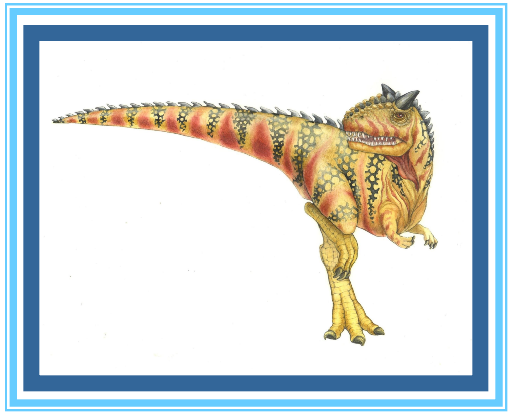
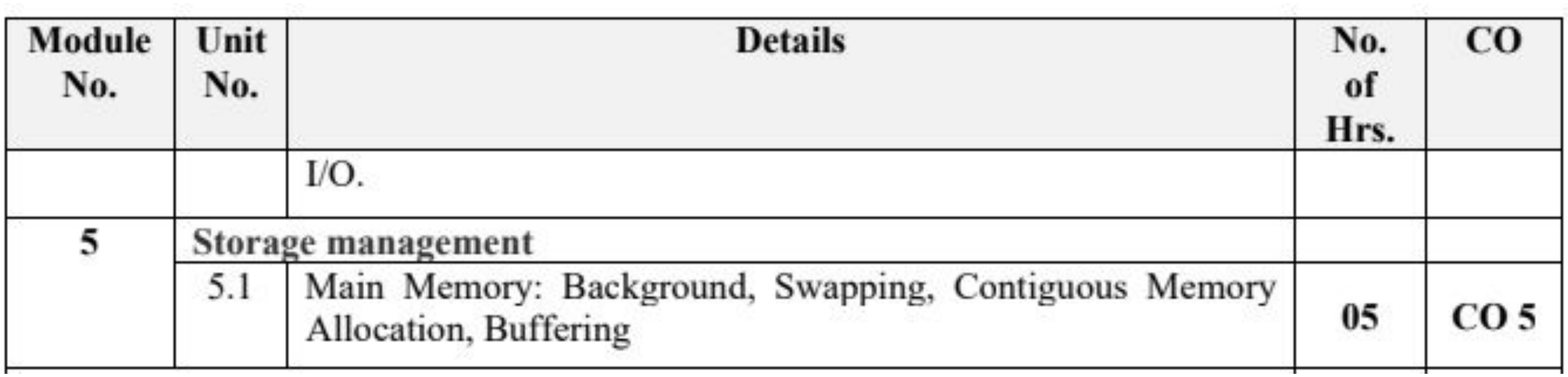
Storage Management
Module 5.1





Module No.	Unit No.	Details	No. of Hrs.	CO
		I/O.		
5	Storage management			
	5.1	Main Memory: Background, Swapping, Contiguous Memory Allocation, Buffering	05	CO 5

How do you differentiate?

- Memory
- Main memory
- Physical Memory
- RAM
- Primary memory

Basics

- Memory is central to operation of computing systems
- Memory = a large array of words/bytes
- Each byte or word has own address
- Memory contains the program to be executed and data, both
- Program is executed line by line with Instruction Fetch, Instruction Decode, Operand Fetch, Execute cycles
- Program counter contains address of memory location to be executed next

Background

- Memory consists of a large array of words or bytes, each with its own address.
- The CPU fetches instructions from memory according to the value of the program counter. These instructions may cause additional loading from and storing to specific memory addresses.

Background

- A typical instruction-execution cycle, for example,

1) first fetches an instruction from memory.
2) The instruction is then decoded and may cause operands to be fetched from memory.
3) After the instruction has been executed on the operands, results may be stored back in memory.

Memory unit only sees a stream of addresses + read requests, or address + data and write requests

Memory : hardware

- CPU can directly access only main memory and processor registers
- The instructions take main memory addresses as program arguments and not disk addresses
- **Hence- Data and instructions executing them, have to be in MM**
- **Issues and concerns?**
  - **Speed of access : solution cache memory**
  - **Protect program data : solution base and limit registers**
  - **Size of memory : solution swapping, virtual memory**
  - **Many more ones….**

Basic Hardware

- Register access in one CPU clock (or less)
- Main memory access can take many cycles, causing a **stall**
- **Cache** sits between main memory and CPU registers
- Protection of memory required to ensure correct operation

Basic Hardware

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- Registers that are built into the CPU are generally accessible within one cycle of the CPU clock.

Basic Hardware

- Register access in one CPU clock (or less)
- **Main memory access can take many cycles, causing a stall**
- **Cache** sits between main memory and CPU registers
- Protection of memory required to ensure correct operation

- Main memory is accessed via a transaction on the memory bus.
- Completing a memory access may take many cycles of the CPU clock.
- In such cases, the processor normally needs to stall, since it does not have the data required to complete the instruction that it is executing

Speed of access

- One of the Speed judgement parameters: number of CPU clock cycles needed to perform memory operation
- CPU is a faster than memory
- CPU registers are accessible in one CPU clock cycle
- But MM is accessed via a transaction on memory bus
- This access takes many CPU clocks to complete
- Result? : CPU has program but not the data to complete instruction execution i.e. **CPU stalling**

Basic Hardware

- Register access in one CPU clock (or less)
- Main memory access can take many cycles, causing a stall
- Cache **sits between main memory and CPU registers**
- Protection of memory required to ensure correct operation

- The remedy is to add fast memory between the CPU and main memory called cache.

Speed of access

- As the data are needed always for instruction execution, frequent memory stalls are bottleneck
- Solution : add a faster memory between CPU and main memory i.e. **cache memory**
- Cache memory: a buffer to accommodate the speed difference

Basic Hardware

- Register access in one CPU clock (or less)
- Main memory access can take many cycles, causing a stall
- Cache **sits between main memory and CPU registers**
- Protection of memory required to ensure correct operation

- Apart from relative speed of accessing physical memory, we also must ensure correct operation.
- To protect the operating system from access by user processes
- To protect user processes from one another. This protection must be provided by the hardware.

Access Protect

- OS must be protected from unauthorized access by user process
- **User processes must be protected from each other**
- **Each process has range of legal addresses to access**
- Base register and limit register ensure process can access only addresses within the legal range

Image courtesy: Galvin

Basic Hardware

- We first need to make sure that each process has a separate memory space.
- **Determine the range of legal addresses that the process may access**
- **To ensure that the process can access only these legal addresses.**
- **We can provide this protection by using two registers, usually a base and a limit.**

Base and Limit Registers

- Base Register-Holds the smallest legal physical memory address
- Limit Register- specifies the size of the range.

Base and Limit Registers

- For example,
- if the base register holds 300040
- and the limit register is 120900,
- then the program can legally access all addresses from 30 0040 through 420939 (inclusive).

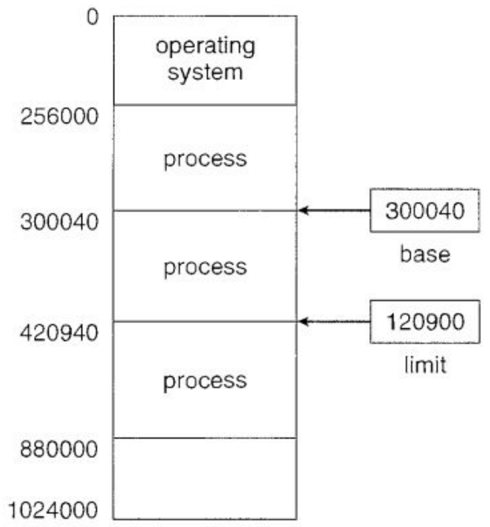


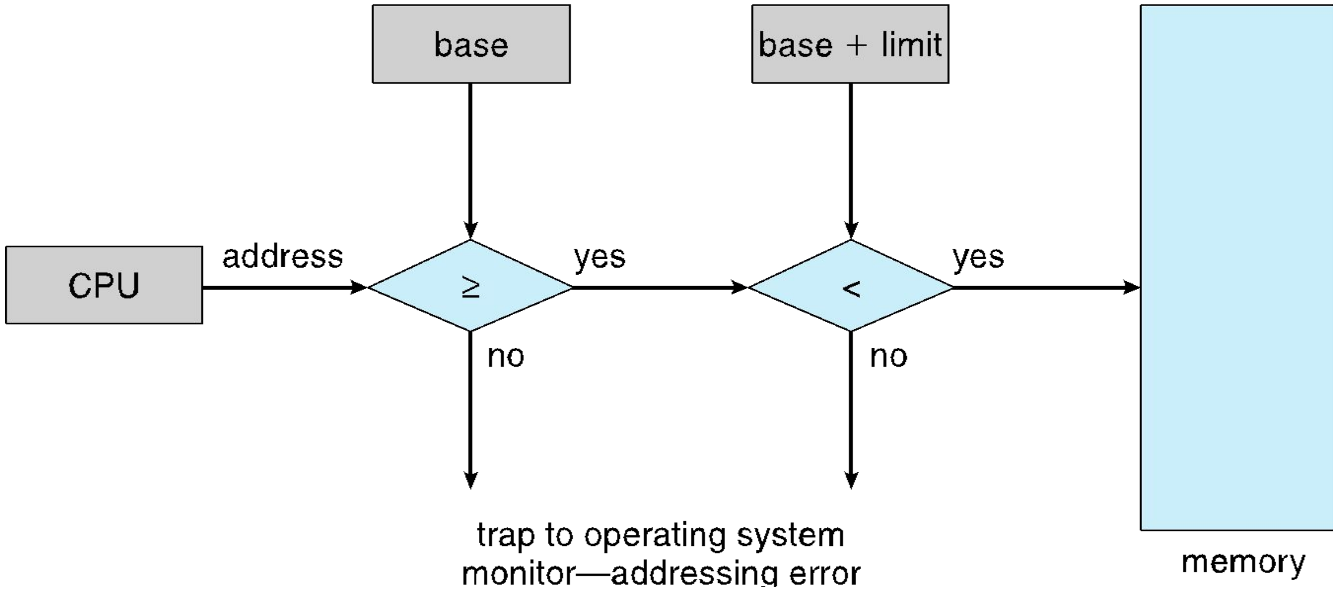
Figure 8.1 A base and a limit register define a logical address space.

Base and Limit Registers

- Protection of memory space is accomplished by having the CPU hardware compare *every* address generated in user mode with the registers.
- Any attempt by a program executing in user mode to access operating-system memory or other users' memory
- **Results in a trap to the operating system, which treats the attempt as a fatal error**
- **This scheme prevents a user program from (accidentally or deliberately) modifying the code or data structures of either the operating system or other users.**

Base and Limit Registers

- CPU must check every memory access generated in user mode to be sure it is between base and limit for that user



Hardware Address Protection

- **The base and limit registers can be loaded only by the operating system**, which uses a special privileged instruction.
- Since privileged instructions can be executed only in kernel mode,
- since only the operating system executes in kernel mode,
- only the operating system can load the base and limit registers.
- **This scheme allows the operating system to change the value of the registers but prevents user programs from changing the registers' contents.**

Hardware Address Protection

- The operating system, executing in kernel mode, is given unrestricted access to both operating system memory and users' memory.
- This provision allows the operating system
    - to load users' programs into users' memory,
    - to dump out those programs in case of errors

Address Binding

- Usually, a program resides on a disk as a binary executable file.
- To be executed, the program must be brought into memory and placed within a process.
- Programs on disk, ready to be brought into memory to execute form an **input queue**
- **The normal procedure is to select one of the processes in the input queue and to load that process into memory.**
- As the process is executed, it accesses instructions and data from memory.
- Eventually, the process terminates, and its memory space is declared available.

Address binding

- User processes reside in any part of main memory
- Computer address space starts at 00000
- But user process need not be loaded at 00000
- The program is processed by various system softwares before being executed such as macro processor, compiler, linker, loader etc..
- User program addresses may be represented in various ways during these executions

Address binding.. contd

- Addresses in source program are symbolic
- Compiler binds symbolic addresses to relocatable addresses
  - E,g. 14 bytes from beginning of this module
- The linker or loaders turn relocatable addresses to absolute addresses
- Each such binding is mapping from one address space to another

Address Binding

- Further, addresses represented in different ways at different stages of a program's life
  - Source code addresses are usually symbolic (Eg-count)
  - A compiler will typically bind these symbolic addresses 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 from one address space to another

Binding of Instructions and Data to Memory

- The binding of instructions and data to memory addresses i.e.
- Address binding of instructions and data to memory addresses can happen at three different stages
  - **Compile time**
  - **Load time**
  - **Execution time**

Binding instructions & data to memory

- Can be done at any step during execution based on available info
- If known at Compile time:
    - generates **absolute code** that resides at given memory.
    - Re-compile if the starting location changes
- If known at Load time but not at compile time:
    - Generates relocatable code
    - Final binding is delayed until load time
    - If starting address changes, only reload the user code to incorporate the changed value
- If known at Execution time
    - If process can be moved from one memory segment to another during execution
    - Binding is delayed until run time
    - Needs special hardware

Binding of Instructions and Data to Memory

- **Compile time**:
  - **If you know at compile time where the process will reside in memory, then absolute code can be generated.**
  - **If memory location known a priori,**
  - For example, if you know that a user process will reside starting at location *R,* then the generated compiler code will start at that location and extend up from there.
- Must recompile code if starting location changes-
  - **If, at some later time, the starting location changes, then it will be necessary to recompile this code.**

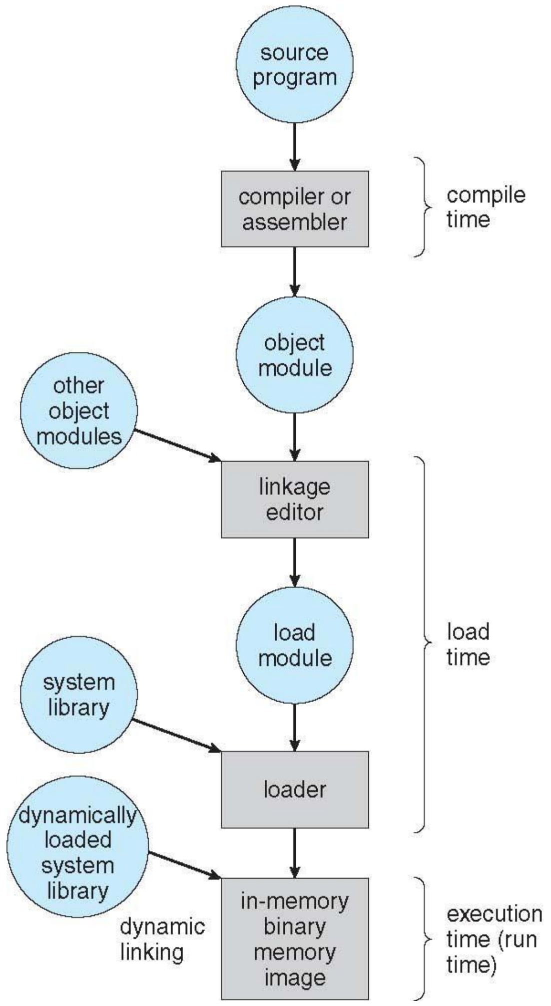
Binding of Instructions and Data to Memory

- **Load time**:
- Must generate **relocatable code** if memory location is not known at compile time
- **If it is not known at compile time where the process will reside in memory, then the compiler must generate relocatable code**
- **In this case, final binding is delayed until load time.**
- If the starting address changes, we need **only reload the user code to incorporate this changed value.**

Binding of Instructions and Data to Memory

- **Execution time**:
- If the process can be moved during its execution from one memory segment to another, then binding must be delayed until run time.
- Need hardware support for address maps (e.g., base and limit registers)

Multistep Processing of a User Program



Logical Vs physical address space

- Logical address: An address generated by CPU
- Physical address : an address loaded into memory address register of memory
- The compile time and load time address-binding methods generate identical logical and physical address
- But, execution time binding results in different logical and physical address space
  - Logical address space: set of all addresses generated by a program
  - Physical address space: set of all physical addresses corresponding to all logical addresses

Logical vs. Physical Address Space

- **Logical address** –
  - An address generated by the CPU
  - also referred to as **virtual address**
- **Physical address** –
  - Address seen by the memory unit
  - that is, the one loaded into memory address register of the memory
- **Logical address space-** the set of all logical addresses generated by a program
- **Physical address space-** the set of all physical addresses corresponding to these logical addresses

Logical vs. Physical Address Space

- 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

Memory-Management Unit (MMU)

- The run-time mapping from virtual to physical addresses is done by a hardware device called the MMU
- Many methods possible for this mapping

MMU

- MMU (memory management unit) maps virtual addresses to physical addresses
- Simple MMU scheme: generalization of base-register scheme
- Base register is called relocation register
- While sending to memory, relocation register value is added to every address generated by user process

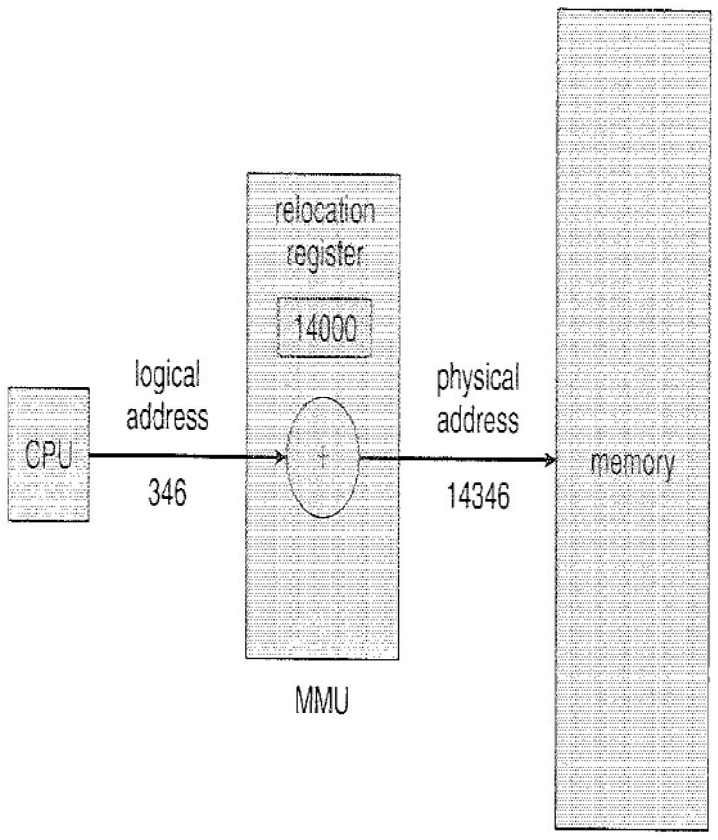
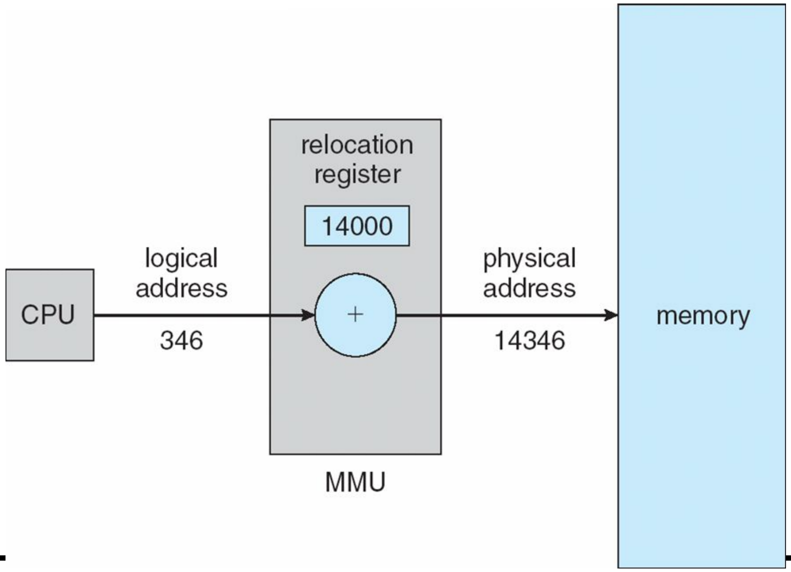


Figure 8.4 Dynamic relocation using a relocation register.

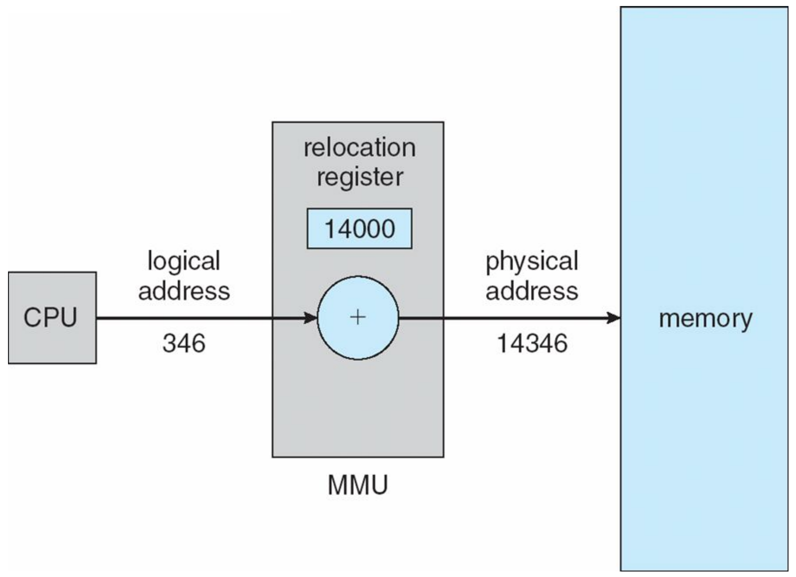
Memory-Management Unit (MMU)

- To start, consider simple scheme –
- Base register now called **relocation register**
- The value in the relocation register is added to every address generated by a user process at the time it is sent to memory



Memory-Management Unit (MMU)

- For example,
- if the reloacation is at 14000,
- then an attempt by the user to address location 0 is dynamically relocated to location 14000;
- an access to location 346 is mapped to location 14346.



- The user program never sees the ‘real’ physical address.
- User program deals with logical addresses
- The memory mapping hardware converts logical addresses to physical addresses
- Logical addresses: Range is 0 to max
- Physical addresses: R+0 to R+max where R is base value

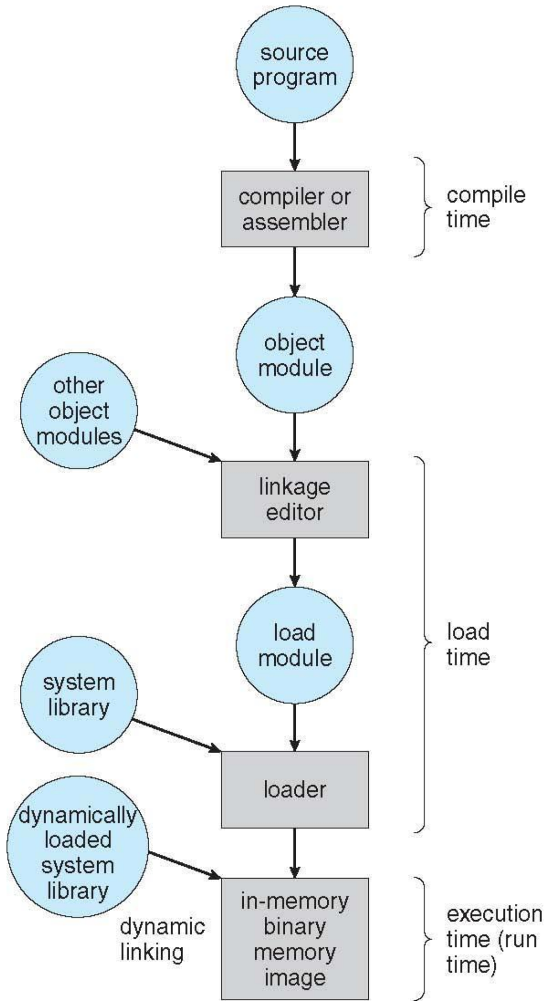
Dynamic Loading

- So far:-
- The entire program and all data of a process to be in physical memory for the process to execute.
- **The size of a process has thus been limited to the size of physical memory.**

Dynamic Loading

- To obtain better memory-space utilization,
- we can use Dynamic Loading

Multistep Processing of a User Program



Dynamic Loading

- Routine is not loaded until it is called
- All routines kept on disk in relocatable load format

1) The main program is loaded into memory and is executed.
2) When a routine needs to call another routine, the calling routine first checks to see whether the other routine has been loaded.
3) If it has not, the relocatable linking loader is called to load the desired routine into memory and to update the program's address tables to reflect this change.
4) Then control is passed to the newly loaded routine.

Dynamic Loading

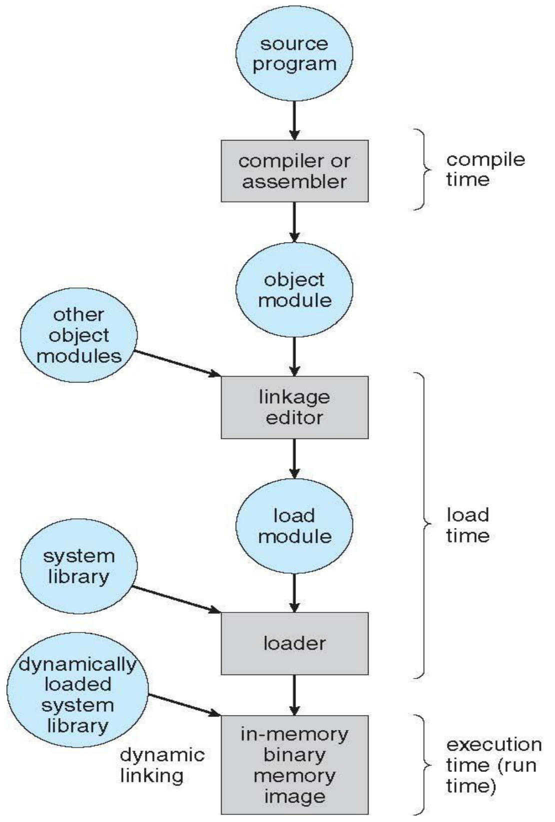
Advantage –

- Unused routine is never loaded.
- Useful when large amounts of code are needed to handle infrequently occurring cases. Eg- Error Routines
- No special support from the operating system is required

- Implemented through program design-
  - It is the responsibility of the users to design their programs to take advantage of such a method.
- Operating systems may help the programmer,
  - by providing library routines to implement dynamic loading.

Dynamic Linking

- **Static linking** –
- System libraries and program code combined by the linker/loader into the binary program image
- Dynamic linking –linking postponed until execution time



Dynamic Linking

- Dynamic linking –
- This feature is usually used with system libraries, such as language subroutine libraries.
- Without this facility, each program on a system must include a copy of its language library (or at least the routines referenced by the program) in the executable image.
- This requirement wastes both disk space and main memory.

Dynamic Linking

- A *stub* is included in the image for each library routine reference.
- The stub is a small piece of code that indicates how to locate the appropriate memory-resident library routine or how to load the library if the routine is not already present.

Dynamic Linking

- When the stub is executed,

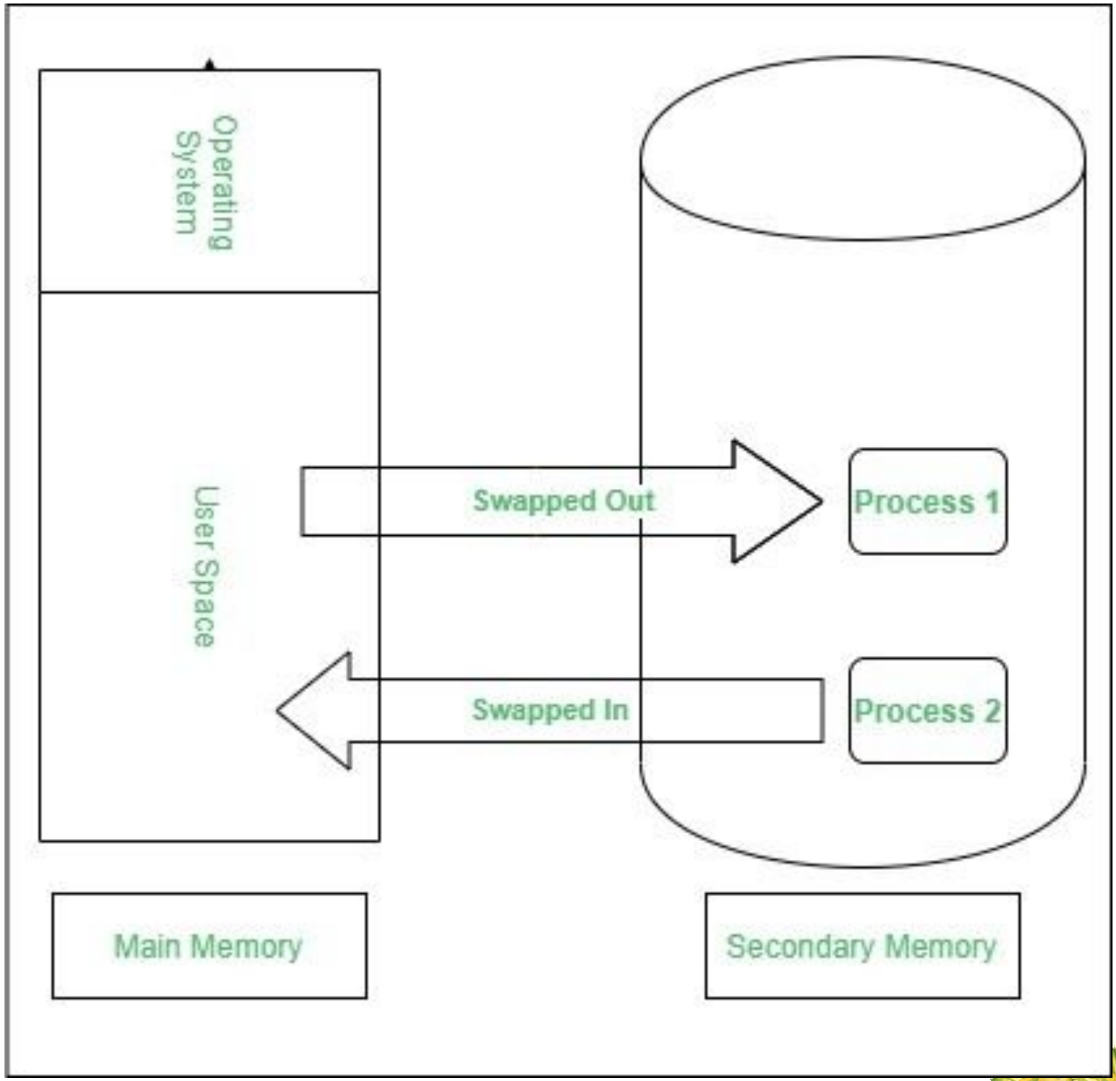
1) It checks to see whether the needed routine is already in memory.
2) If it is not, the program loads the routine into memory.
3) Either way, the stub replaces itself with the address of the routine and executes the routine.
4) Thus, the next time that particular code segment is reached, the library routine is executed directly, incurring no cost for dynamic linking.

Dynamic Linking

- This feature can be extended to library updates (such as bug fixes).
- A library may be replaced by a new version,
- All programs that reference the library will automatically use the new version. Without dynamic linking, all such programs would need to be relinked to gain access to the new library.

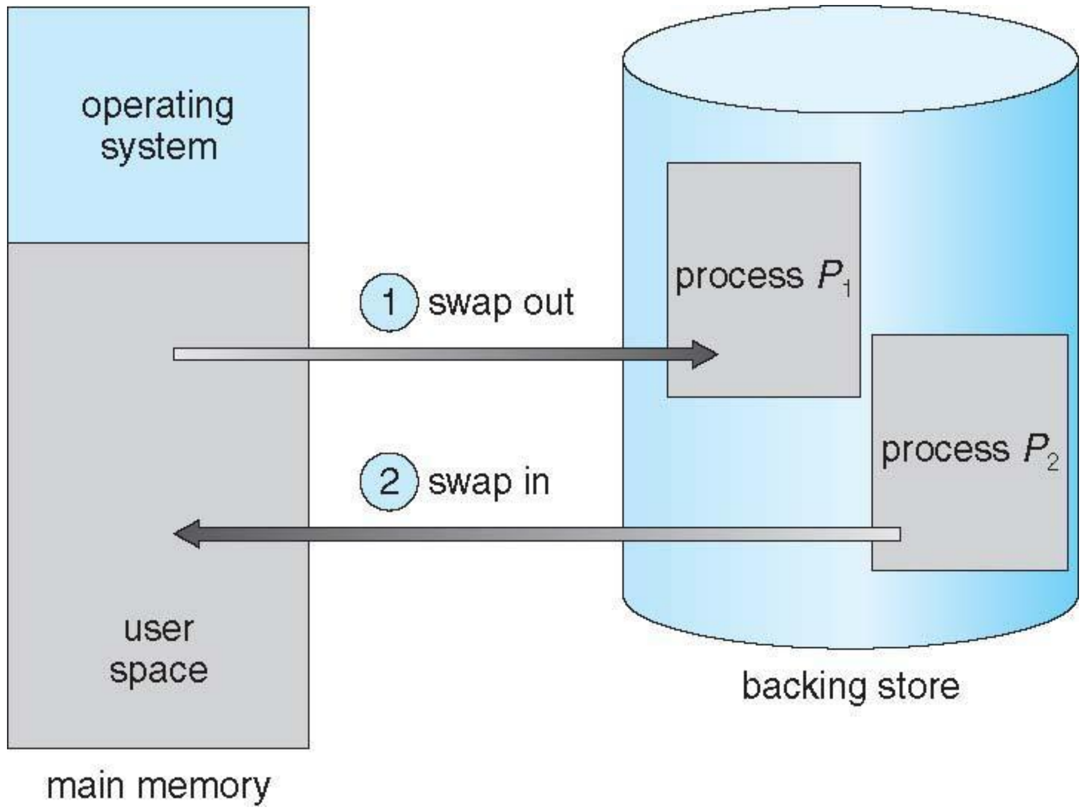
Swapping

- Swapping is a process of swapping a process temporarily to a secondary memory from the main memory



Swapping

- A process can be **swapped** temporarily out of memory to a backing store, and then brought back into memory for continued execution



Swapping

- **Backing store** –
- fast disk large enough to accommodate copies of all memory images for all users;
- must provide direct access to these memory images

Swapping

Q
MMU /Dispatcher

For example,

- Assume a multiprogramming environment with a round-robin CPU-scheduling algorithm.

1) When a quantum expires, the memory manager will start to swap out the process that just finished and to swap another process into the memory space that has been freed
2) In the meantime, the CPU scheduler will allocate a time slice to some other process in memory.
3) When each process finishes its quantum, it will be swapped with another process.
4) Ideally, the memory manager can swap processes fast enough that some processes will be in memory, ready to execute, when the CPU scheduler wants to reschedule the CPU.

Swapping

- **Roll out, roll in** –
- A variant of this swapping policy is used for priority-based scheduling algorithms.

1) If a higher-priority process arrives and wants service,
2) The memory manager can swap out the lower-priority process and then load and execute the higher-priority process.
3) When the higher-priority process finishes, the lower-priority process can be swapped back in and continued.

- This variant of swapping is sometimes called roll out, roll in.

Swapping

- Major part of swap time is transfer time;
- total transfer time is directly proportional to the amount of memory swapped
- System maintains a **ready queue** of ready-to-run processes which have memory images on disk

Swapping (Cont.)

- Does the swapped out process need to swap back in to same physical addresses?

Swapping

- Normally, a process that is swapped out will be swapped back into the same memory space it occupied previously.
- The restriction is dictated by the method of address binding.
- If binding is done at assembly/Compile or load time, then the process cannot be easily moved to a different location.
- if execution time binding is being used, then a process can be swapped into a different memory space as the physical addresses are computed at execution time

Dispatcher and swapper

- Swapping requires a backing store.
- The backing store is commonly a fast disk, large enough to accommodate copies of all memory images for all users
- Provides direct access to these memory images.
- **The system maintains a ready queue of all processes whose memory images are in memory and are ready to run.**
- Whenever the CPU scheduler decides to execute a process, it calls the dispatcher.
- The dispatcher checks to see whether the next process in the queue is in memory.
- If it is not, and if there is no free memory region, the swapper swaps out a process currently in memory and swaps in the desired process.
- It then reloads registers and transfers control to the selected process.

- The context-switch time in such a swapping system is fairly high.
- Assume a user process of 10 MB size and the backing store is a standard hard disk with a transfer rate of 40 MB per second. The actual transfer of the 10-MB process to or from main memory takes:

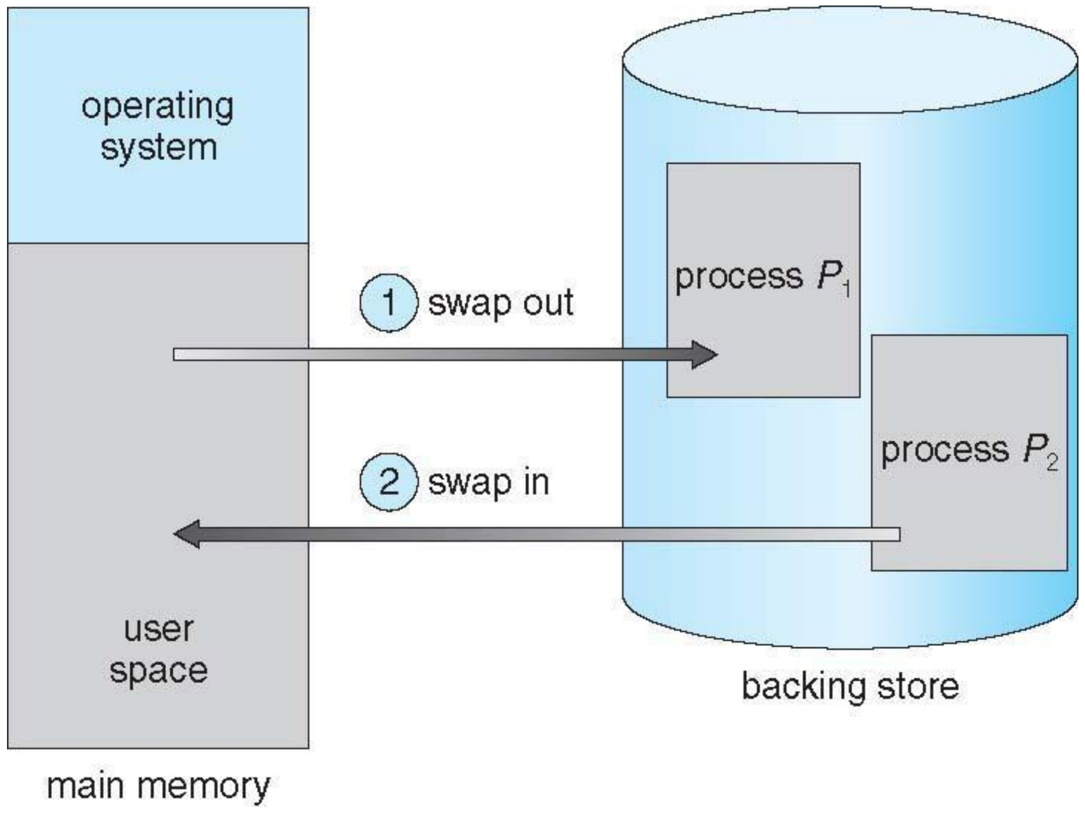
$$\begin{aligned} 10000 \text{ KB}/40000 \text{ KB per second} &= 1/4 \text{ second} \\ &= 250 \text{ milliseconds.} \end{aligned}$$

- Assuming that no head seeks are necessary, and assuming an average latency of 8 milliseconds, the swap time is 258 milliseconds.
- Considering both swap out and swap in, the total swap time = 516 milliseconds.
- For efficient CPU utilization, the execution time for each process should be long relative to the swap time.
- Thus, in a round-robin CPU-scheduling algorithm, for example, the time quantum should be substantially larger than 0.516 seconds.

Swapping (Cont.)

- Modified versions of swapping are found on many systems (i.e., UNIX, Linux, and Windows)
  - Swapping normally disabled
  - Started if more than threshold amount of memory allocated
  - Disabled again once memory demand reduced below threshold

Schematic View of Swapping



Contiguous Allocation

- Main memory must support both OS and user processes
- Limited resource, must allocate efficiently
- Contiguous allocation per process is one early method

Memory allocation to OS and User programs

- The main memory must accommodate both the operating system and the various user processes.
- Hence, OS needs to allocate the parts of the main memory in the most efficient way possible.
- The memory is divided into two partitions:
  - For the resident operating system and
  - For the user processes.
- So the operating system in either low memory or high memory.
- The major factor affecting this decision is the location of the interrupt vector.
- Since the interrupt vector is often in low memory, programmers usually place the operating system in low memory as well.
- User processes then held in high memory

Contiguous Allocation

- In contiguous memory allocation, each process is contained in a single contiguous section of memory.

Memory Mapping and Protection

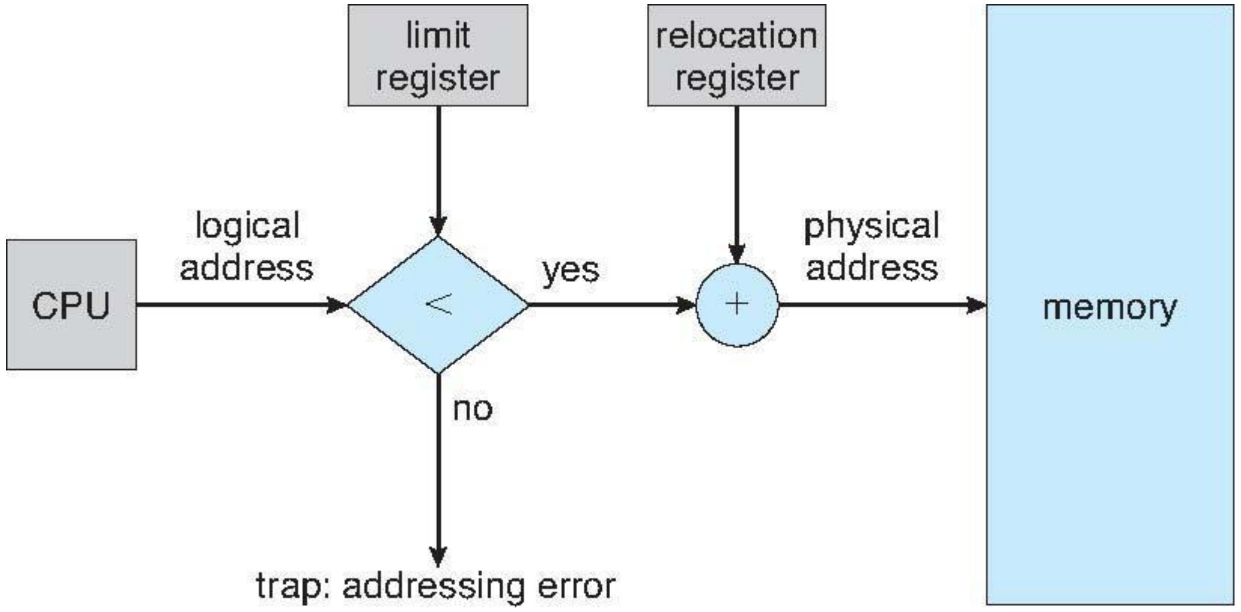
- To protect user processes from each other, and from changing operating-system code and data by using a relocation register together with a limit register.

1) The relocation register contains the value of the smallest physical address
2) The limit register contains the range of logical addresses – each logical address must be less than the limit register

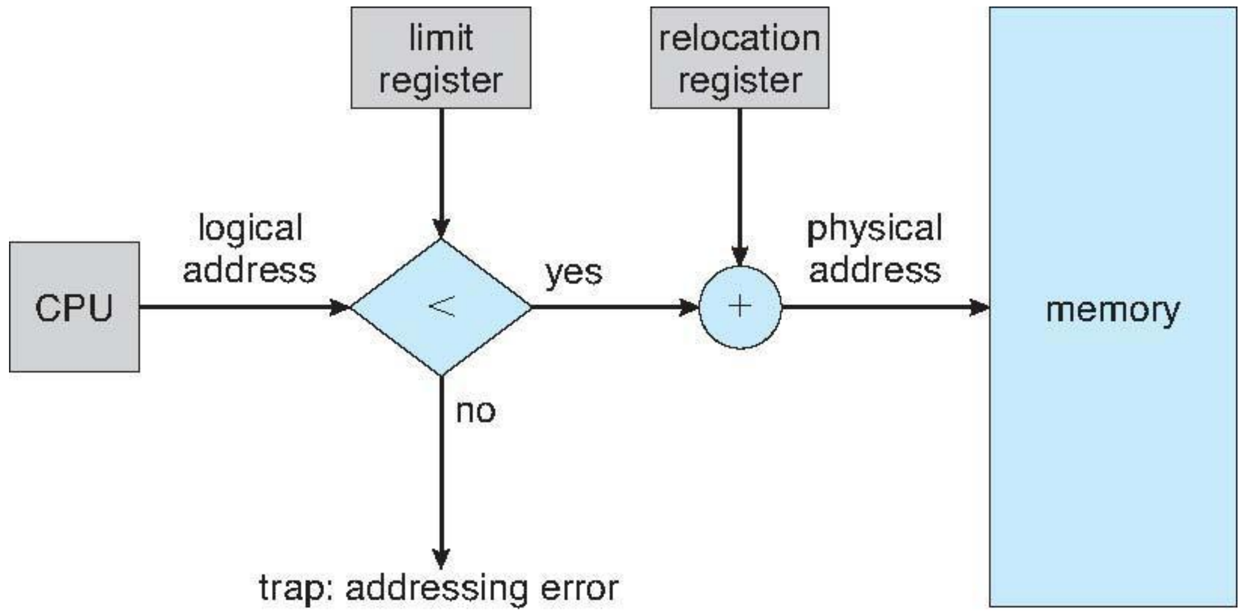
Memory Mapping and Protection

1) **Each logical address must be less than the limit register;**
2) **The MMU maps the logical address *dynamically* by adding the value in the relocation register.**
3) **This mapped address is sent *to* memory**

(for example, relocation= 100040 and limit= 74600).



Hardware Support for Relocation and Limit Registers



Types of Memory Management Techniques

- Contiguous
- Non-Contiguous

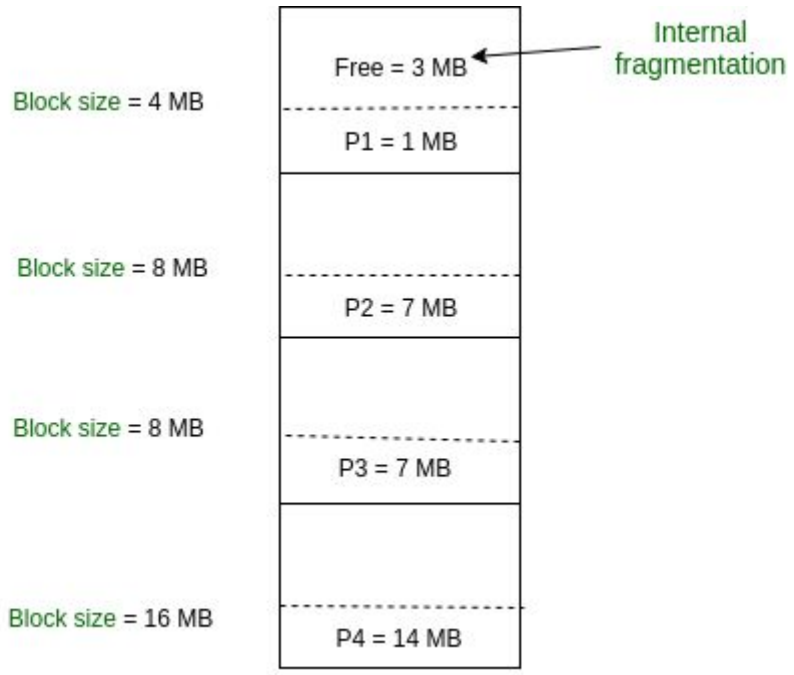
- **In Contiguous Technique, executing process must be loaded entirely in the main memory.**
- The contiguous Technique can be divided into:
  - Fixed (or static) partitioning
  - Variable (or dynamic) partitioning

Fixed partitioning

- Also known as static partitioning,
- **No of Partitions are fixed**
- **In this partitioning, the number of partitions (non-overlapping) in RAM is fixed but the size of each partition may or may not be the same.**

Fixed partitioning

- Is a memory allocation technique used in operating systems to divide the physical memory into fixed-size partitions or regions, each assigned to a specific process or user.
- **Partitions are made before execution or during system configure.**
- Each partition remains dedicated to a specific process until it terminates or releases the partition.



Fixed size partition

Fixed partitioning

- Disadvantages:
- **It can lead to internal fragmentation, where memory in a partition remains unused.** This can happen when the process's memory requirements are smaller than the partition size, leaving some memory unused

Memory Allocation-Fixed Size Partitions

- One of the simplest methods for allocating memory is –
- To divide memory into several **fixed-sized partitions.**
- Each partition may contain exactly one process.
- Thus, the degree of multiprogramming is bound by the number of partitions.
- In this Multiple partition method, when a partition is free, a process is selected from the **input queue** and is loaded into the free partition.
- When the process terminates, the partition becomes available for another process.
- This method was originally used by the IBM OS/360 operating system (called MFT); it is no longer in use.

Memory Allocation-Fixed Size Partitions

- As processes enter the system, they are put into an input queue.
- At any given time, then, we have a list of available block sizes and an input queue.
- The operating system can order the input queue according to a scheduling algorithm.
  - Process selected from input queue is allocated memory from a hole large enough to accommodate it
  - The operating system can wait until a large enough block is available,
  - or it can skip down the input queue to see whether the smaller memory requirements of some other process can be met.

Memory Allocation-Fixed Size Partitions

- The memory blocks available comprise a *set* of holes of various sizes scattered throughout memory.
- When a process arrives and needs memory, the system searches the set for a hole that is large enough for this process.
    - If the hole is too large, it is split into two parts.
    - **One part is allocated to the arriving process;**
    - **the other is returned to the set of holes.**

Memory Allocation-Fixed Size Partitions

- When a process terminates, it releases its block of memory, which is then placed back in the set of holes.
  - **If the new hole is adjacent to other holes, these adjacent holes are merged to form one larger hole.**
  - At this point, the system may need to check whether there are processes waiting for memory and whether this newly freed and recombined memory could satisfy the demands of any of these waiting processes.

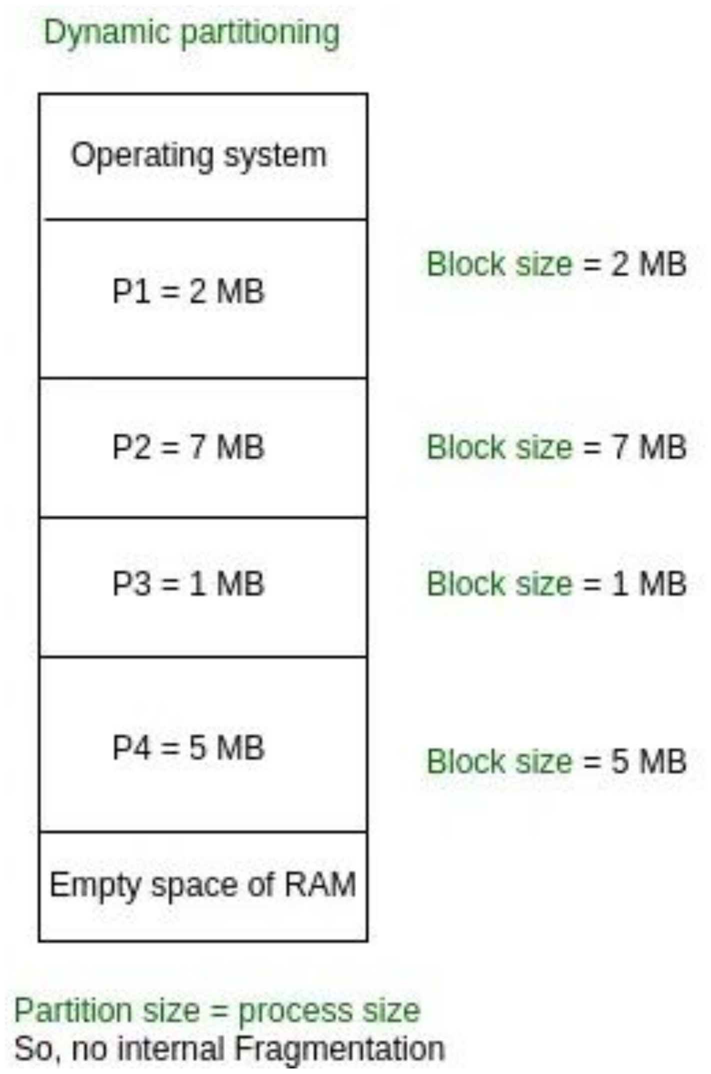
Variable (or Dynamic) Partitioning

- In contrast with fixed partitioning, partitions are not made before the execution or during system configuration.
- **No of partitions are not fixed**

Variable (or Dynamic) Partitioning

- **Features**:
- Initially, RAM is empty and partitions are made during the run-time according to the process's need instead of partitioning during system configuration.
- The size of the partition will be equal to the incoming process.
- The partition size varies according to the need of the process so that internal fragmentation can be avoided to ensure efficient utilization of RAM.
- The number of partitions in RAM is not fixed and depends on the number of incoming processes and the Main Memory's size.

Variable (or Dynamic) Partitioning



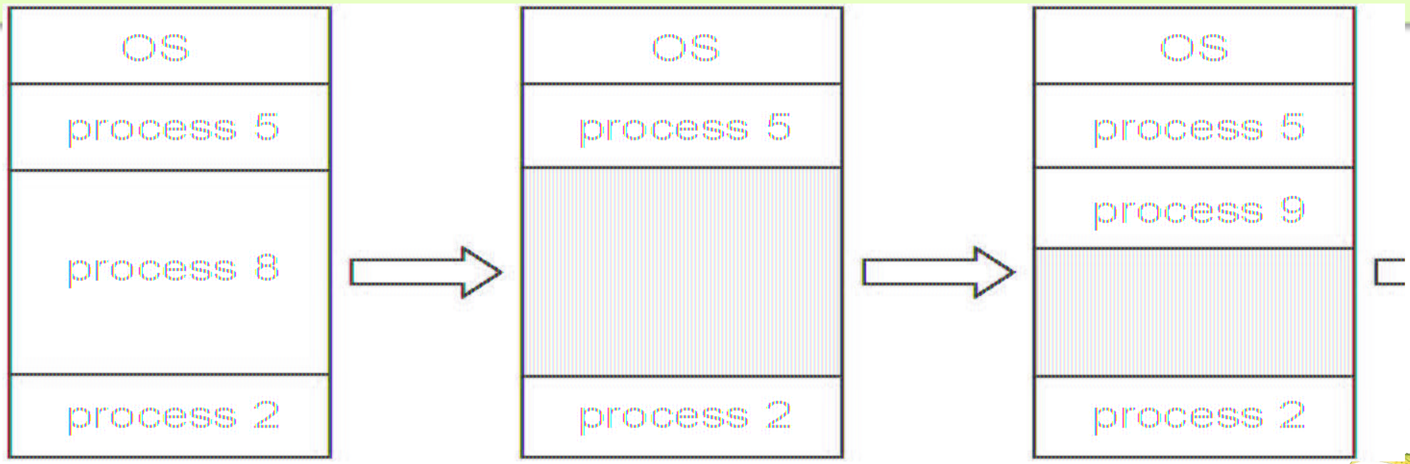
Memory Allocation

- **In the Variable Partition scheme,**
- The operating system keeps a table indicating which parts of memory are available and which are occupied.
- Initially, all memory is available for user processes and is considered one large block of available memory-**a Hole.**
- **Eventually as you will see, memory contains a set of holes of various sizes.**

"Hole – block of available memory; holes of various size are scattered throughout memory"

Multiple-partition allocation

- **Variable-partition** sizes for efficiency (sized to a given process' needs)
  - **Hole** – block of available memory; holes of various size are scattered throughout memory
  - When a process arrives, it is allocated memory from a hole large enough to accommodate it
  - Process exiting frees its partition, adjacent free partitions combined
  - Operating system maintains information about:
    a) allocated partitions   b) free partitions (hole)



Dynamic Storage-Allocation Problem

How to satisfy a request of size ***n*** from a list of free holes?

- **First-fit**
- **Best-fit**
- **Worst-fit**

Dynamic Storage-Allocation Problem

How to satisfy a request of size ***n*** from a list of free holes?

- **First-fit**:
- Allocate the ***first*** hole that is big enough
- Searching can start either at the beginning of the set of holes or at the location where the previous first-fit search ended.
- We can stop searching as soon as we find a free hole that is large enough.

Dynamic Storage-Allocation Problem

How to satisfy a request of size ***n*** from a list of free holes?

- **Best-fit**:
- Allocate the ***smallest*** hole that is big enough;
- We must search entire list, unless ordered by size
- This strategy produces the smallest leftover hole

Dynamic Storage-Allocation Problem

How to satisfy a request of size ***n*** from a list of free holes?

- **Worst-fit**:
- Allocate the ***largest*** hole;
- We must also search entire list unless it is sorted by size.
- This strategy produces the largest leftover hole which may be more useful than the smaller leftover hole from a best-fit approach.

Dynamic Storage-Allocation Problem

- Simulations have shown that

1) Both first fit and best fit are better than worst fit in terms of decreasing time and storage utilization.
2) Neither first fit nor best fit is clearly better than the other in terms of storage utilization, **but first fit is generally faster.**

Dynamic Storage-Allocation Problem

How to satisfy a request of size ***n*** from a list of free holes?

- **First-fit**: Allocate the ***first*** hole that is big enough
- **Best-fit**: Allocate the ***smallest*** hole that is big enough; must search entire list, unless ordered by size
  - Produces the smallest leftover hole
- **Worst-fit**: Allocate the ***largest*** hole; must also search entire list
  - Produces the largest leftover hole

First-fit and best-fit better than worst-fit in terms of speed and storage utilization

Fragmentation

- As processes are loaded and removed from memory, the free memory space is broken into little pieces

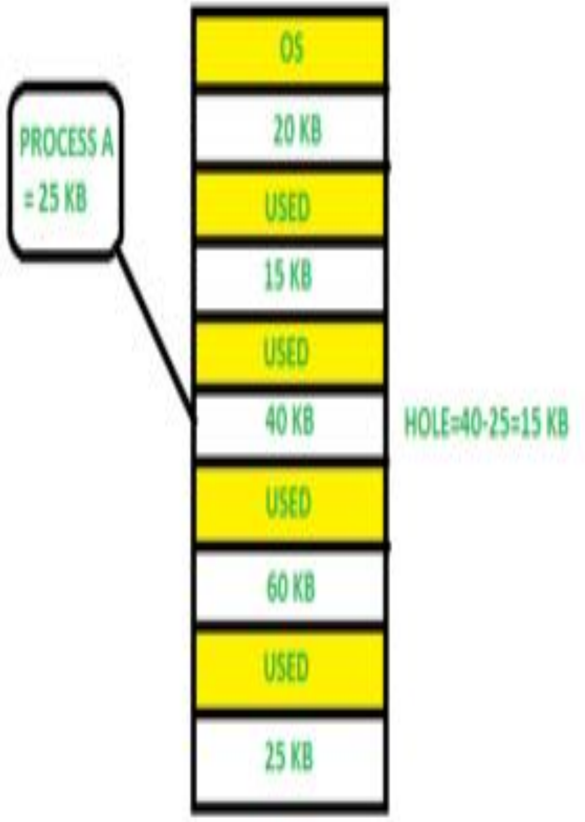
Fragmentation

Memory fragmentation can be-

- External Fragmentation
- Internal Fragmentation

Fragmentation

- **External Fragmentation** –
- Total memory space exists to satisfy a request, but it is not contiguous
- Storage is fragmented into a large number of small holes.
- This fragmentation problem can be severe
- In the worst case,
  - A block of free (or wasted) memory between every two processes.
  - If all these small pieces of memory were in one big free block instead, we might be able to run several more processes.



Fragmentation

- **Internal Fragmentation** –
- Allocated memory may be slightly larger than requested memory;
- This size difference is memory internal to a partition, but not being used
- Unused Memory Internal to a partition

Fragmentation

- **Internal Fragmentation** –
- Consider a multiple-partition allocation scheme with a hole of 18,464 bytes.
- Suppose that the next process requests 18,462 bytes.
- If we allocate exactly the requested block,
- We are left with a hole of 2 bytes.

Fragmentation

- First fit analysis reveals that given *N* blocks allocated, 0.5 *N* blocks lost to fragmentation
  - 1/3 may be unusable -> **50-percent rule**

Fragmentation (Cont.)

- Reduce external fragmentation by **compaction**
  - Shuffle memory contents to place all free memory together in one large block
  - Compaction is possible *only* if relocation is dynamic, and is done at execution time
  - If addresses are relocated dynamically, relocation requires only moving the program and data and then changing the base register to reflect the new base address.

Fragmentation (Cont.)

- The simplest compaction algorithm is
  - To move all processes toward one end of memory;
  - all holes move in the other direction,
  - producing one large hole of available memory.
  - This scheme can be expensive.

Fragmentation (Cont.)

- Another possible solution-
  - To permit the logical address space of the processes to be non contiguous,
  - thus allowing a process to be allocated physical memory wherever such memory is available.

Non-Contiguous Memory Allocation

- In this technique, each process is allocated a series of non-contiguous blocks of memory that can be located anywhere in the physical memory.

- Paging and Segmentation are the two ways that allow a process's physical address space to be non-contiguous. It has the advantage of reducing memory wastage but it increases the overheads due to address translation. It slows the execution of the memory because time is consumed in address translation.