Concurrency Management in Operating Systems

What is Concurrency?

It refers to the execution of multiple instruction sequences at the same time. It occurs in an operating system when multiple process threads are executing concurrently. These threads can interact with one another via shared memory or message passing. Concurrency results in resource sharing, which causes issues like deadlocks and resource scarcity. It aids with techniques such as process coordination, memory allocation, and execution schedule to maximize throughput.

Principles of Concurrency

Today's technology, like multi-core processors and parallel processing, allows multiple processes and threads to be executed simultaneously. Multiple processes and threads can access the same memory space, the same declared variable in code, or even read or write to the same file.

The amount of time it takes a process to execute cannot be simply estimated, and you cannot predict which process will complete first, enabling you to build techniques to deal with the problems that concurrency creates.

Interleaved and overlapping processes are two types of concurrent processes with the same problems. It is impossible to predict the relative speed of execution, and the following factors determine it:

1. The way operating system handles interrupts
2. Other processes' activities
3. The operating system's scheduling policies

Problems in Concurrency: Some of them are as follows:

1. Locating the programming errors

It's difficult to spot a programming error because reports are usually repeatable due to the varying states of shared components each time the code is executed.

2. Sharing Global Resources

Sharing global resources is difficult. If two processes utilize a global variable and both alter the variable's value, the order in which the many changes are executed is critical.

3. Locking the channel

It could be inefficient for the OS to lock the resource and prevent other processes from using it.

4. Optimal Allocation of Resources

It is challenging for the OS to handle resource allocation properly.

Advantages of Concurrency in OS

1. Better Performance

It improves the operating system's performance. When one application only utilizes the processor, and another only uses the disk drive, the time it takes to perform both apps simultaneously is less than the time it takes to run them sequentially.

2. Better Resource Utilization

It enables resources that are not being used by one application to be used by another.

3. Running Multiple Applications

It enables you to execute multiple applications simultaneously.

Disadvantages of Concurrency

1. It is necessary to protect multiple applications from each other.
2. It is necessary to use extra techniques to coordinate several applications.
3. Additional performance overheads and complexities in OS are needed for switching between applications.

Issues of Concurrency: Various issues of concurrency are as follows:

1. issues of Non-atomic operations

Operations that are non-atomic but interruptible by several processes may happen issues. A non-atomic operation depends on other processes, and an atomic operation runs independently of other processes.

2. Deadlock

In concurrent computing, it occurs when one group member waits for another member, including itself, to send a message and release a lock. Software and hardware locks are commonly used to arbitrate shared resources and implement process synchronization in parallel computing, distributed systems, and multiprocessing.

3. Blocking

A blocked process is waiting for some event, like the availability of a resource or completing an I/O operation. Processes may block waiting for resources, and

a process may be blocked for a long time waiting for terminal input. If the process is needed to update some data periodically, it will be very undesirable.

4. Race Conditions

A race problem occurs when the output of a software application is determined by the timing or sequencing of other uncontrollable events. Race situations can also happen in multithreaded software, runs in a distributed environment, or is interdependent on shared resources.

5. Starvation

A problem in concurrent computing is where a process is continuously denied the resources it needs to complete its work. It could be caused by errors in scheduling or mutual exclusion algorithm, but resource leaks may also cause it.

> Concurrent system design frequently requires developing dependable strategies for coordinating their execution, data interchange, memory allocation, and execution schedule to decrease response time and maximize throughput

CPU Scheduling in Operating Systems

Scheduling of processes/work is done to finish the work on time. **CPU Scheduling** is a process that allows one process to use the CPU while another process is delayed (in standby) due to unavailability of any resources such as I / O etc, thus making full use of the CPU. The purpose of CPU Scheduling is to make the system more efficient, faster, and fairer.

Whenever the CPU becomes idle, the operating system must select one of the processes in the line ready for launch. The selection process is done by a temporary (CPU) scheduler. The Scheduler selects between memory processes ready to launch and assigns the CPU to one of them.

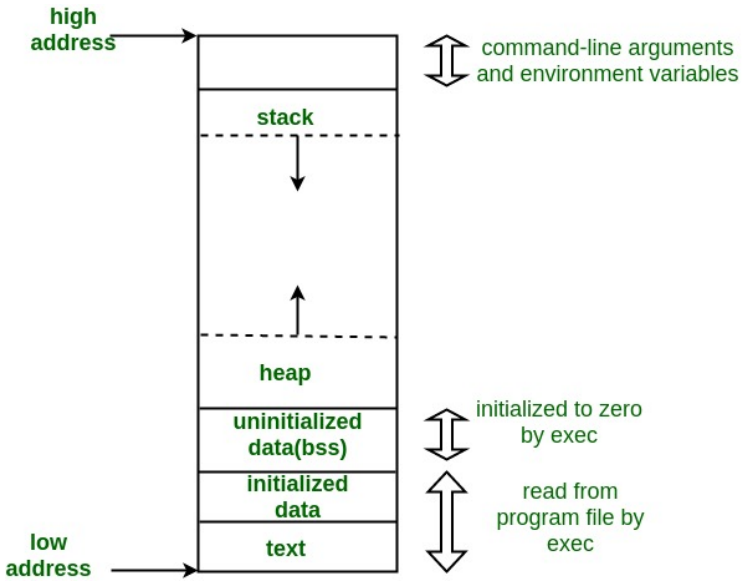
What is a process?

In computing, a process is **the instance of a computer program that is being executed by one or many threads**. It contains the program code and its activity. Depending on the operating system (OS), a process may be made up of multiple threads of execution that execute instructions concurrently.

How is process memory used for efficient operation?

The process memory is divided into four sections for efficient operation:

- The **text category** is composed of integrated program code, which is read from fixed storage when the program is launched.
- The **data class** is made up of global and static variables, distributed and executed before the main action.
- Heap is used for flexible, or dynamic memory allocation and is managed by calls to new, delete, malloc, free, etc.
- The stack is used for local variables. The space in the stack is reserved for local variables when it is announced.



What is Process Scheduling?

Process Scheduling is the process of the process manager handling the removal of an active process from the CPU and selecting another process based on a specific strategy.

Process Scheduling is an integral part of Multi-programming applications. Such operating systems allow more than one process to be loaded into usable memory at a time and the loaded shared CPU process uses repetition time.

There are three types of process schedulers:

- Long term or Job Scheduler
- Short term or CPU Scheduler
- Medium-term Scheduler

Why do we need to schedule processes?

- **Scheduling** is important in many different computer environments. One of the most important areas is scheduling which programs will work on the CPU. This task is handled by the Operating System (OS) of the computer and there are many different ways in which we can choose to configure programs.

- **Process Scheduling** allows the OS to allocate CPU time for each process. Another important reason to use a process scheduling system is that it keeps the CPU busy at all times. This allows you to get less response time for programs.

- Considering that there may be hundreds of programs that need to work, the OS must launch the program, stop it, switch to another program, etc.

The way the OS configures the system to run another in the CPU is called “context switching”. If the OS keeps context-switching programs in and out of the provided CPUs, it can give the user a tricky idea that he or she can run any programs he or she wants to run, all at once.

- So now that we know we can run 1 program at a given CPU, and we know we can change the operating system and remove another one using the context switch, how do we choose which programs we need. run, and with what program?

- That’s where **scheduling** comes in! First, you determine the metrics, saying something like “the amount of time until the end”. We will define this metric as “the time interval between which a function enters the system until it is completed”. Second, you decide on a metrics that reduces metrics. We want our tasks to end as soon as possible.

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What is the need for CPU scheduling algorithm?

CPU scheduling is the process of deciding which process will own the CPU to use while another process is suspended. The main function of the CPU scheduling is to ensure that whenever the CPU remains idle, the OS has at least selected one of the processes available in the ready-to-use line.
In Multiprogramming, if the long-term scheduler selects multiple I / O binding processes then most of the time, the CPU remains an idle. The function of an effective program is to improve resource utilization.

If most operating systems change their status from performance to waiting then there may always be a chance of failure in the system. So in order to minimize this excess, the OS needs to schedule tasks in order to make full use of the CPU and avoid the possibility of deadlock.

Objectives of Process Scheduling Algorithm:

- Utilization of CPU at maximum level. **Keep CPU as busy as possible**.
- **Allocation of CPU should be fair**.
- **Throughput should be Maximum**. i.e. Number of processes that complete their execution per time unit should be maximized.
- **Minimum turnaround time**, i.e. time taken by a process to finish execution should be the least.
- There should be a **minimum waiting time** and the process should not starve in the ready queue.
- **Minimum response time.** It means that the time when a process produces the first response should be as less as possible.

What are the different terminologies to take care of in any CPU Scheduling algorithm?

- **Arrival Time:** Time at which the process arrives in the ready queue.
- **Completion Time:** Time at which process completes its execution.
- **Burst Time:** Time required by a process for CPU execution.
- **Turn Around Time:** Time Difference between completion time and arrival time.

$$\textit{Turn Around Time} = \textit{Completion Time} - \textit{Arrival Time}$$

- **Waiting Time (W.T):** Time Difference between turnaround time and burst time.

$$\textit{Waiting Time} = \textit{Turn Around Time} - \textit{Burst Time}$$

CPU Scheduling Criteria

Different **CPU Scheduling algorithms** have different structures and the choice of a particular algorithm depends on a variety of factors. Many criteria have been suggested for comparing CPU scheduling algorithms. The criteria include the following:

1. **CPU utilization:** The main objective of any CPU scheduling algorithm is to keep the CPU as busy as possible. Theoretically, CPU utilization can range from 0 to 100 but in a real-time system, it varies from 40 to 90 percent depending on the load upon the system.
2. **Throughput:** A measure of the work done by the CPU is the number of processes being executed and completed per unit of time. This is called throughput. The throughput may vary depending on the length or duration of the processes.
3. **Turnaround time:** For a particular process, an important criterion is how long it takes to execute that process. The time elapsed from the time of submission of a process to the time of completion is known as the turnaround time. Turn-around time is the sum of times spent waiting to get into memory, waiting in the ready queue, executing in CPU, and waiting for I/O. The formula to calculate Turn Around Time = Completion Time – Arrival Time.
4. **Waiting time:** A scheduling algorithm does not affect the time required to complete the process once it starts execution. It only affects the waiting time of a process i.e. time spent by a process waiting in the ready

queue. The formula for calculating Waiting Time = Turnaround Time – Burst Time.

5. **Response time:** In an interactive system, turn-around time is not the best criterion. A process may produce some output fairly early and continue computing new results while previous results are being output to the user. Thus, another criterion is the time taken from submission of the process of the request until the first response is produced. This measure is called response time. The formula to calculate Response Time = CPU Allocation Time (when the CPU was allocated for the first) – Arrival Time
6. **Completion time:** The completion time is the time when the process stops executing, which means that the process has completed its burst time and is completely executed.
7. **Priority:** If the operating system assigns priorities to processes, the scheduling mechanism should favor the higher-priority processes.
8. **Predictability:** A given process always should run in about the same amount of time under a similar system load.

What are the different types of CPU Scheduling Algorithms?

There are mainly two types of scheduling methods:

Preemptive Scheduling

Preemptive scheduling is used when a process switches from the running state to the ready state or from the waiting state to the ready state. The resources (mainly CPU cycles) are allocated to the process for a limited amount of time and then taken away, and the process is again placed back in the ready queue if that process still has CPU burst time remaining. That process stays in the ready queue till it gets its next chance to execute.

Non-Preemptive Scheduling

Non-preemptive Scheduling is used when a process terminates, or a process switches from running to the waiting state. In this scheduling, once the resources (CPU cycles) are allocated to a process, the process holds the CPU till it gets terminated or reaches a waiting state. In the case of non-preemptive scheduling does not interrupt a process running CPU in the middle of the execution. Instead, it waits till the process completes its CPU burst time, and then it can allocate the CPU to another process.

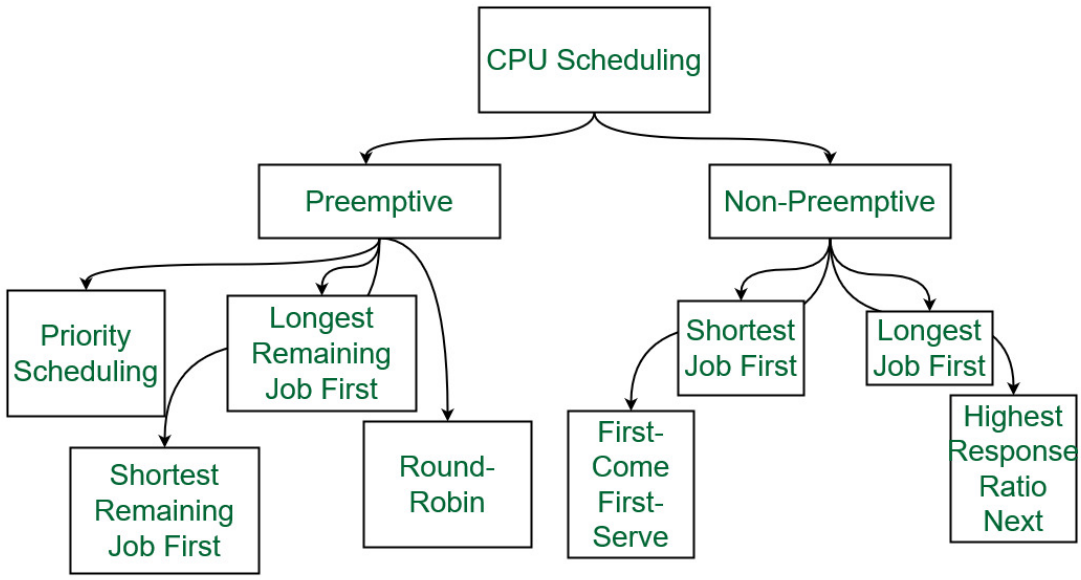
Key Differences Between Preemptive and Non-Preemptive Scheduling

1. In preemptive scheduling, the CPU is allocated to the processes for a limited time whereas, in Non-preemptive scheduling, the CPU is allocated to the process till it terminates or switches to the waiting state.
2. The executing process in preemptive scheduling is interrupted in the middle of execution when a higher priority one comes whereas, the executing process in non-preemptive scheduling is not interrupted in the middle of execution and waits till its execution.
3. In Preemptive Scheduling, there is the overhead of switching the process from the ready state to the running state, vise-verse, and maintaining the ready queue. Whereas in the case of non-preemptive scheduling has no overhead of switching the process from running state to ready state.
4. In preemptive scheduling, if a high-prior The process The process non-preemptive low-priority process frequently arrives in the ready queue then the process with low priority has to wait for a long, and it may have to starve. , in non-preemptive scheduling, if CPU is allocated to the process having a larger burst time then the processes with a small burst time may have to starve.
5. Preemptive scheduling attains flexibility by allowing the critical processes to access the CPU as they arrive in the ready queue, no matter what process is executing currently. Non-preemptive scheduling is called rigid as even if a critical process enters the ready queue the process running CPU is not disturbed.
6. Preemptive Scheduling has to maintain the integrity of shared data that's why it is cost associative which is not the case with Non-Preemptive Scheduling.

Parameter	PREEMPTIVE SCHEDULING	NON-PREEMPTIVE SCHEDULING
Basic	In this resources(CPU Cycle) are allocated to a process for a limited time.	Once resources(CPU Cycle) are allocated to a process, the process holds it till it completes its burst time or switches to waiting state.

Parameter	PREEMPTIVE SCHEDULING	NON-PREEMPTIVE SCHEDULING
Interrupt	Process can be interrupted in between.	Process can not be interrupted until it terminates itself or its time is up.
Starvation	If a process having high priority frequently arrives in the ready queue, a low priority process may starve.	If a process with a long burst time is running CPU, then later coming process with less CPU burst time may starve.
Overhead	It has overheads of scheduling the processes.	It does not have overheads.
Flexibility	flexible	rigid
Cost	cost associated	no cost associated
CPU Utilization	In preemptive scheduling, CPU utilization is high.	It is low in non preemptive scheduling.
Waiting Time	Preemptive scheduling waiting time is less.	Non-preemptive scheduling waiting time is high.
Response Time	Preemptive scheduling response time is less.	Non-preemptive scheduling response time is high.
Decision making	Decisions are made by the scheduler and are based on priority and time slice allocation	Decisions are made by the process itself and the OS just follows the process's instructions
Process control	The OS has greater control over the scheduling of processes	The OS has less control over the scheduling of processes

Parameter	PREEMPTIVE SCHEDULING	NON-PREEMPTIVE SCHEDULING
Overhead	Higher overhead due to frequent context switching	Lower overhead since context switching is less frequent
Examples	Examples of preemptive scheduling are Round Robin and Shortest Remaining Time First.	Examples of non-preemptive scheduling are First Come First Serve and Shortest Job First.



Different types of CPU Scheduling Algorithms

Let us now learn about these CPU scheduling algorithms in operating systems one by one:

1. First Come First Serve:

FCFS considered to be the simplest of all operating system scheduling algorithms. First come first serve scheduling algorithm states that the process that requests the CPU first is allocated the CPU first and is implemented by using FIFO queue.

Characteristics of FCFS:

- FCFS supports non-preemptive and preemptive CPU scheduling algorithms.
- Tasks are always executed on a First-come, First-serve concept.
- FCFS is easy to implement and use.
- This algorithm is not much efficient in performance, and the wait time is quite high.

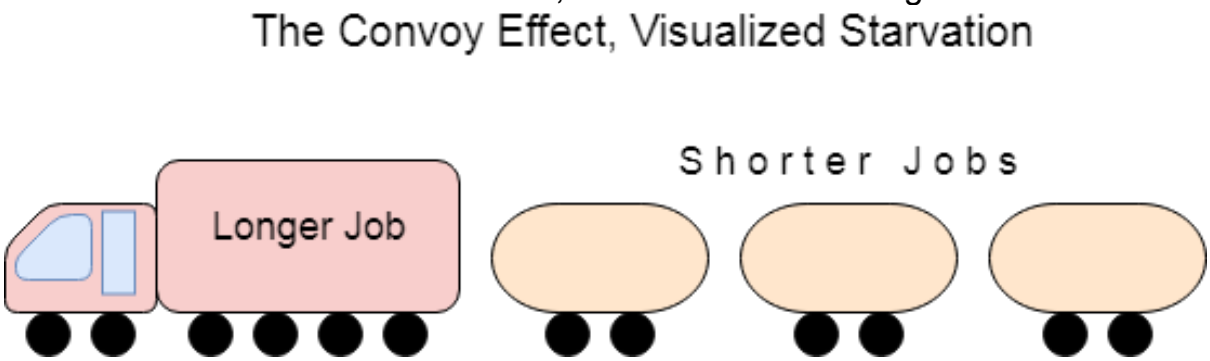
Advantages of FCFS:

- Easy to implement
- First come, first serve method

Disadvantages of FCFS:

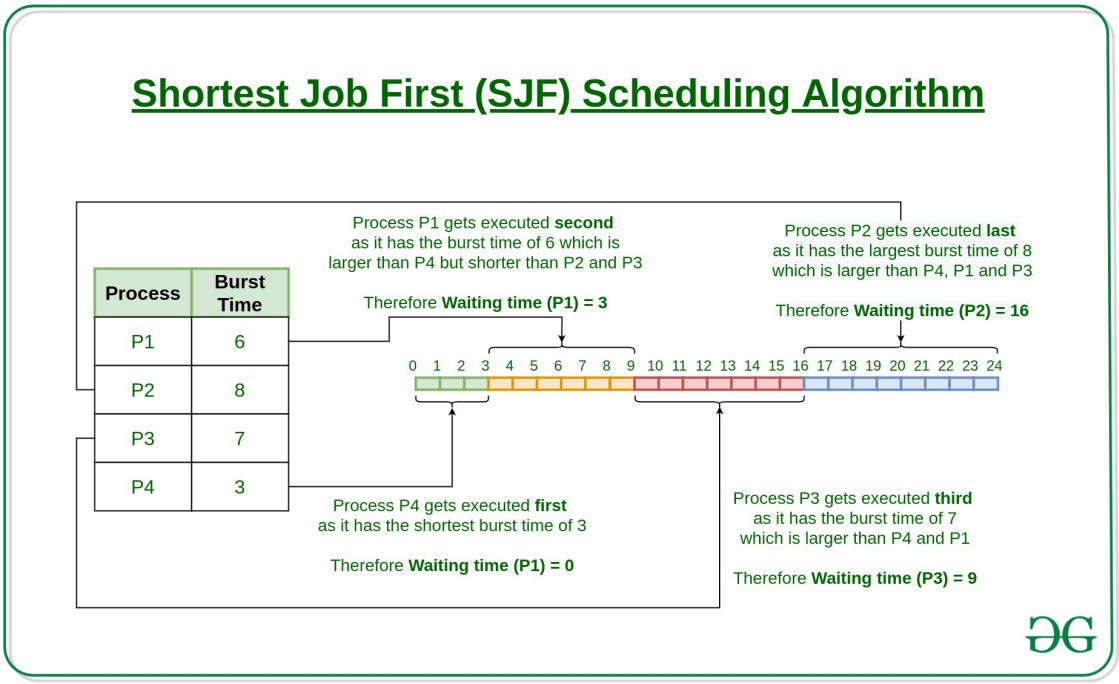
- FCFS suffers from **Convoy effect**.
- The average waiting time is much higher than the other algorithms.
- FCFS is very simple and easy to implement and hence not much efficient.

To learn about how to implement this CPU scheduling algorithm, please refer to our detailed article on First come, First serve Scheduling.



2. Shortest Job First(SJF):

Shortest job first (SJF) is a scheduling process that selects the waiting process with the smallest execution time to execute next. This scheduling method may or may not be preemptive. Significantly reduces the average waiting time for other processes waiting to be executed. The full form of SJF is Shortest Job First.



Characteristics of SJF:

- Shortest Job first has the advantage of having a minimum average waiting time among all operating system scheduling algorithms.
- It is associated with each task as a unit of time to complete.
- It may cause starvation if shorter processes keep coming. This problem can be solved using the concept of ageing.

Advantages of Shortest Job first:

- As SJF reduces the average waiting time thus, it is better than the first come first serve scheduling algorithm.
- SJF is generally used for long term scheduling

Disadvantages of SJF:

- One of the demerit SJF has is starvation.
- Many times, it becomes complicated to predict the length of the upcoming CPU request

To learn about how to implement this CPU scheduling algorithm, please refer to our detailed article on Shortest Job First.

3. Longest Job First(LJF):

Longest Job First(LJF) scheduling process is just opposite of shortest job first (SJF), as the name suggests this algorithm is based upon the fact that the process with the largest burst time is processed first. Longest Job First is non-pre-emptive in nature.

Characteristics of LJF:

- Among all the processes waiting in a waiting queue, CPU is always assigned to the process having largest burst time.
- If two processes have the same burst time then the tie is broken using FCFS i.e. the process that arrived first is processed first.
- LJF CPU Scheduling can be of both preemptive and non-preemptive types.

Advantages of LJF:
- No other task can schedule until the longest job or process executes completely.
- All the jobs or processes finish at the same time approximately.

Disadvantages of LJF:
- Generally, the LJF algorithm gives a very high average waiting time and average turn-around time for a given set of processes.
- This may lead to convoy effect.

To learn about how to implement this CPU scheduling algorithm, please refer to our detailed article on the Longest job first scheduling.

4. Priority Scheduling:

Pre-emptive Priority CPU Scheduling Algorithm is a pre-emptive method of CPU scheduling algorithm that works **based on the priority** of a process. In this algorithm, the editor sets the functions to be as important, meaning that the most important process must be done first. In the case of any conflict, that is, where there is more than one processor with equal value, then the most important CPU planning algorithm works on the basis of the FCFS (First Come First Serve) algorithm.

Characteristics of Priority Scheduling:
- Schedules tasks based on priority.
- When the higher priority work arrives while a task with less priority is executed, the higher priority work takes the place of the less priority one and
- The latter is suspended until the execution is complete.
- Lower is the number assigned, higher is the priority level of a process.

Advantages of Priority Scheduling:
- The average waiting time is less than FCFS
- Less complex

Disadvantages of Priority Scheduling:
- One of the most common demerits of the Preemptive priority CPU scheduling algorithm is the Starvation Problem. This is the problem in

which a process has to wait for a longer amount of time to get scheduled into the CPU. This condition is called the starvation problem.

To learn about how to implement this CPU scheduling algorithm, please refer to our detailed article on Priority Pre-emptive Scheduling algorithm.

5. Round robin:

Round Robin is a CPU scheduling algorithm where each process is cyclically assigned a fixed time slot. It is the preemptive version of First come First Serve CPU Scheduling algorithm. Round Robin CPU Algorithm generally focuses on Time Sharing technique.

Characteristics of Round robin:

- It's simple, easy to use, and starvation-free as all processes get the balanced CPU allocation.
- One of the most widely used methods in CPU scheduling as a core.
- It is considered preemptive as the processes are given to the CPU for a very limited time.

Advantages of Round robin:

- Round robin seems to be fair as every process gets an equal share of CPU.
- The newly created process is added to the end of the ready queue.

To learn about how to implement this CPU scheduling algorithm, please refer to our detailed article on the Round robin Scheduling algorithm.

6. Shortest Remaining Time First:

Shortest remaining time first is the preemptive version of the Shortest job first which we have discussed earlier where the processor is allocated to the job closest to completion. In SRTF the process with the smallest amount of time remaining until completion is selected to execute.

Characteristics of Shortest remaining time first:

- SRTF algorithm makes the processing of the jobs faster than SJF algorithm, given its overhead charges are not counted.
- The context switch is done a lot more times in SRTF than in SJF and consumes the CPU's valuable time for processing. This adds up to its processing time and diminishes its advantage of fast processing.

Advantages of SRTF:

- In SRTF the short processes are handled very fast.

- The system also requires very little overhead since it only makes a decision when a process completes or a new process is added.

Disadvantages of SRTF:
- Like the shortest job first, it also has the potential for process starvation.
- Long processes may be held off indefinitely if short processes are continually added.

To learn about how to implement this CPU scheduling algorithm, please refer to our detailed article on the shortest remaining time first.

7. Longest Remaining Time First:

The longest remaining time first is a preemptive version of the longest job first scheduling algorithm. This scheduling algorithm is used by the operating system to program incoming processes for use in a systematic way. This algorithm schedules those processes first which have the longest processing time remaining for completion.

Characteristics of longest remaining time first:
- Among all the processes waiting in a waiting queue, the CPU is always assigned to the process having the largest burst time.
- If two processes have the same burst time then the tie is broken using FCFS i.e. the process that arrived first is processed first.
- LJF CPU Scheduling can be of both preemptive and non-preemptive types.

Advantages of LRTF:
- No other process can execute until the longest task executes completely.
- All the jobs or processes finish at the same time approximately.

Disadvantages of LRTF:
- This algorithm gives a very high average waiting time and average turn-around time for a given set of processes.
- This may lead to a convoy effect.

To learn about how to implement this CPU scheduling algorithm, please refer to our detailed article on the longest remaining time first.

8. Highest Response Ratio Next:

Highest Response Ratio Next is a non-preemptive CPU Scheduling algorithm and it is considered as one of the most optimal scheduling algorithms. The name itself states that we need to find the response ratio of all available processes and select the one with the highest Response Ratio. A process once selected will run till completion.

Characteristics of Highest Response Ratio Next:

- The **criteria** for HRRN is **Response Ratio,** and the **mode** is **Non-Preemptive.**
- HRRN is considered as the modification of Shortest Job First to reduce the problem of starvation.
- In comparison with SJF, during the HRRN scheduling algorithm, the CPU is allotted to the next process which has the **highest response ratio** and not to the process having less burst time.

Response Ratio = (W + S)/S

*Here, **W** is the waiting time of the process so far and **S** is the Burst time of the process.*

Advantages of HRRN:

- HRRN Scheduling algorithm generally gives better performance than the shortest job first Scheduling.
- There is a reduction in waiting time for longer jobs and also it encourages shorter jobs.
-

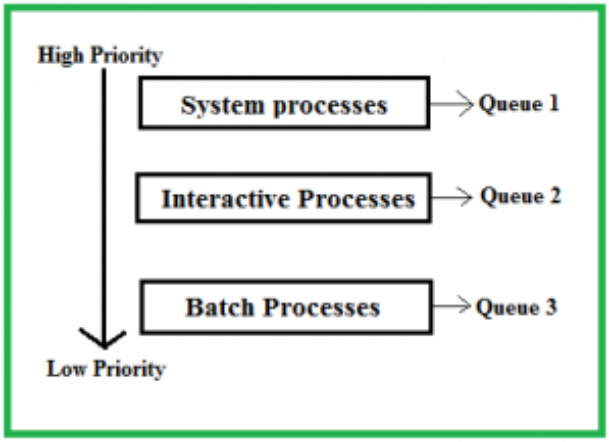
Disadvantages of HRRN:

- The implementation of HRRN scheduling is not possible as it is not possible to know the burst time of every job in advance.
- In this scheduling, there may occur an overload on the CPU.

To learn about how to implement this CPU scheduling algorithm, please refer to our detailed article on Highest Response Ratio Next.

9. Multiple Queue Scheduling:

Processes in the ready queue can be divided into different classes where each class has its own scheduling needs. For example, a common division is a **foreground (interactive)** process and a **background (batch)** process. These two classes have different scheduling needs. For this kind of situation **Multilevel Queue Scheduling** is used.



The description of the processes in the above diagram is as follows:

- **System Processes:** The CPU itself has its process to run, generally termed as System Process.
- **Interactive Processes:** An Interactive Process is a type of process in which there should be the same type of interaction.
- **Batch Processes:** Batch processing is generally a technique in the Operating system that collects the programs and data together in the form of a **batch** before the **processing** starts.

Advantages of multilevel queue scheduling:
- The main merit of the multilevel queue is that it has a low scheduling overhead.

Disadvantages of multilevel queue scheduling:
- Starvation problem
- It is inflexible in nature

To learn about how to implement this CPU scheduling algorithm, please refer to our detailed article on Multilevel Queue Scheduling.

10. Multilevel Feedback Queue Scheduling:

Multilevel Feedback Queue Scheduling (MLFQ) CPU Scheduling is like Multilevel **Queue Scheduling** but in this process, can move between the queues. And thus, much more efficient than multilevel queue scheduling.

Characteristics of Multilevel Feedback Queue Scheduling:
- In a multilevel queue-scheduling algorithm, processes are permanently assigned to a queue on entry to the system, and processes are not allowed to move between queues.
- As the processes are permanently assigned to the queue, this setup has the advantage of low scheduling overhead,
- But on the other hand, disadvantage of being inflexible.

Advantages of Multilevel feedback queue scheduling:
- It is more flexible
- It allows different processes to move between different queues

Disadvantages of Multilevel feedback queue scheduling:
- It also produces CPU overheads
- It is the most complex algorithm.

To learn about how to implement this CPU scheduling algorithm, please refer to our detailed article on Multilevel Feedback Queue Scheduling.

Multiple-Processor Scheduling in Operating System

In multiple-processor scheduling **multiple CPU's** are available and hence **Load Sharing** becomes possible. However multiple processor scheduling is more **complex** as compared to single processor scheduling. In multiple processor scheduling, there are cases when the processors are identical i.e. HOMOGENEOUS, in terms of their functionality, we can use any processor available to run any process in the queue.

Why is multiple-processor scheduling important?
Multiple-processor scheduling is important because it enables a computer system to perform multiple tasks simultaneously, which can greatly improve overall system performance and efficiency.

How does multiple-processor scheduling work?
Multiple-processor scheduling works by dividing tasks among multiple processors in a computer system, which allows tasks to be processed simultaneously and reduces the overall time needed to complete them.

Approaches to Multiple-Processor Scheduling –

- One approach is when all the scheduling decisions and I/O processing are handled by a single processor which is called the **Master Server** and the other processors executes only the **user code**. This is simple and reduces the need of data sharing. This entire scenario is called **Asymmetric Multiprocessing**.

- A second approach uses **Symmetric Multiprocessing** where each processor is **self-scheduling**. All processes may be in a common ready queue or each processor may have its own private queue for ready processes. The scheduling proceeds further by having the scheduler for each processor examine the ready queue and select a process to execute.

Processor Affinity

Processor Affinity means a process has an **affinity** for the processor on which it is currently running. When a process runs on a specific processor there are certain effects on the cache memory. The data most recently accessed by the process populate the cache for the processor and as a result successive memory access by the process are often satisfied in the cache memory. Now if the process migrates to another processor, the contents of the cache memory must be invalidated for the first processor and

the cache for the second processor must be repopulated. Because of the high cost of invalidating and repopulating caches, most of the SMP (symmetric multiprocessing) systems try to avoid migration of processes from one processor to another and try to keep a process running on the same processor. This is known as **PROCESSOR AFFINITY**. There are two types of processor affinity:

1. **Soft Affinity –** When an operating system has a policy of attempting to keep a process running on the same processor but not guaranteeing it will do so, this situation is called soft affinity.
2. **Hard Affinity –** Hard Affinity allows a process to specify a subset of processors on which it may run. Some systems such as Linux implements soft affinity but also provide some system calls like *sched_setaffinity()* that supports hard affinity.

Load Balancing

Load Balancing is the **phenomena** which keep
the **workload** evenly **distributed** across all processors in an SMP system. Load balancing is necessary only on systems where each processor has its own private queue of process which are eligible to execute. Load balancing is unnecessary because once a processor becomes idle it immediately extracts a runnable process from the common run queue. On SMP (symmetric multiprocessing), it is important to keep the workload balanced among all processors to fully utilize the benefits of having more than one processor else one or more processor will sit idle while other processors have high workloads along with lists of processors awaiting the CPU. There are two general approaches to load balancing:

1. **Push Migration –** In push migration a task routinely checks the load on each processor and if it finds an imbalance then it evenly distributes load on each processor by moving the processes from overloaded to idle or less busy processors.
2. **Pull Migration –** Pull Migration occurs when an idle processor pulls a waiting task from a busy processor for its execution.

Multicore Processors

In multicore processors, **multiple processor** cores are places on the same physical chip. Each core has a register set to maintain its architectural state and thus appears to the operating system as a separate physical processor. **SMP systems** that use multicore processors are faster and consume **less power** than systems in which each processor has its own physical chip. However multicore processors may **complicate** the scheduling problems. When processor accesses memory then it spends a significant

amount of time waiting for the data to become available. This situation is called **MEMORY STALL**. It occurs for various reasons such as cache miss, which is accessing the data that is not in the cache memory. In such cases the processor can spend up to fifty percent of its time waiting for data to become available from the memory. To solve this problem recent hardware designs have implemented multithreaded processor cores in which two or more hardware threads are assigned to each core. Therefore, if one thread stalls while waiting for the memory, core can switch to another thread. There are two ways to multithread a processor:

1. **Coarse-Grained Multithreading –** In coarse grained multithreading a thread executes on a processor until a long latency event such as a memory stall occurs, because of the delay caused by the long latency event, the processor must switch to another thread to begin execution. The cost of switching between threads is high as the instruction pipeline must be terminated before the other thread can begin execution on the processor core. Once this new thread begins execution it begins filling the pipeline with its instructions.

2. **Fine-Grained Multithreading –** This multithreading switches between threads at a much finer level mainly at the boundary of an instruction cycle. The architectural design of fine grained systems include logic for thread switching and as a result the cost of switching between threads is small.

Virtualization and Threading

In this type of **multiple-processor** scheduling even a single CPU system acts like a multiple-processor system. In a system with Virtualization, the virtualization presents one or more virtual CPU to each of virtual machines running on the system and then schedules the use of physical CPU among the virtual machines. Most virtualized environments have one host operating system and many guests operating systems. The host operating system creates and manages the virtual machines. Each virtual machine has a guest operating system installed and applications run within that guest. Each guest operating system may be assigned for specific use cases, applications or users including time sharing or even real-time operation. Any guest operating-system scheduling algorithm that assumes a certain amount of progress in a given amount of time will be negatively impacted by the virtualization.
A time-sharing operating system tries to allot 100 milliseconds to each time slice to give users a reasonable response time. A given 100 millisecond time

slice may take much more than 100 milliseconds of virtual CPU time. Depending on how busy the system is, the time slice may take a second or more which results in a very poor response time for users logged into that virtual machine. The net effect of such scheduling layering is that individual virtualized operating systems receive only a portion of the available CPU cycles, even though they believe they are receiving all cycles and that they are scheduling all of those cycles.
Commonly, the time-of-day clocks in virtual machines are incorrect because timers take no longer to trigger than they would on dedicated CPU's. **Virtualizations** can thus undo the good scheduling-algorithm efforts of the operating systems within virtual machines.

What is Deadlock in Operating System (OS)?

Every process needs some resources to complete its execution. However, the resource is granted in a sequential order.

1. The process requests for some resource.
2. OS grant the resource if it is available otherwise let the process waits.
3. The process uses it and release on the completion.

A Deadlock is a situation where each of the computer process waits for a resource which is being assigned to some another process. In this situation, none of the process gets executed since the resource it needs, is held by some other process which is also waiting for some other resource to be released.

Let us assume that there are three processes P1, P2 and P3. There are three different resources R1, R2 and R3. R1 is assigned to P1, R2 is assigned to P2 and R3 is assigned to P3.

After some time, P1 demands for R1 which is being used by P2. P1 halts its execution since it can't complete without R2. P2 also demands for R3 which is being used by P3. P2 also stops its execution because it can't continue without R3. P3 also demands for R1 which is being used by P1 therefore P3 also stops its execution.

In this scenario, a cycle is being formed among the three processes. None of the process is progressing and they are all waiting. The computer becomes unresponsive since all the processes got blocked.

Difference between Starvation and Deadlock

Sr.	Deadlock	Starvation
1	Deadlock is a situation where no process got blocked and no process proceeds	Starvation is a situation where the low priority process got blocked and the high priority processes proceed.
2	Deadlock is an infinite waiting.	Starvation is a long waiting but not infinite.
3	Every Deadlock is always a starvation.	Every starvation need not be deadlock.

4	The requested resource is blocked by the other process.	The requested resource is continuously be used by the higher priority processes.
5	Deadlock happens when Mutual exclusion, hold and wait, No preemption and circular wait occurs simultaneously.	It occurs due to the uncontrolled priority and resource management.

Necessary conditions for Deadlocks

1. **Mutual Exclusion**

   A resource can only be shared in mutually exclusive manner. It implies, if two process cannot use the same resource at the same time.

2. **Hold and Wait**

   A process waits for some resources while holding another resource at the same time.

3. **No preemption**

   The process which once scheduled will be executed till the completion. No other process can be scheduled by the scheduler meanwhile.

4. **Circular Wait**

   All the processes must be waiting for the resources in a cyclic manner so that the last process is waiting for the resource which is being held by the first process.

Strategies for handling Deadlock

1. Deadlock Ignorance

Deadlock Ignorance is the most widely used approach among all the mechanism. This is being used by many operating systems mainly for end user uses. In this approach, the Operating system assumes that deadlock never occurs. It simply ignores deadlock. This approach is best suitable for a single end user system where User uses the system only for browsing and all other normal stuff.

There is always a tradeoff between Correctness and performance. The operating systems like Windows and Linux mainly focus upon performance. However, the performance of the system decreases if it uses deadlock handling mechanism all the time if deadlock happens 1 out of 100 times then it is completely unnecessary to use the deadlock handling mechanism all the time.

In these types of systems, the user has to simply restart the computer in the case of deadlock. Windows and Linux are mainly using this approach.

2. Deadlock prevention

Deadlock happens only when Mutual Exclusion, hold and wait, No preemption and circular wait holds simultaneously. If it is possible to violate one of the four conditions at any time then the deadlock can never occur in the system.

The idea behind the approach is very simple that we have to fail one of the four conditions but there can be a big argument on its physical implementation in the system.

We will discuss it later in detail.

3. Deadlock avoidance

In deadlock avoidance, the operating system checks whether the system is in safe state or in unsafe state at every step which the operating system performs. The process continues until the system is in safe state. Once the system moves to unsafe state, the OS has to backtrack one step.

In simple words, The OS reviews each allocation so that the allocation doesn't cause the deadlock in the system.

We will discuss Deadlock avoidance later in detail.

4. Deadlock detection and recovery

This approach let the processes fall in deadlock and then periodically check whether deadlock occur in the system or not. If it occurs then it applies some of the recovery methods to the system to get rid of deadlock.

We will discuss deadlock detection and recovery later in more detail since it is a matter of discussion.

Deadlock Prevention

If we simulate deadlock with a table which is standing on its four legs then we can also simulate four legs with the four conditions which when occurs simultaneously, cause the deadlock.

However, if we break one of the legs of the table then the table will fall definitely. The same happens with deadlock, if we can be able to violate one of the four necessary conditions and don't let them occur together then we can prevent the deadlock.

Let's see how we can prevent each of the conditions.

1. Mutual Exclusion

Mutual section from the resource point of view is the fact that a resource can never be used by more than one process simultaneously which is fair enough but that is the main reason behind the deadlock. If a resource could have been used by more than one process at the same time then the process would have never been waiting for any resource.

However, if we can be able to violate resources behaving in the mutually exclusive manner then the deadlock can be prevented.

Spooling

For a device like printer, spooling can work. There is a memory associated with the printer which stores jobs from each of the process into it. Later, Printer collects all the jobs and print each one of them according to FCFS. By using this mechanism, the process doesn't have to wait for the printer and it can continue whatever it was doing. Later, it collects the output when it is produced.

Although, Spooling can be an effective approach to violate mutual exclusion but it suffers from two kinds of problems.

1. This cannot be applied to every resource.
2. After some point of time, there may arise a race condition between the processes to get space in that spool.

We cannot force a resource to be used by more than one process at the same time since it will not be fair enough and some serious problems may arise in the performance. Therefore, we cannot violate mutual exclusion for a process practically.

2. Hold and Wait

Hold and wait condition lies when a process holds a resource and waiting for some other resource to complete its task. Deadlock occurs because there can be more than one process which are holding one resource and waiting for other in the cyclic order.

However, we have to find out some mechanism by which a process either doesn't hold any resource or doesn't wait. That means, a process must be assigned all the necessary resources before the execution starts. A process must not wait for any resource once the execution has been started.

!(Hold and wait) = !hold or !wait (negation of hold and wait is, either you don't hold or you don't wait)

This can be implemented practically if a process declares all the resources initially. However, this sounds very practical but can't be done in the computer system because a process can't determine necessary resources initially.

Process is the set of instructions which are executed by the CPU. Each of the instruction may demand multiple resources at the multiple times. The need cannot be fixed by the OS.

The problem with the approach is:

1. Practically not possible.
2. Possibility of getting starved will be increases due to the fact that some process may hold a resource for a very long time.

3. No Preemption

Deadlock arises due to the fact that a process can't be stopped once it starts. However, if we take the resource away from the process which is causing deadlock then we can prevent deadlock.

This is not a good approach at all since if we take a resource away which is being used by the process then all the work which it has done till now can become inconsistent.

Consider a printer is being used by any process. If we take the printer away from that process and assign it to some other process then all the data which has been printed can become inconsistent and ineffective and also the fact that the process can't start printing again from where it has left which causes performance inefficiency.

4. Circular Wait

To violate circular wait, we can assign a priority number to each of the resource. A process can't request for a lesser priority resource. This ensures that not a single process can request a resource which is being utilized by some other process and no cycle will be formed.

Among all the methods, violating Circular wait is the only approach that can be implemented practically.

Deadlock avoidance

In deadlock avoidance, the request for any resource will be granted if the resulting state of the system doesn't cause deadlock in the system. The state of the system will continuously be checked for safe and unsafe states.

In order to avoid deadlocks, the process must tell OS, the maximum number of resources a process can request to complete its execution.

The simplest and most useful approach states that the process should declare the maximum number of resources of each type it may ever need. The Deadlock avoidance algorithm examines the resource allocations so that there can never be a circular wait condition.

The resource allocation state of a system can be defined by the instances of available and allocated resources, and the maximum instance of the resources demanded by the processes.

A state of a system recorded at some random time is shown below.

Resources Assigned

Process	Type 1	Type 2	Type 3	Type 4
A	3	0	2	2
B	0	0	1	1
C	1	1	1	0
D	2	1	4	0

Resources still needed

Process	Type 1	Type 2	Type 3	Type 4
A	1	1	0	0
B	0	1	1	2
C	1	2	1	0
D	2	1	1	2

1. E = (7 6 8 4)
2. P = (6 2 8 3)
3. A = (1 4 0 1)

Above tables and vector E, P and A describes the resource allocation state of a system. There are 4 processes and 4 types of the resources in a system. Table 1 shows the instances of each resource assigned to each process.

Table 2 shows the instances of the resources, each process still needs. Vector E is the representation of total instances of each resource in the system.

Vector P represents the instances of resources that have been assigned to processes. Vector A represents the number of resources that are not in use.

A state of the system is called safe if the system can allocate all the resources requested by all the processes without entering into deadlock.

If the system cannot fulfill the request of all processes then the state of the system is called unsafe.

The key of Deadlock avoidance approach is when the request is made for resources then the request must only be approved in the case if the resulting state is also a safe state.

Resource Allocation Graph

The resource allocation graph is the pictorial representation of the state of a system. As its name suggests, the resource allocation graph is the complete information about all the processes which are holding some resources or waiting for some resources.

It also contains the information about all the instances of all the resources whether they are available or being used by the processes.

In Resource allocation graph, the process is represented by a Circle while the Resource is represented by a rectangle. Let's see the types of vertices and edges in detail.

Vertices are mainly of two types, Resource and process. Each of them will be represented by a different shape. Circle represents process while rectangle represents resource.

A resource can have more than one instance. Each instance will be represented by a dot inside the rectangle.

Edges in RAG are also of two types, one represents assignment and other represents the wait of a process for a resource. The above image shows each of them.

A resource is shown as assigned to a process if the tail of the arrow is attached to an instance to the resource and the head is attached to a process.

A process is shown as waiting for a resource if the tail of an arrow is attached to the process while the head is pointing towards the resource.

Example

Let'sconsider 3 processes P1, P2 and P3, and two types of resources R1 and R2. The resources are having 1 instance each.

According to the graph, R1 is being used by P1, P2 is holding R2 and waiting for R1, P3 is waiting for R1 as well as R2.

The graph is deadlock free since no cycle is being formed in the graph.

Deadlock Detection using RAG

If a cycle is being formed in a Resource allocation graph where all the resources have the single instance then the system is deadlocked.

In Case of Resource allocation graph with multi-instanced resource types, Cycle is a necessary condition of deadlock but not the sufficient condition.

The following example contains three processes P1, P2, P3 and three resources R2, R2, R3. All the resources are having single instances each.

If we analyze the graph then we can find out that there is a cycle formed in the graph since the system is satisfying all the four conditions of deadlock.

Allocation Matrix

Allocation matrix can be formed by using the Resource allocation graph of a system. In Allocation matrix, an entry will be made for each of the resource assigned. For Example, in

the following matrix, en entry is being made in front of P1 and below R3 since R3 is assigned to P1.

Process	R1	R2	R3
P1	0	0	1
P2	1	0	0
P3	0	1	0

Request Matrix

In request matrix, an entry will be made for each of the resource requested. As in the following example, P1 needs R1 therefore an entry is being made in front of P1 and below R1.

Process	R1	R2	R3
P1	1	0	0
P2	0	1	0
P3	0	0	1

Avial = (0,0,0)

Neither we are having any resource available in the system nor a process going to release. Each of the process needs at least single resource to complete therefore they will continuously be holding each one of them.

We cannot fulfill the demand of at least one process using the available resources therefore the system is deadlocked as determined earlier when we detected a cycle in the graph.

Deadlock Detection and Recovery

In this approach, The OS doesn't apply any mechanism to avoid or prevent the deadlocks. Therefore the system considers that the deadlock will definitely occur. In order to get rid of deadlocks, The OS periodically checks the system for any deadlock. In case, it finds any of the deadlock then the OS will recover the system using some recovery techniques.

The main task of the OS is detecting the deadlocks. The OS can detect the deadlocks with the help of Resource allocation graph.

In single instanced resource types, if a cycle is being formed in the system then there will definitely be a deadlock. On the other hand, in multiple instanced resource type graph, detecting a cycle is not just enough. We have to apply the safety algorithm on the system by converting the resource allocation graph into the allocation matrix and request matrix.

In order to recover the system from deadlocks, either OS considers resources or processes.

For Resource

Preempt the resource

We can snatch one of the resources from the owner of the resource (process) and give it to the other process with the expectation that it will complete the execution and will release this resource sooner. Well, choosing a resource which will be snatched is going to be a bit difficult.

Rollback to a safe state

System passes through various states to get into the deadlock state. The operating system canrollback the system to the previous safe state. For this purpose, OS needs to implement check pointing at every state.

The moment, we get into deadlock, we will rollback all the allocations to get into the previous safe state.

For Process

Kill a process

Killing a process can solve our problem but the bigger concern is to decide which process to kill. Generally, Operating system kills a process which has done least amount of work until now.

Kill all process

This is not a suggestible approach but can be implemented if the problem becomes very serious. Killing all process will lead to inefficiency in the system because all the processes will execute again from starting.

Process Synchronization

Introduction:

Process Synchronization is the coordination of execution of multiple processes in a multi-process system to ensure that they access shared resources in a controlled and predictable manner. It aims to resolve the problem of race conditions and other synchronization issues in a concurrent system.

The main objective of process synchronization is to ensure that multiple processes access shared resources without interfering with each other, and to prevent the possibility of inconsistent data due to concurrent access. To achieve this, various synchronization techniques such as semaphores, monitors, and critical sections are used.

In a multi-process system, synchronization is necessary to ensure data consistency and integrity, and to avoid the risk of deadlocks and other synchronization problems. Process synchronization is an important aspect of modern operating systems, and it plays a crucial role in ensuring the correct and efficient functioning of multi-process systems.

On the basis of synchronization, processes are categorized as one of the following two types:

- **Independent Process**: The execution of one process does not affect the execution of other processes.
- **Cooperative Process**: A process that can affect or be affected by other processes executing in the system.

Process synchronization problem arises in the case of Cooperative process also because resources are shared in Cooperative processes.

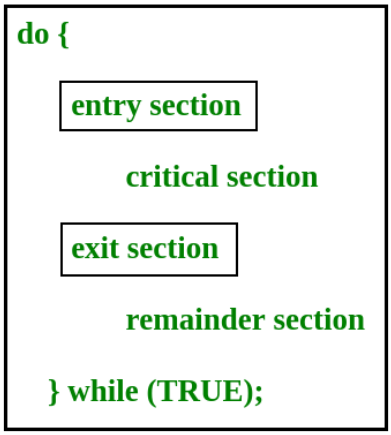
Race Condition:

When more than one process is executing the same code, or accessing the same memory or any shared variable in that condition there is a possibility that the output or the value of the shared variable is wrong so for that all the processes doing the race to say that my output is correct this condition known as a race condition. Several processes access and process the manipulations over the same data concurrently, then the outcome depends on the particular order in which the access takes place. A race condition is a situation that may occur inside a critical section. This happens when the result of multiple thread

execution in the critical section differs according to the order in which the threads execute. Race conditions in critical sections can be avoided if the critical section is treated as an atomic instruction. Also, proper thread synchronization using locks or atomic variables can prevent race conditions.

Critical Section Problem:

A critical section is a code segment that can be accessed by only one process at a time. The critical section contains shared variables that need to be synchronized to maintain the consistency of data variables. So, the critical section problem means designing a way for cooperative processes to access shared resources without creating data inconsistencies.



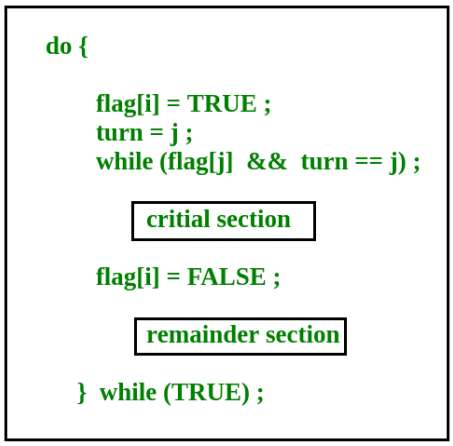
In the entry section, the process requests for entry in the **Critical Section.** Any solution to the critical section problem must satisfy three requirements:

- **Mutual Exclusion**: If a process is executing in its critical section, then no other process is allowed to execute in the critical section.
- **Progress**: If no process is executing in the critical section and other processes are waiting outside the critical section, then only those processes that are not executing in their remainder section can participate in deciding which will enter in the critical section next, and the selection cannot be postponed indefinitely.
- **Bounded Waiting**: A bound must exist on the number of times that other processes are allowed to enter their critical sections after a process has made a request to enter its critical section and before that request is granted.

Peterson's Solution:

Peterson's Solution is a classical software-based solution to the critical section problem. In Peterson's solution, we have two shared variables:

- boolean flag[i]: Initialized to FALSE, initially no one is interested in entering the critical section
- int turn: The process whose turn is to enter the critical section.



Peterson's Solution preserves all three conditions:

- Mutual Exclusion is assured as only one process can access the critical section at any time.
- Progress is also assured, as a process outside the critical section does not block other processes from entering the critical section.
- Bounded Waiting is preserved as every process gets a fair chance.

Disadvantages of Peterson's solution:

- It involves busy waiting. (In the Peterson's solution, the code statement- "while(flag[j] && turn == j);" is responsible for this. Busy waiting is not favored because it wastes CPU cycles that could be used to perform other tasks.)
- It is limited to 2 processes.
- Peterson's solution cannot be used in modern CPU architectures.

Semaphores:

A semaphore is a signalling mechanism and a thread that is waiting on a semaphore can be signalled by another thread. This is different than a mutex as the mutex can be signalled only by the thread that is called the wait function.

A semaphore uses two atomic operations, wait and signal for process synchronization.
A Semaphore is an integer variable, which can be accessed only through two operations wait() and signal().
There are two types of semaphores: Binary Semaphores and Counting Semaphores.

- **Binary Semaphores:** They can only be either 0 or 1. They are also known as mutex locks, as the locks can provide mutual exclusion. All the processes can share the same mutex semaphore that is initialized to 1.

Then, a process has to wait until the lock becomes 0. Then, the process can make the mutex semaphore 1 and start its critical section. When it completes its critical section, it can reset the value of the mutex semaphore to 0 and some other process can enter its critical section.

- **Counting Semaphores:** They can have any value and are not restricted over a certain domain. They can be used to control access to a resource that has a limitation on the number of simultaneous accesses. The semaphore can be initialized to the number of instances of the resource. Whenever a process wants to use that resource, it checks if the number of remaining instances is more than zero, i.e., the process has an instance available. Then, the process can enter its critical section thereby decreasing the value of the counting semaphore by 1. After the process is over with the use of the instance of the resource, it can leave the critical section thereby adding 1 to the number of available instances of the resource.

Advantages of Process Synchronization:

- Ensures data consistency and integrity
- Avoids race conditions
- Prevents inconsistent data due to concurrent access
- Supports efficient and effective use of shared resources

Disadvantages of Process Synchronization:

- Adds overhead to the system
- Can lead to performance degradation
- Increases the complexity of the system
- Can cause deadlocks if not implemented properly.

Memory Management in Operating System

Memory management is the functionality of an operating system which handles or manages primary memory and moves processes back and forth between main memory and disk during execution. Memory management keeps track of each and every memory location, regardless of either it is allocated to some process or it is free. It checks how much memory is to be allocated to processes. It decides which process will get memory at what time. It tracks whenever some memory gets freed or unallocated and correspondingly it updates the status.

This tutorial will teach you basic concepts related to Memory Management.

Process Address Space

The process address space is the set of logical addresses that a process references in its code. For example, when 32-bit addressing is in use, addresses can range from 0 to 0x7fffffff; that is, 2^31 possible numbers, for a total theoretical size of 2 gigabytes.

The operating system takes care of mapping the logical addresses to physical addresses at the time of memory allocation to the program. There are three types of addresses used in a program before and after memory is allocated –

S.N.	Memory Addresses & Description
1	**Symbolic addresses** The addresses used in a source code. The variable names, constants, and instruction labels are the basic elements of the symbolic address space.
2	**Relative addresses** At the time of compilation, a compiler converts symbolic addresses into relative addresses.
3	**Physical addresses** The loader generates these addresses at the time when a program is loaded into main memory.

Virtual and physical addresses are the same in compile-time and load-time address-binding schemes. Virtual and physical addresses differ in execution-time address-binding scheme.

The set of all logical addresses generated by a program is referred to as a **logical address space**. The set of all physical addresses corresponding to these logical addresses is referred to as a **physical address space.**

The runtime mapping from virtual to physical address is done by the memory management unit (MMU) which is a hardware device. MMU uses following mechanism to convert virtual address to physical address.

- The value in the base register is added to every address generated by a user process, which is treated as offset at the time it is sent to memory. For example, if the base register value is 10000, then an attempt by the user to use address location 100 will be dynamically reallocated to location 10100.
- The user program deals with virtual addresses; it never sees the real physical addresses.

What is Memory?

Computer memory can be defined as a collection of some data represented in the binary format. On the basis of various functions, memory can be classified into various categories. We will discuss each one of them later in detail.

A computer device that is capable to store any information or data temporally or permanently, is called storage device.

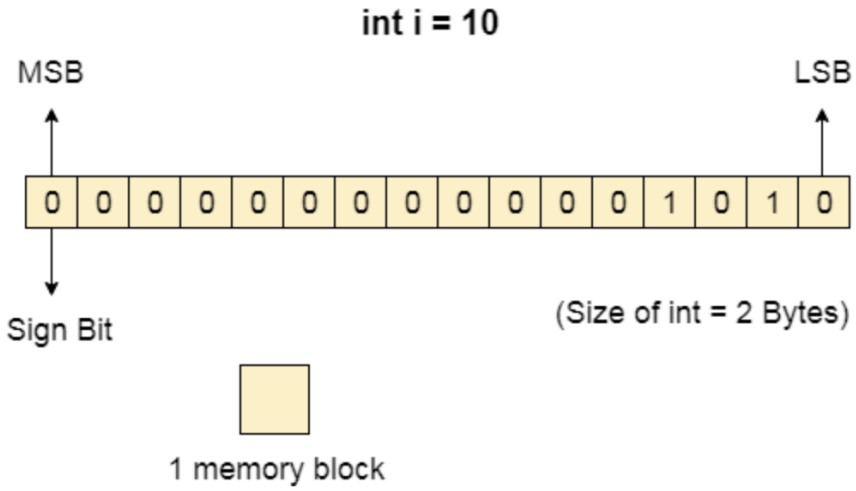
How Data is being stored in a computer system?

In order to understand memory management, we have to make everything clear about how data is being stored in a computer system.

Machine understands only binary language that is 0 or 1. Computer converts every data into binary language first and then stores it into the memory.

That means if we have a program line written as **int α = 10** then the computer converts it into the binary language and then store it into the memory blocks.

The representation of **inti = 10** is shown below.



The binary representation of 10 is 1010. Here, we are considering 32 bit system therefore, the size of int is 2 bytes i.e. 16 bit. 1 memory block stores 1 bit. If we are using signed integer then the most significant bit in the memory array is always a signed bit.

Signed bit value 0 represents positive integer while 1 represents negative integer. Here, the range of values that can be stored using the memory array is -32768 to +32767.

well, we can enlarge this range by using unsigned int. in that case, the bit which is now storing the sign will also store the bit value and therefore the range will be 0 to 65,535.

Need for Multi programming

However, The CPU can directly access the main memory, Registers and cache of the system. The program always executes in main memory. The size of main memory affects degree of Multi programming to most of the extant. If the size of the main memory is larger than CPU can load more processes in the main memory at the same time and therefore will increase degree of Multi programming as well as CPU utilization.

Let's consider,
Process Size = 4 MB
Main memory size = 4 MB
The process can only reside in the main memory at any time.
If the time for which the process does IO is P,

Then,

CPU utilization = (1-P)
let's say,
P = 70%
CPU utilization = 30 %
Now, increase the memory size, Let's say it is 8 MB.
Process Size = 4 MB
Two processes can reside in the main memory at the same time.
Let's say the time for which, one process does its IO is P,

Then

CPU utilization = (1-P^2)
let's say P = 70 %
CPU utilization = (1-0.49) =0.51 = 51 %

Therefore, we can state that the CPU utilization will be increased if the memory size gets increased.

Static vs Dynamic Loading

The choice between Static or Dynamic Loading is to be made at the time of computer program being developed. If you have to load your program statically, then at the time of compilation, the complete programs will be compiled and linked without leaving any external program or module dependency. The linker combines the object program with other necessary object modules into an absolute program, which also includes logical addresses.

If you are writing a Dynamically loaded program, then your compiler will compile the program and for all the modules which you want to include dynamically, only references will be provided and rest of the work will be done at the time of execution.

At the time of loading, with **static loading**, the absolute program (and data) is loaded into memory in order for execution to start.

If you are using **dynamic loading**, dynamic routines of the library are stored on a disk in relocatable form and are loaded into memory only when they are needed by the program.

Static vs Dynamic Linking

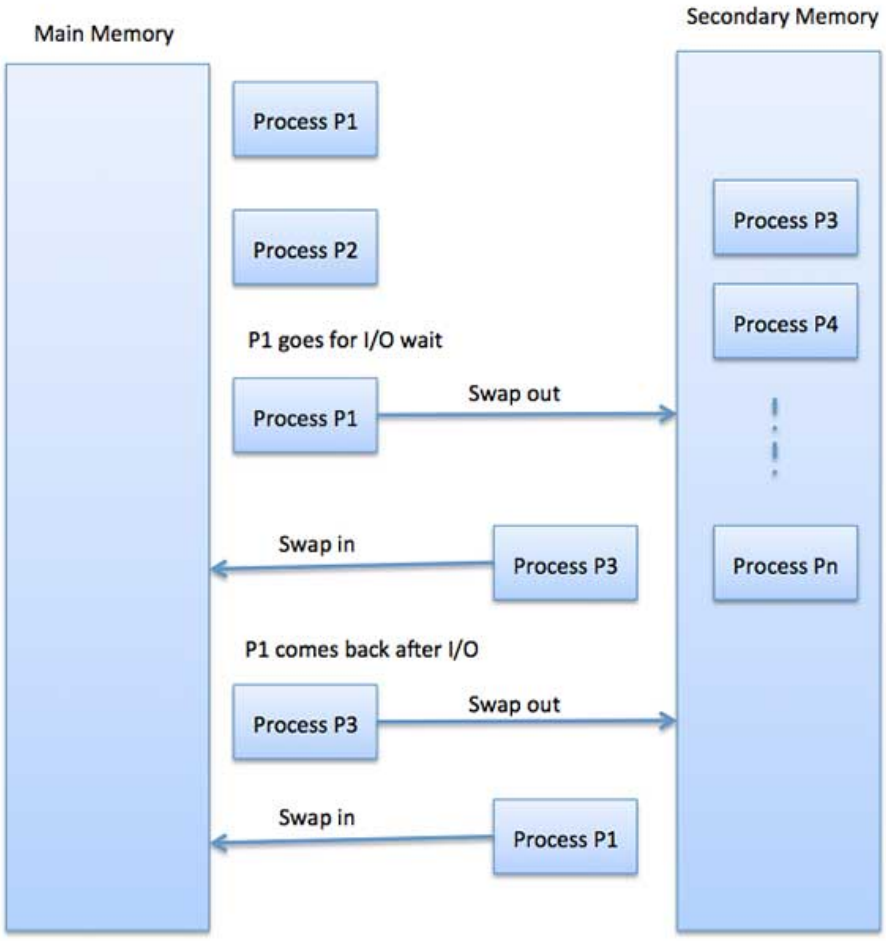
As explained above, when static linking is used, the linker combines all other modules needed by a program into a single executable program to avoid any runtime dependency.

When dynamic linking is used, it is not required to link the actual module or library with the program, rather a reference to the dynamic module is provided at the time of compilation and linking. Dynamic Link Libraries (DLL) in Windows and Shared Objects in Unix are good examples of dynamic libraries.

Swapping

Swapping is a mechanism in which a process can be swapped temporarily out of main memory (or move) to secondary storage (disk) and make that memory available to other processes. At some later time, the system swaps back the process from the secondary storage to main memory.

Though performance is usually affected by swapping process but it helps in running multiple and big processes in parallel and that's the reason **Swapping is also known as a technique for memory compaction**.



The total time taken by swapping process includes the time it takes to move the entire process to a secondary disk and then to copy the process back to memory, as well as the time the process takes to regain main memory.

Let us assume that the user process is of size 2048KB and on a standard hard disk where swapping will take place has a data transfer rate around 1 MB per second. The actual transfer of the 1000K process to or from memory will take

2048KB / 1024KB per second
= 2 seconds
= 2000 milliseconds

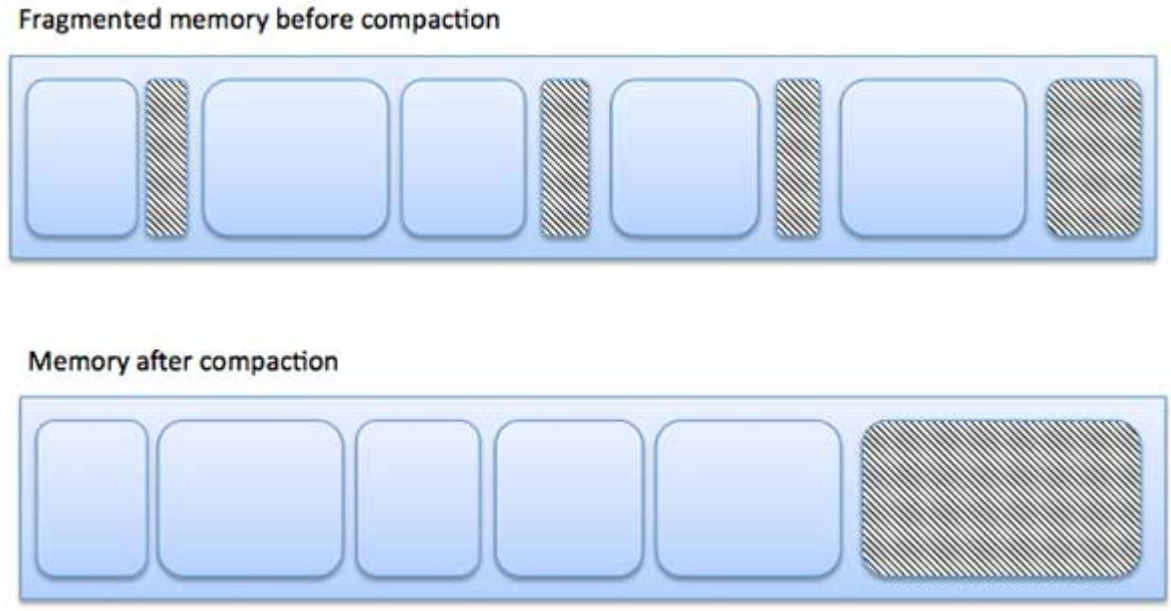
Now considering in and out time, it will take complete 4000 milliseconds plus other overhead where the process competes to regain main memory.

Fragmentation

As processes are loaded and removed from memory, the free memory space is broken into little pieces. It happens after sometimes that processes cannot be allocated to memory blocks considering their small size and memory blocks remains unused. This problem is known as Fragmentation. Fragmentation is of two types –

S.N.	Fragmentation & Description
1	**External fragmentation** Total memory space is enough to satisfy a request or to reside a process in it, but it is not contiguous, so it cannot be used.
2	**Internal fragmentation** Memory block assigned to process is bigger. Some portion of memory is left unused, as it cannot be used by another process.

The following diagram shows how fragmentation can cause waste of memory and a compaction technique can be used to create more free memory out of fragmented memory –



External fragmentation can be reduced by compaction or shuffle memory contents to place all free memory together in one large block. To make compaction feasible, relocation should be dynamic.

The internal fragmentation can be reduced by effectively assigning the smallest partition but large enough for the process.

Memory Allocation

Main memory usually has two partitions –

- **Low Memory** – Operating system resides in this memory.
- **High Memory** – User processes are held in high memory.

Operating system uses the following memory allocation mechanism.

S.N.	Memory Allocation & Description
1	**Single-partition allocation** In this type of allocation, relocation-register scheme is used to protect user processes from each other, and from changing operating-system code and data. Relocation register contains value of smallest physical address whereas limit register contains range of logical addresses. Each logical address must be less than the limit register.

2	**Multiple-partition allocation** In this type of allocation, main memory is divided into a number of fixed-sized partitions where each partition should contain only one process. 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.

Fixed Partitioning

The earliest and one of the simplest technique which can be used to load more than one processes into the main memory is Fixed partitioning or Contiguous memory allocation.

In this technique, the main memory is divided into partitions of equal or different sizes. The operating system always resides in the first partition while the other partitions can be used to store user processes. The memory is assigned to the processes in contiguous way.

In fixed partitioning,

1. The partitions cannot overlap.
2. A process must be contiguously present in a partition for the execution.

There are various cons of using this technique.

1. Internal Fragmentation

If the size of the process is lesser then the total size of the partition then some size of the partition get wasted and remain unused. This is wastage of the memory and called internal fragmentation.

As shown in the image below, the 4 MB partition is used to load only 3 MB process and the remaining 1 MB got wasted.

2. External Fragmentation

The total unused space of various partitions cannot be used to load the processes even though there is space available but not in the contiguous form.

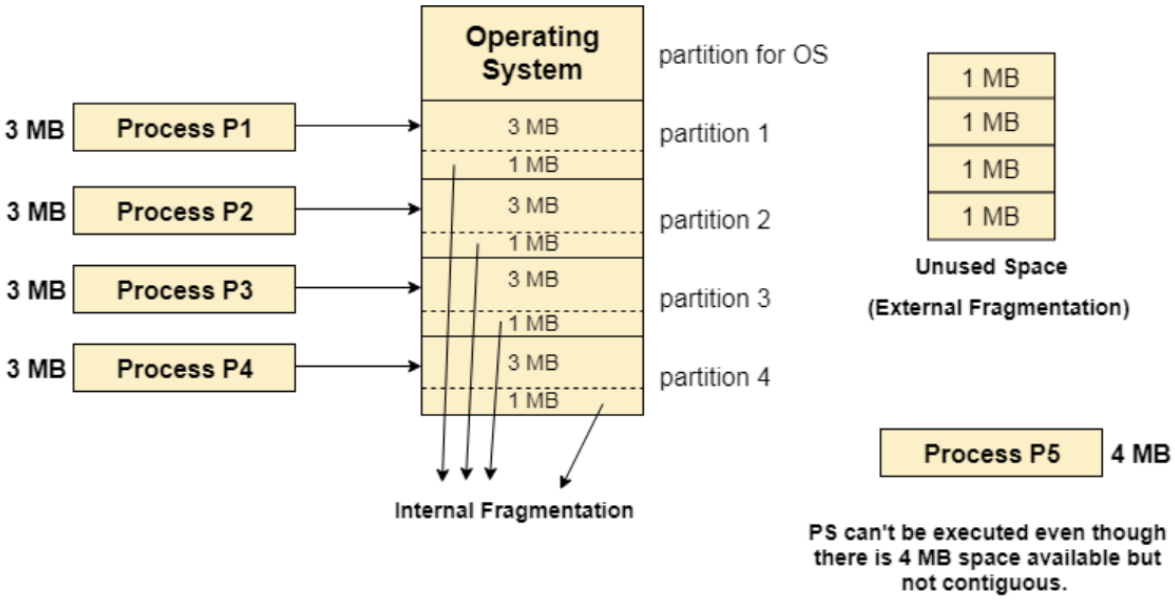
As shown in the image below, the remaining 1 MB space of each partition cannot be used as a unit to store a 4 MB process. Despite of the fact that the sufficient space is available to load the process, process will not be loaded.

3. Limitation on the size of the process

If the process size is larger than the size of maximum sized partition then that process cannot be loaded into the memory. Therefore, a limitation can be imposed on the process size that is it cannot be larger than the size of the largest partition.

4. Degree of multiprogramming is less

By Degree of multi programming, we simply mean the maximum number of processes that can be loaded into the memory at the same time. In fixed partitioning, the degree of multiprogramming is fixed and very less due to the fact that the size of the partition cannot be varied according to the size of processes.



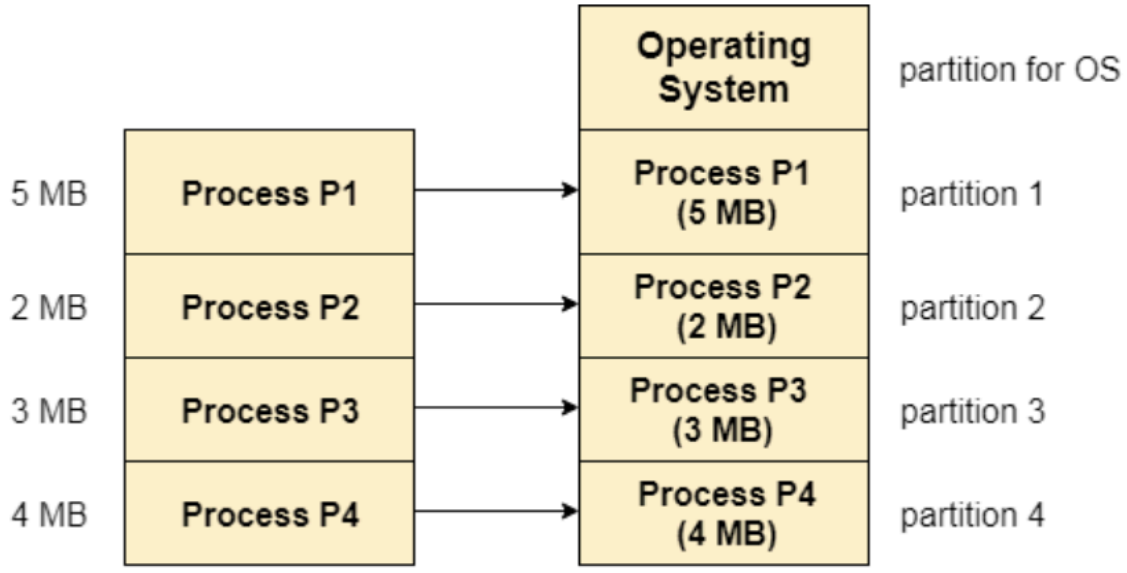
Fixed Partitioning

(Contiguous memory allocation)

Dynamic Partitioning

Dynamic partitioning tries to overcome the problems caused by fixed partitioning. In this technique, the partition size is not declared initially. It is declared at the time of process loading.

The first partition is reserved for the operating system. The remaining space is divided into parts. The size of each partition will be equal to the size of the process. The partition size varies according to the need of the process so that the internal fragmentation can be avoided.



Dynamic Partitioning

(Process Size = Partition Size)

Advantages of Dynamic Partitioning over fixed partitioning

1. No Internal Fragmentation

Given the fact that the partitions in dynamic partitioning are created according to the need of the process, It is clear that there will not be any internal fragmentation because there will not be any unused remaining space in the partition.

2. No Limitation on the size of the process

In Fixed partitioning, the process with the size greater than the size of the largest partition could not be executed due to the lack of sufficient contiguous memory. Here, In Dynamic partitioning, the process size can't be restricted since the partition size is decided according to the process size.

3. Degree of multiprogramming is dynamic

Due to the absence of internal fragmentation, there will not be any unused space in the partition hence more processes can be loaded in the memory at the same time.

Disadvantages of dynamic partitioning

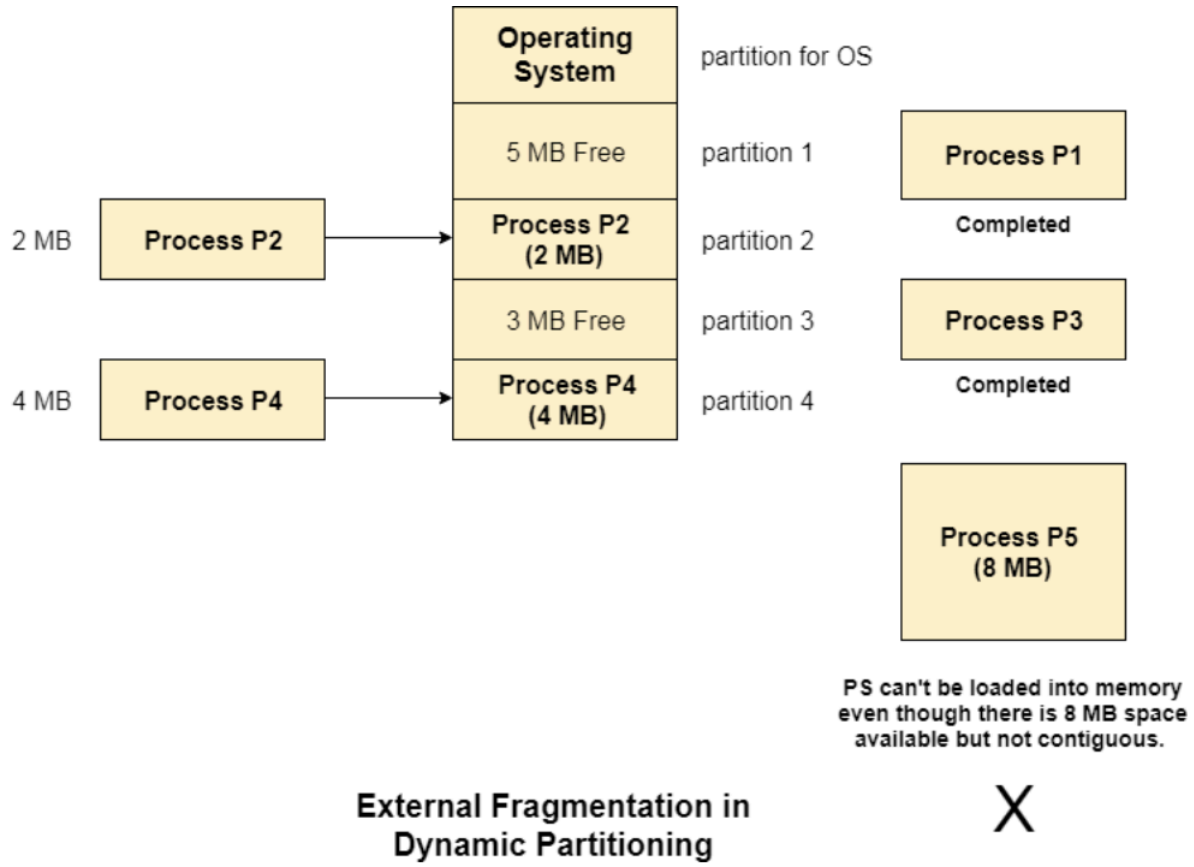
External Fragmentation

Absence of internal fragmentation doesn't mean that there will not be external fragmentation.

Let's consider three processes P1 (1 MB) and P2 (3 MB) and P3 (1 MB) are being loaded in the respective partitions of the main memory.

After some time P1 and P3 got completed and their assigned space is freed. Now there are two unused partitions (1 MB and 1 MB) available in the main memory but they cannot be used to load a 2 MB process in the memory since they are not contiguously located.

The rule says that the process must be contiguously present in the main memory to get executed. We need to change this rule to avoid external fragmentation.



Complex Memory Allocation

In Fixed partitioning, the list of partitions is made once and will never change but in dynamic partitioning, the allocation and deallocation is very complex since the partition size will be varied every time when it is assigned to a new process. OS has to keep track of all the partitions.

Due to the fact that the allocation and deallocation are done very frequently in dynamic memory allocation and the partition size will be changed at each time, it is going to be very difficult for OS to manage everything.

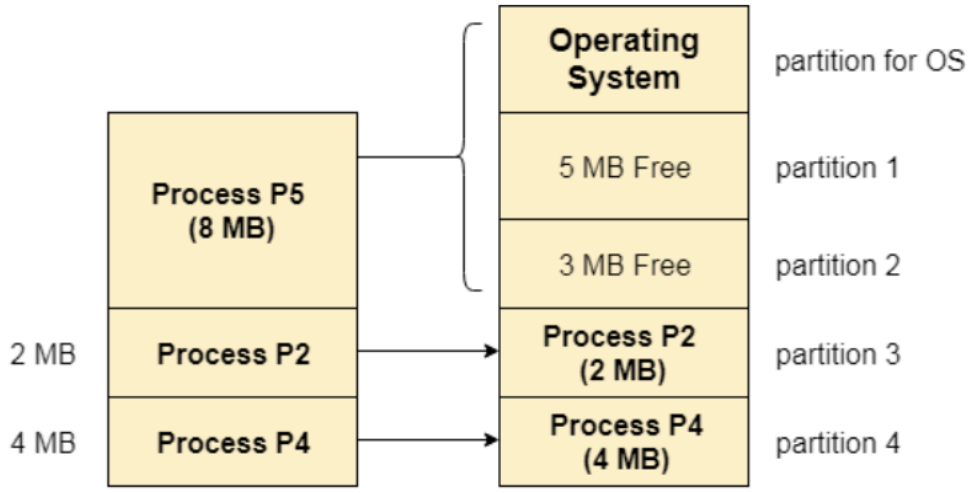
Compaction

We got to know that the dynamic partitioning suffers from external fragmentation. However, this can cause some serious problems.

To avoid compaction, we need to change the rule which says that the process can't be stored in the different places in the memory.

We can also use compaction to minimize the probability of external fragmentation. In compaction, all the free partitions are made contiguous and all the loaded partitions are brought together.

By applying this technique, we can store the bigger processes in the memory. The free partitions are merged which can now be allocated according to the needs of new processes. This technique is also called defragmentation.



Compaction

As shown in the image above, the process P5, which could not be loaded into the memory due to the lack of contiguous space, can be loaded now in the memory since the free partitions are made contiguous.

Problem with Compaction

The efficiency of the system is decreased in the case of compaction due to the fact that all the free spaces will be transferred from several places to a single place.

Huge amount of time is invested for this procedure and the CPU will remain idle for all this time. Despite of the fact that the compaction avoids external fragmentation, it makes system inefficient.

Let us consider that OS needs 6 NS to copy 1 byte from one place to another.

1. 1 B transfer needs 6 NS
2. 256 MB transfer needs 256 X 2^20 X 6 X 10 ^ -9 secs

hence, it is proved to some extent that the larger size memory transfer needs some huge amount of time that is in seconds.

Bit Map for Dynamic Partitioning

The Main concern for dynamic partitioning is keeping track of all the free and allocated partitions. However, the Operating system uses following data structures for this task.

1. Bit Map
2. Linked List

Bit Map is the least famous data structure to store the details. In this scheme, the main memory is divided into the collection of allocation units. One or more allocation units may be allocated to a process according to the need of that process. However, the size of the allocation unit is fixed that is defined by the Operating System and never changed. Although the partition size may vary but the allocation size is fixed.

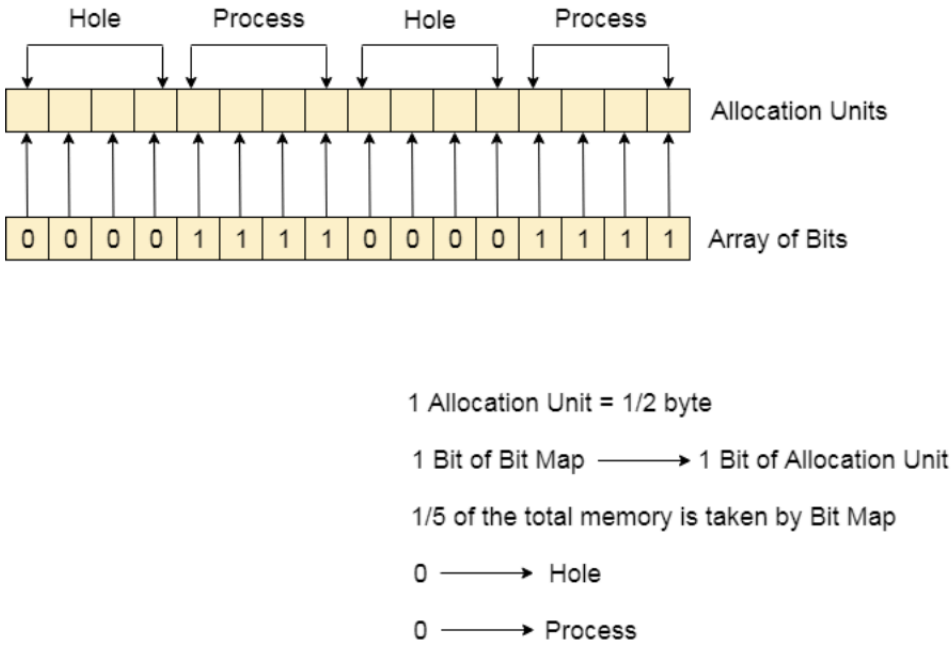
The main task of the operating system is to keep track of whether the partition is free or filled. For this purpose, the operating system also manages another data structure that is called bitmap.

The process or the hole in Allocation units is represented by a flag bit of bitmap. In the image shown below, a flag bit is defined for every bit of allocation units.

However, it is not the general case, it depends on the OS that, for how many bits of the allocation units, it wants to store the flag bit.

The flag bit is set to 1 if there is a contiguously present process at the adjacent bit in allocation unit otherwise it is set to 0.

A string of 0s in the bitmap shows that there is a hole in the relative Allocation unit while the string of 1s represents the process in the relative allocation unit.



Bit Map for Dynamic Partitioning

Disadvantages of using Bitmap

1. The OS has to assign some memory for bitmap as well since it stores the details about allocation units. That much amount of memory cannot be used to load any process therefore that decreases the degree of multiprogramming as well as throughput.

In the above image,

The allocation unit is of 4 bits that is 0.5 bits. Here, 1 bit of the bitmap is representing 1 bit of allocation unit.

1. Size of 1 allocation unit = 4 bits

2. Size of bitmap = 1/(4+1) = 1/5 of total main memory.

   Therefore, in this bitmap configuration, 1/5 of total main memory is wasted.

   2. To identify any hole in the memory, the OS need to search the string of 0s in the bitmap. This searching takes a huge amount of time which makes the system inefficient to some extent

Linked List for Dynamic Partitioning

The better and the most popular approach to keep track the free or filled partitions is using Linked List.

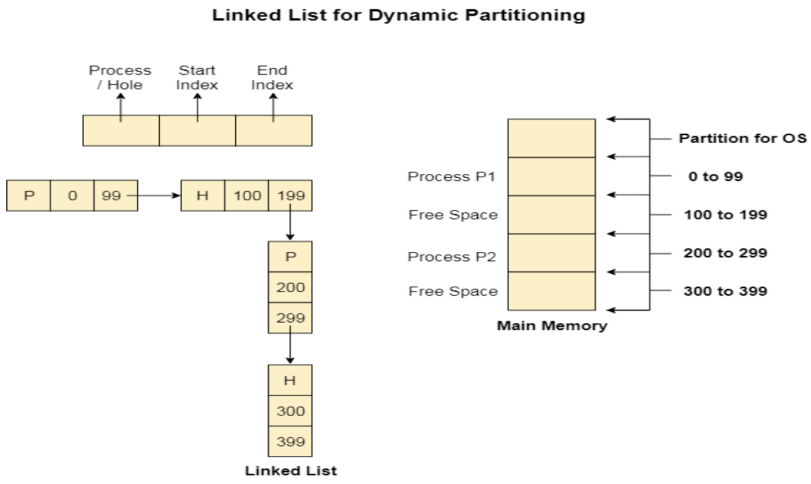
In this approach, the Operating system maintains a linked list where each node represents each partition. Every node has three fields.

1. First field of the node stores a flag bit which shows whether the partition is a hole or some process is inside.
2. Second field stores the starting index of the partition.
3. Third filed stores the end index of the partition.

If a partition is freed at some point of time then that partition will be merged with its adjacent free partition without doing any extra effort.

There are some points which need to be focused while using this approach.

1. The OS must be very clear about the location of the new node which is to be added in the linked list. However, adding the node according to the increasing order of starting index is suggestible.
2. Using a doubly linked list will make some positive effects on the performance due to the fact that a node in the doubly link list can also keep track of its previous node.



Partitioning Algorithms

There are various algorithms which are implemented by the Operating System in order to find out the holes in the linked list and allocate them to the processes.

The explanation about each of the algorithm is given below.

1. First Fit Algorithm

First Fit algorithm scans the linked list and whenever it finds the first big enough hole to store a process, it stops scanning and load the process into that hole. This procedure produces two partitions. Out of them, one partition will be a hole while the other partition will store the process.

First Fit algorithm maintains the linked list according to the increasing order of starting index. This is the simplest to implement among all the algorithms and produces bigger holes as compare to the other algorithms.

2. Next Fit Algorithm

Next Fit algorithm is similar to First Fit algorithm except the fact that, Next fit scans the linked list from the node where it previously allocated a hole.

Next fit doesn't scan the whole list, it starts scanning the list from the next node. The idea behind the next fit is the fact that the list has been scanned once therefore the probability of finding the hole is larger in the remaining part of the list.

Experiments over the algorithm have shown that the next fit is not better then the first fit. So it is not being used these days in most of the cases.

3. Best Fit Algorithm

The Best Fit algorithm tries to find out the smallest hole possible in the list that can accommodate the size requirement of the process.

Using Best Fit has some disadvantages.

1. 1. It is slower because it scans the entire list every time and tries to find out the smallest hole which can satisfy the requirement the process.
2. Due to the fact that the difference between the whole size and the process size is very small, the holes produced will be as small as it cannot be used to load any process and therefore it remains useless. Despite of the fact that the name of the algorithm is best fit, It is not the best algorithm among all.
3.

4. Worst Fit Algorithm

The worst fit algorithm scans the entire list every time and tries to find out the biggest hole in the list which can fulfill the requirement of the process.

Despite of the fact that this algorithm produces the larger holes to load the other processes, this is not the better approach due to the fact that it is slower because it searches the entire list every time again and again.

5. Quick Fit Algorithm

The quick fit algorithm suggestsmaintaining the different lists of frequently used sizes. Although, it is not practically suggestible because the procedure takes so much time to create the different lists and then expending the holes to load a process.

The first fit algorithm is **the best algorithm** among all because

1. It takes lesser time compare to the other algorithms.
2. It produces bigger holes that can be used to load other processes later on.
3. It is easiest to implement.

What is Caching?

The ***cache*** is the processor-implemented memory that holds the ***original data copy***. The main concept behind the caching memory is that the recently accessed disk blocks should be saved in the cache memory so that if any user again requires access to the same disk blocks, it may be handled locally via the cache memory eliminating the network traffic.

Cache memory size is limited because it only stores recently used data in the memory. You may also see changes in the original file when you change the cache file. If you need the data that is not in the cache memory, it is copied from the source to the cached memory and made available to the user the next time the data is requested.

The cache data may also be stored on disk instead of RAM, which is more reliable. If the computer system is destroyed, the cached data remains on the disk, but data will be lost in volatile memory, such as RAM. One main benefit of storing cached data in the main memory is that it may be accessed quickly.

Example: Cache is utilized in systems to increase speed access to usually used data.

Advantages and Disadvantages of Caching

There are various advantages and disadvantages of caching in the operating system. Some advantages and disadvantages of caching are as follows:

Advantages

1. It is faster than the system's main and second memory.
2. It increases the CPU's performance by storing all the information and instructions that are regularly used by the CPU.
3. Cache memory has a faster data access time than RAM.
4. The CPU works more quickly as data access speeds increases.

Disadvantages

1. It is quite expensive than the other memory.
2. Its storage capacity is limited.
3. It holds the data temporarily.
4. If the system is turned off, the stored data in the memory is destroyed.

File Management in Operating System

Introduction

File management is one of the basic but essential features provided by the operating system. **File management in operating system** is nothing but software that manages or handles the files (video, audio, docs, pdf, text, etc.) present in computer software. The operating system's file system can manage individuals and groups of files present in the computer system. The operating system's file system talks to us about the modification time of creation, owner, location, and state of a file present on the computer system.

What is File Management in Operating System?

File management in Operating Systems is a fundamental and crucial component. The operating system manages computer system files. Operating systems control all files with various extensions.

A file is collection of specific information stored in the memory of computer system. File management is defined as the process of manipulating files in computer system, it management includes the process of creating, modifying and deleting the files. Therefore, file management is one of the simple but crucial features offered by the operating system. The operating system's file management function entails software that handles or maintains files (**binary, text, PDF, docs, audio, video,** etc.) included in computer software.
The operating system's file system can manage single and group files in a computer system. The operating system's file management manages all of the files on the computer system with different extensions (such as **.exe, .pdf, .txt, .docx,** etc.).

Features of File Management in an Operating System

1. Providing security to application software and system.
2. Memory management
3. Disk management.
4. I/O operations.
5. File management, etc

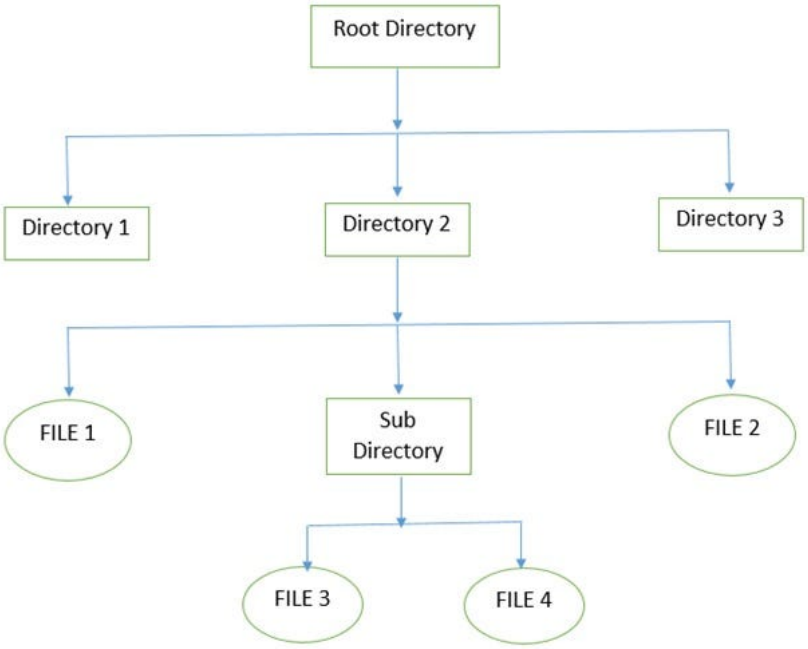
So, **file management** is one of the basic but important features of the operating system.

We can also use the files system in operating system to get details of any files present on our system. The details can be:

- locations of the file (the logical locations where the files are stored in the computer system)
- the owners of the file (who can write or read the particular file)
- when were the files created (modification time and time of file creation)
- a type of file (format of the files, for example, docs, pdfs, text, etc.).
- State of completion of files etc.

Some of the most common operations provided by the operating system of almost every operating system are:

1. File creation
2. File modification
3. File deletion
4. File transfer
5. File renaming
6. File copying and moving
7. Changing file creation



File management is the operating system, or to make the operating system understand a file, the file must be in a structure or format or predefined structure. There are **three types of file structures** present in the operating systems:

1. **Text file**: The text file is a non-executable file containing a sequence of symbols, numbers, and letters organized in the form of lines.
2. **Source file**: A source file is an executable file that contains a series of processes and functions. In simpler terms, we can say that a source file is a file that contains the instructions of a program.
3. **Object file**: An object file is a file that contains object code in the form of assembling language code or machine language code. In simpler terms, we can say that an object file contains program instructions in the form of a series of organized bytes in the form of blocks.

Functions of a File Management System in Operating System

Now let us talk about some essential file management functions in operating systems.

- Allows users to modify, create, and delete files on the computer system.
- Operates on and manages a file's permissions for different users and groups.
- Enables improved visualization by structuring the files like a tree.
- Interface for I/O operations is provided.
- Protects data from hackers and unwanted access.

Objectives of File management in Operating System

- File management in the operating system allows users to create a modified and new file and delete the old file present at different locations.
- The operating system file management software manages the location of the file store so that files can be extracted easily.
- An important feature of file management in an operating system is to make files sharable between processes. It helps the various approaches securely access the required information from a file.
- File management in operating system software also manages the files so that there is significantly less chance of data loss or destruction.

- File management in operating system provides input-output operation support to the files to read, write, or extract data from the file(s).
- They provide a standard input-output interface for the system processes and users. The simple interface allows the fast and easy modification of data.
- File management in operating system also manages various user permission present on a file. The operating system provides three user permissions. They are: read, written, and execute.
- File management in operating system supports various storage devices such as magnetic tapes, flash drives, hard disk drives (HDD), optical disks, etc., allowing the users to extract and store them conveniently.

They organize the files hierarchically in the form of folders and files so that managing these files can be more accessible from the user's perspective as well.

Advantages of File Management in Operating System

- Protection of files from unauthorized access.
- Recovers the free space created when files are deleted or removed from the hard disk.
- Assigns the **disk spaces** to various files with the help of disk management software of an operating system.
- Files may be stored at various locations as a segment, so file management in the operating system also keeps track of all the segments or blocks of particular files.
- To Helps to manage the various user permission so that only authorized persons can modify the file.
- They also keep our files secure from hackers with the help of security management in an operating system.

Disadvantages of File Management in OS

- If the size of the files becomes very large, then management takes a good amount of time due to the hierarchical order.
- We need an advanced version of the file management systems to get a more advanced management feature. One of the advanced features can be the document management feature (DMS) that can organize important documents.
- The file systems in the operating system can manage the local files that are present in the computer systems.
- Security is an issue sometimes, as a virus in a file can spread across various other files due to a tree-like (hierarchal) structure.
- Due to the hierarchal structure, file accessing can be very slow sometimes.

Examples of File Management in Operating System

An example of file management in File management in an operating system or a **file browser**. A file operating system is a user interface developed to manage various folders and files in the operating system.

Examples of file browsers are

1. Windows file manager (This PC)
2. Finder(MAC)
3. Dolphin
4. One Drive
5. GNOME Files, etc

What are the 3 basic types of File Management in an Operating System?

The 3 basic types of file management in operating system are relational, network, and hierarchical. These types are used alone or in combination to allow the whole organization of digital files and ensure they are properly destroyed, archived, and secured when needed.

The 3 basic types of file management in operating system are:

- ### Hierarchical Electronic File Management in Operating System

It is one of the most popular methods for organizing files. This type contains files by creating a hierarchy of folders arranged from the most to least important. The ranking is created by creating a folder starting with the broad category and then branching out into more specifics subcategory.

- ### Network Electronics File Management in Operating System

It is a new method for organizing files that organize files based on their locations on the computer's hard drive or another type of storage media. This type of file organization is not as popular because it can be challenging to find particular files without a search engine or strong knowledge of computer science.

- ### Relational Electronic File Management in Operating System

It is a new method for organizing data that organize files based on the relationships between data stored in each file. It helps grow in popularity because it provides an easier way to manage and find the additional information stored on a particular computer.

Conclusion

- File management is one of the basic but essential features provided by the operating system. File management in operating system is software that handles or manages the files present in computer software.
- The operating system's file system can manage individual and group files present in the computer system.
- The operating system's file system tells us about the owner's location, modification and time of creation, state, and file type present on the computer system.
- File management in the operating system allows users to create a new file and delete and modify the old files present at different locations of the computer system.
- Processes share files, so file management in the operating system makes files sharable between processes. It helps the various approaches securely access the required information from a file.
- File management in operating system provides an input-output operation that supports the files so that the data can be read, written, or extracted from the files.
- It organizes files hierarchically in the form of folders and files so that management of these files can be more accessible from the user's perspective as well.