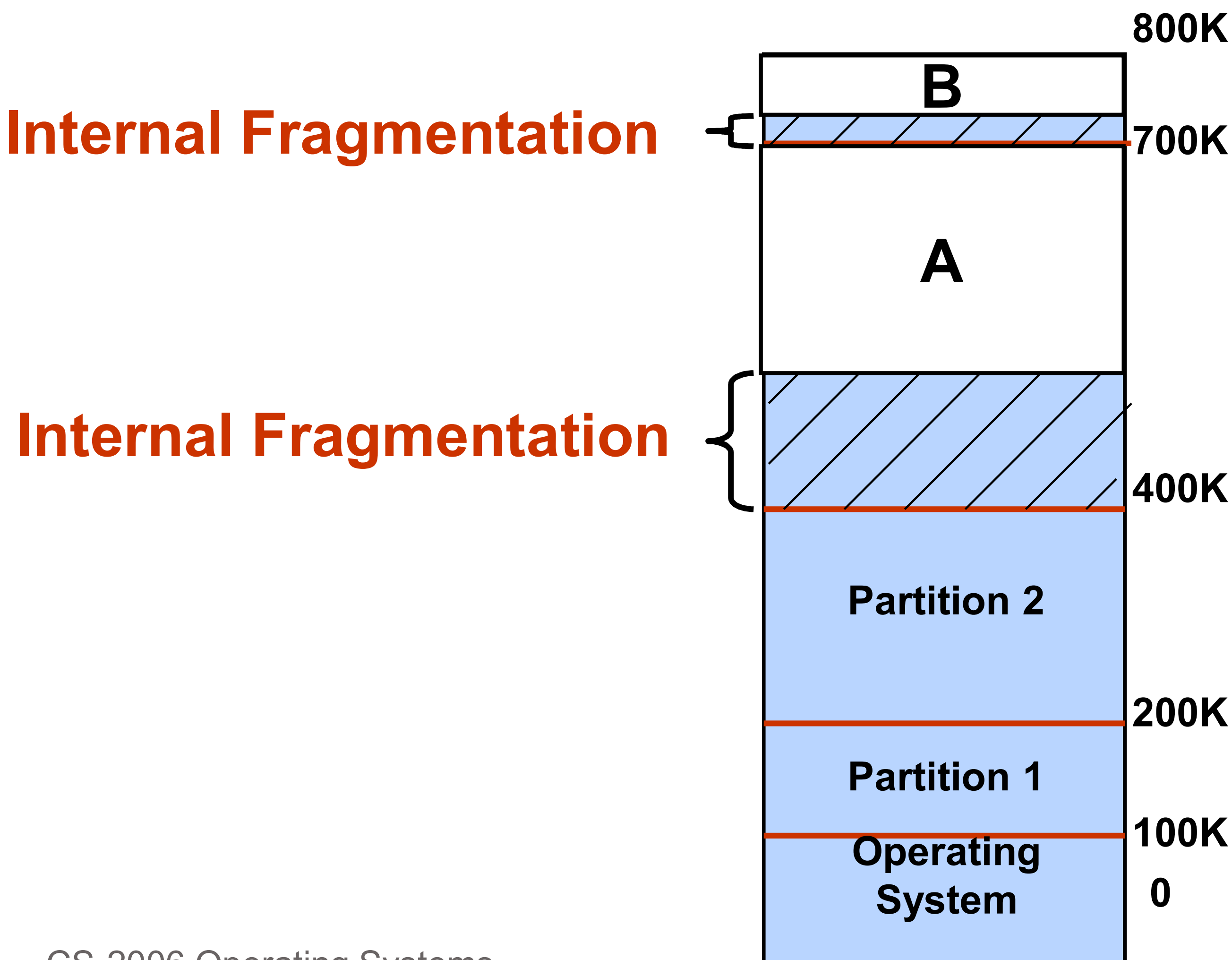
Multiprogramming with Fixed Partitions

- Whenever a partition becomes free, a job is selected
  - Closest to the front of the queue
  - Smaller than the partition size
- Undesirable to waste a large partition for smaller job
  - Search the queue, find the largest job that fits is
- Unfair for smaller jobs
  - A job may not be skipped more than ***k*** times



Internal Fragmentation

Memory that is internal to a partition but not being used



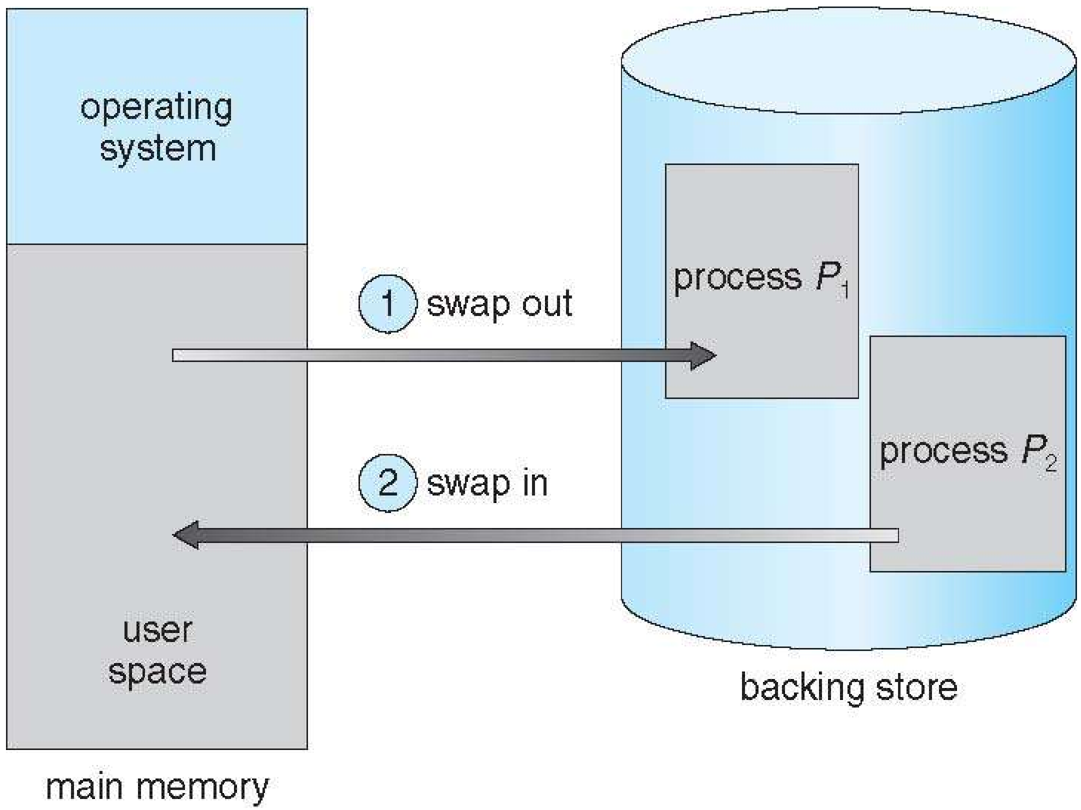
Swapping

- If ***not enough space*** in memory for all the currently active processes
- Excess processes must be kept on disk
  - Fully ➔ Swapping
  - Partially ➔ Virtual Memory
- Example of Swapping
  - Round Robin Scheduling
- When the quantum expires
  - Swap out the currently running process
  - Swap in another process to freed memory space

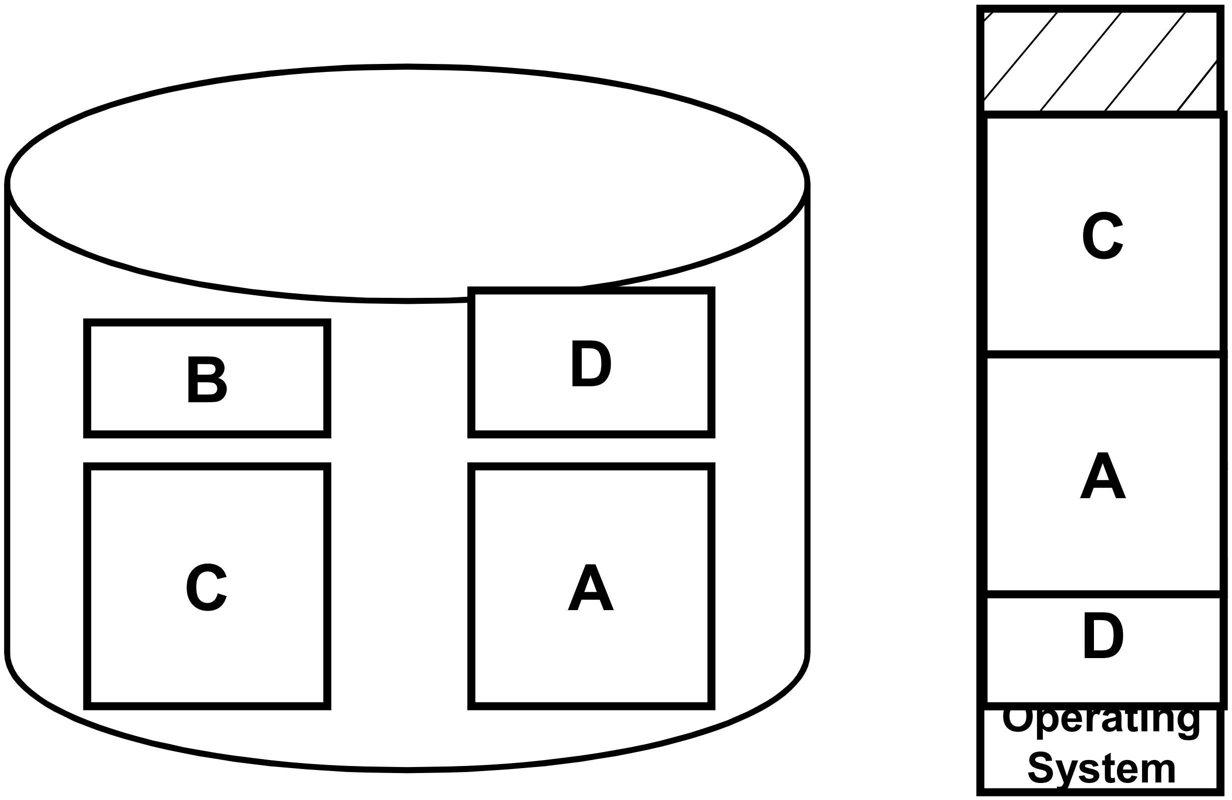
Swapping

- Another Example:
  - Priority based scheduling
- If a higher priority process arrives
  - Swap out a lower priority process
  - Swap in the higher priority process
- When the higher priority process exits
  - Swap in the lower priority process

Schematic View of Swapping



Swapping



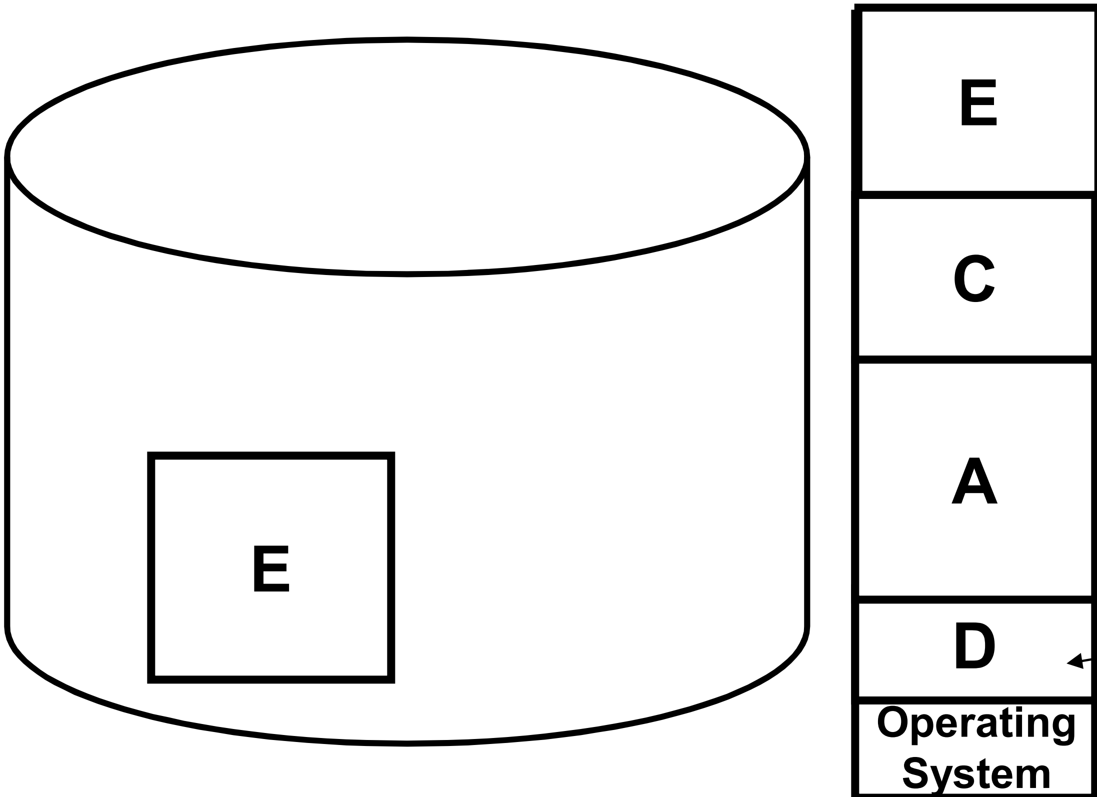
The number, size and location of the partition is decided dynamically.

D is of Higher Priority, A is of Lower Priority!!!
B exits now, Swap in A

Swapping

Its possible to combine all the holes into one big hole

This is called COMPACTION



EXTERNAL FRAGMENTATION

Memory External to all partitions is Fragmented

Enough total memory exists to satisfy the request

But is *not Contiguous*

Swapping has created Holes

D exits now

No Space for E !!!

Now E has enough space

Compaction

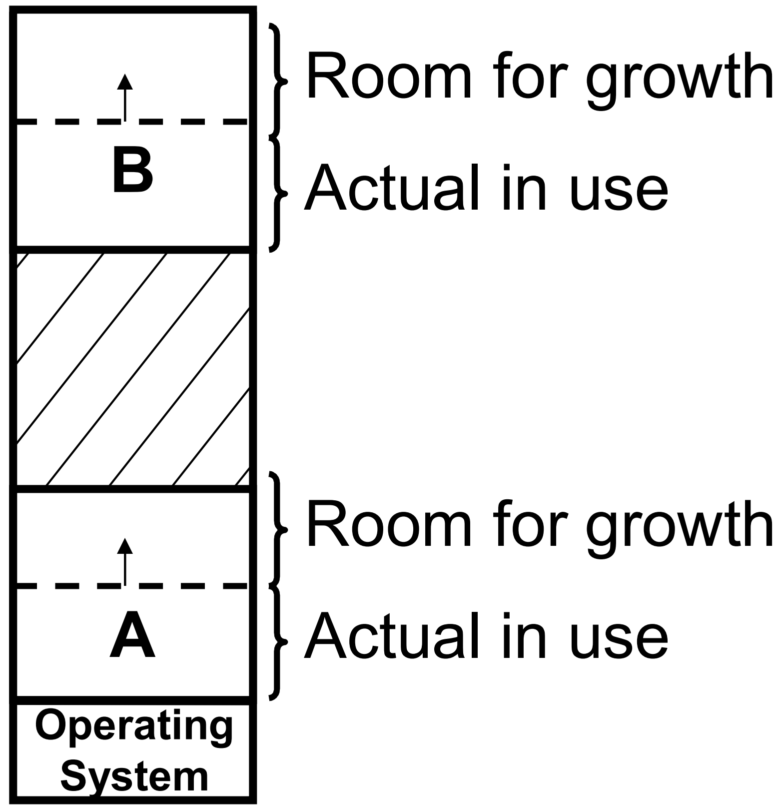
- Compaction involves CPU overhead
- If addresses are not generated relative to the partition location:
  - Then Compaction is not possible
- How much memory should be allocated for a process?
  - If all the memory is allocated statically in a program
  - Then, OS knows exactly the amount of memory to be allocated: **`executable code + variables`**
- However, if memory is allocated dynamically (say using **`new`**)

Memory allocation for Processes

- Problem may occur whenever a process tries to grow
- If a hole is adjacent to the growing process then it can be allowed to grow
- If another process is adjacent to the growing process, then
  - The growing process should be moved to a larger hole
  - If a larger hole is not available, then, one or more processes should be swapped out
  - If a process cannot be swapped out (say, there is not enough space on disk
    - The growing process has to wait
    - Or should be killed!!!

Memory allocation for Processes

- If most of the processes grow as they run,
- It is better to allocate a little extra memory for a process



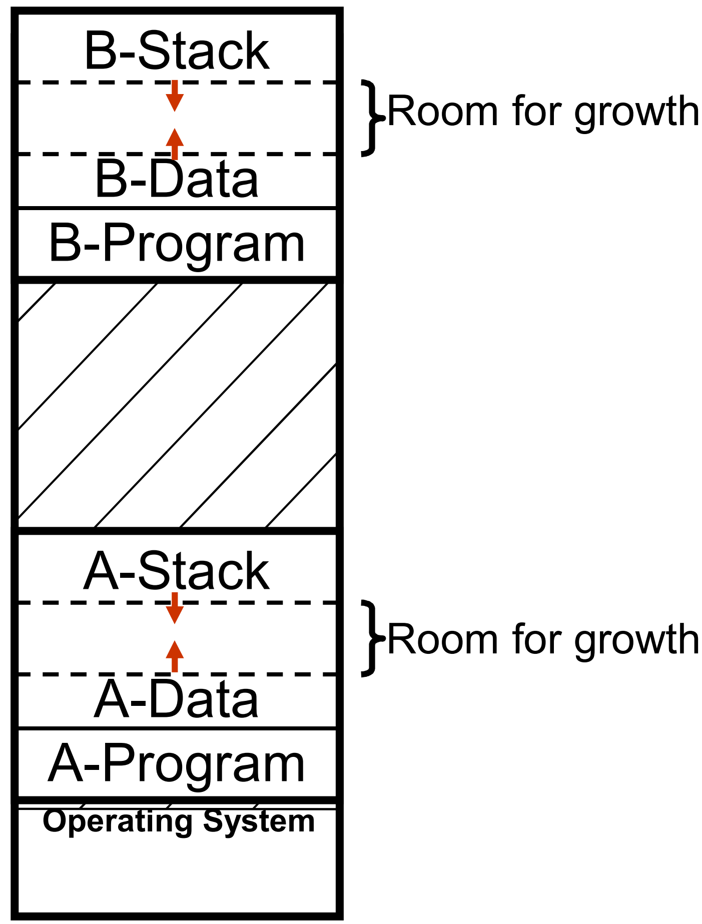
Memory allocation for Processes

- If processes have two growing segments
  - Data
    - (as heap for dynamically allocated variables)
  - Stack

•The memory can be used by either of the two segments

•If it runs out the process either

- Has to be moved to a larger hole
- Or swapped out
- Or Killed

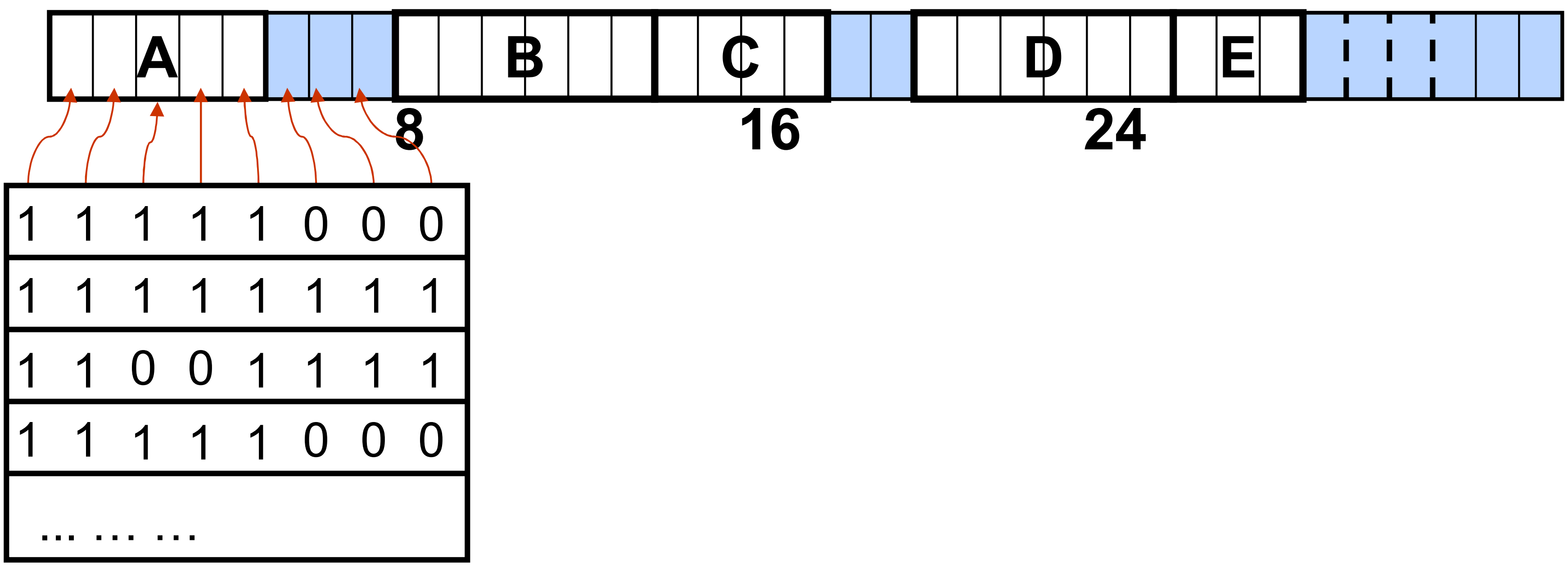


How to keep track of Memory

- We need to keep track of
  - Allocated memory
  - Free memory
- Memory management with bitmaps
- Memory management with linked lists

Memory management with bitmaps

- Memory is divided up into allocation units
  - Few words
  - Or several kilobytes



Memory management with bitmaps

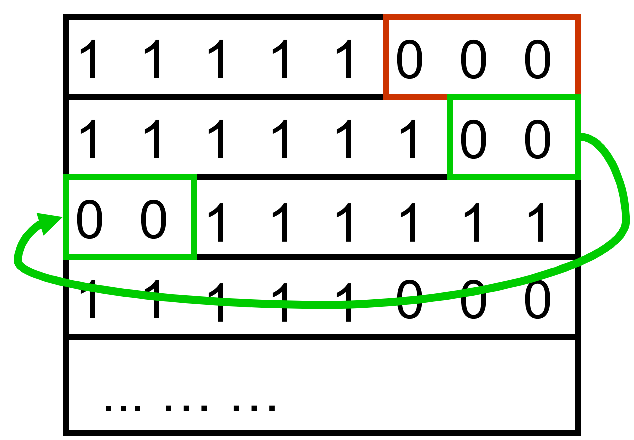
- Size of allocation unit is important
- Smaller allocation unit
  - Larger bitmap required
- Larger allocation unit
  - Smaller bitmap required
  - More memory will be wasted
    - If the process size is not an exact multiple of the allocation unit

Memory management with bitmaps

- To bring a k unit process in memory
- Search for a k run consecutive 0 bits in the map
- Search can be slow
- Since, k run may cross word boundaries

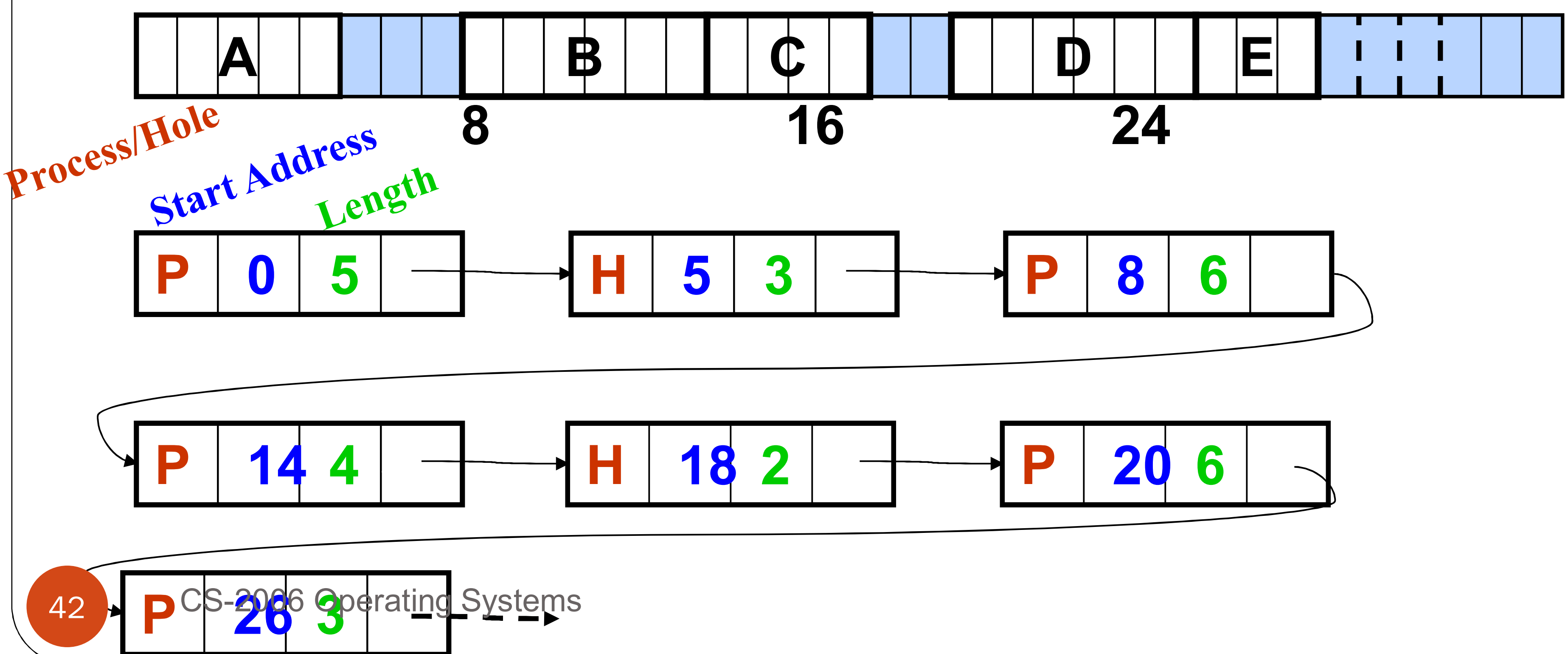
Find run of length = 3

Find run of length = 4



Memory management with Linked Lists

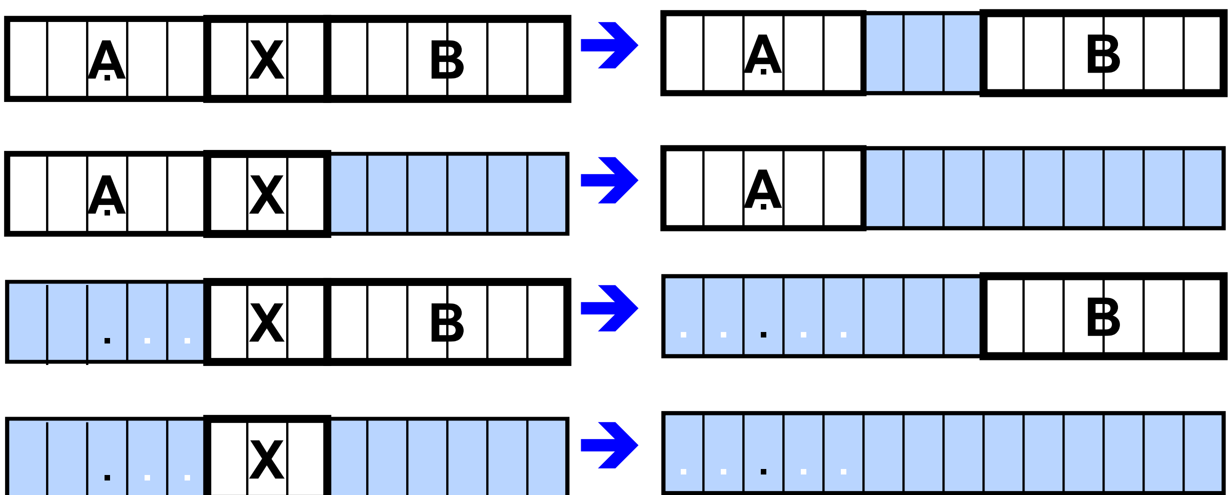
- Linked list of memory segments
  - Free segments ➔ Holes
  - Allocated segments ➔ Processes



Memory management with Linked Lists

- Segment list is sorted by addresses
- Sorting helps in updating the list, when a process is swapped out or exits
- A process usually has two neighbors

Updating the list requires



Replace P by H

Two entries are merged

Two entries are merged

Three entries are merged

Memory Allocation with Linked Lists

- Several algorithms for allocating memory with linked list
- **FIRST FIT:**
  - Scan the segment list, until
  - A hole large enough is found
  - Split the hole into two pieces (if not exact match)
  - One for the new process
  - One for the unused memory
- The algorithm is fast since it searches as little as possible

Memory Allocation with Linked Lists

- **NEXT FIT**
  - Works the same as First Fit, except,
  - Does not always start searching from the beginning
  - Rather starts searching the list, from where it left last time
- Simulations show, that gives no better performance than First Fit

Memory Allocation with Linked Lists

- **BEST FIT**
  - Search the entire list
  - Take the smallest hole that is adequate
- Best Fit tries to find the hole closest to the size of Process
- Slower than First Fit
  - Every time has to search the entire list
- But still results in more memory wastage
  - Tends to fill up memory, with tiny useless holes
  - First Fit generates larger holes on the average

Memory Allocation with Linked Lists

- **WORST FIT**
  - Take the largest hole available
  - So that, the hole broken off will be large enough to be useful
  - What if the larger holes left by worst fit are not useful
  - ➔ more memory wasted than Best Fit

References

- Chapter 3, Modern Operating System
- http://cseweb.ucsd.edu/classes/sp00/cse120_A/mem.html
- Operating System Concepts (Silberschatz, 9th edition) Chapter 8