Unit -2
Process Management

Program vs Process

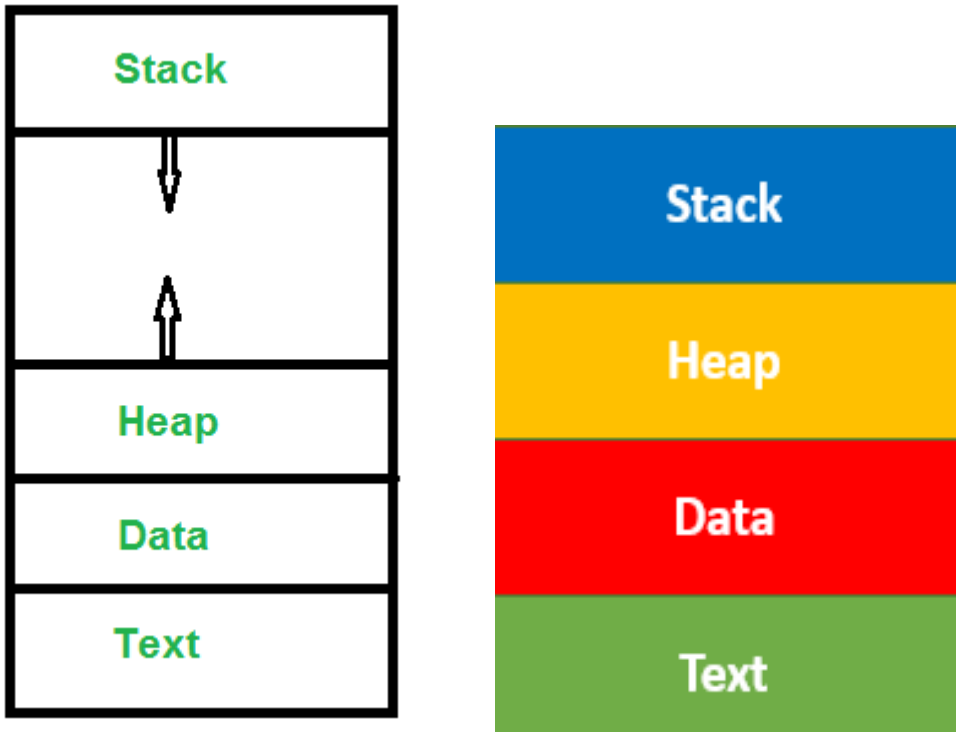
A process is a program in execution.
For example, when we write a program in C or C++ and compile it, the compiler creates binary code. The original code and binary code are both programs. When we actually run the binary code, it becomes a process.
A process is an 'active' entity, as opposed to a program, which is considered to be a '**passive' entity**. A single program can create ma

ny processes when run multiple times; for example, when we open a .exe or binary file multiple times, multiple instances begin (multiple processes are created).

Process management involves various tasks like creation, scheduling, termination of processes, and a dead lock. Process is a program that is under execution, which is an important part of modern-day operating systems. The OS must allocate resources that enable processes to share and exchange information. It also protects the resources of each process from other methods and allows synchronization among processes.

It is the job of OS to manage all the running processes of the system. It handles operations by performing tasks like process scheduling and such as resource allocation.

What does a process look like in memory?



Text Section*:* A Process, sometimes known as the Text Section, also includes the current activity represented by the value of the ***Program Counter***.
Stack*:* The Stack contains the temporary data, such as function parameters, returns addresses, and local variables. The Stack stores temporary data like function parameters, returns addresses, and local variables.
Data Section*:* Contains the global variable.
Heap Section*:* Dynamically allocated memory to process during its run time. Allocates memory, which may be processed during its run time.

Attributes of a process

The Attributes of the process are used by the Operating System to create the process control block (PCB) for each of them. This is also called context of the process. Attributes which are stored in the PCB are described below.

1. Process ID--(PID)

When a process is created, a unique id is assigned to the process which is used for unique identification of the process in the system.

2. Program counter

A program counter stores the address of the last instruction of the process on which the process was suspended. The CPU uses this address when the execution of this process is resumed.

3. Process State

The Process, from its creation to the completion, goes through various states which are new, ready, running and waiting. We will discuss about them later in detail.

4. Priority (NUMBER IS ASSIGNED)

Every process has its own priority. The process with the highest priority among the processes gets the CPU first. This is also stored on the process control block.

5. General Purpose Registers

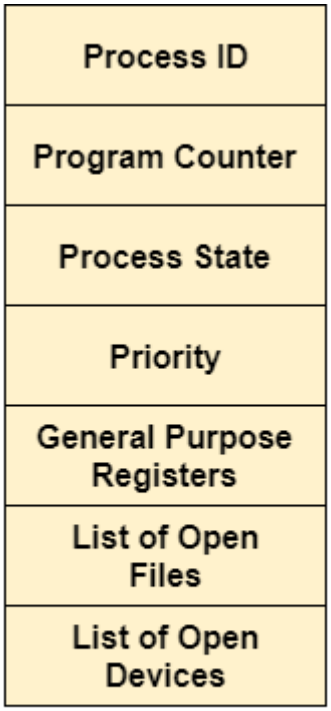
Every process has its own set of registers which are used to hold the data which is generated during the execution of the process.

6. List of open files

During the Execution, Every process uses some files which need to be present in the main memory. OS also maintains a list of open files in the PCB.

7. List of open devices

OS also maintain the list of all open devices which are used during the execution of the process.



Process Attributes

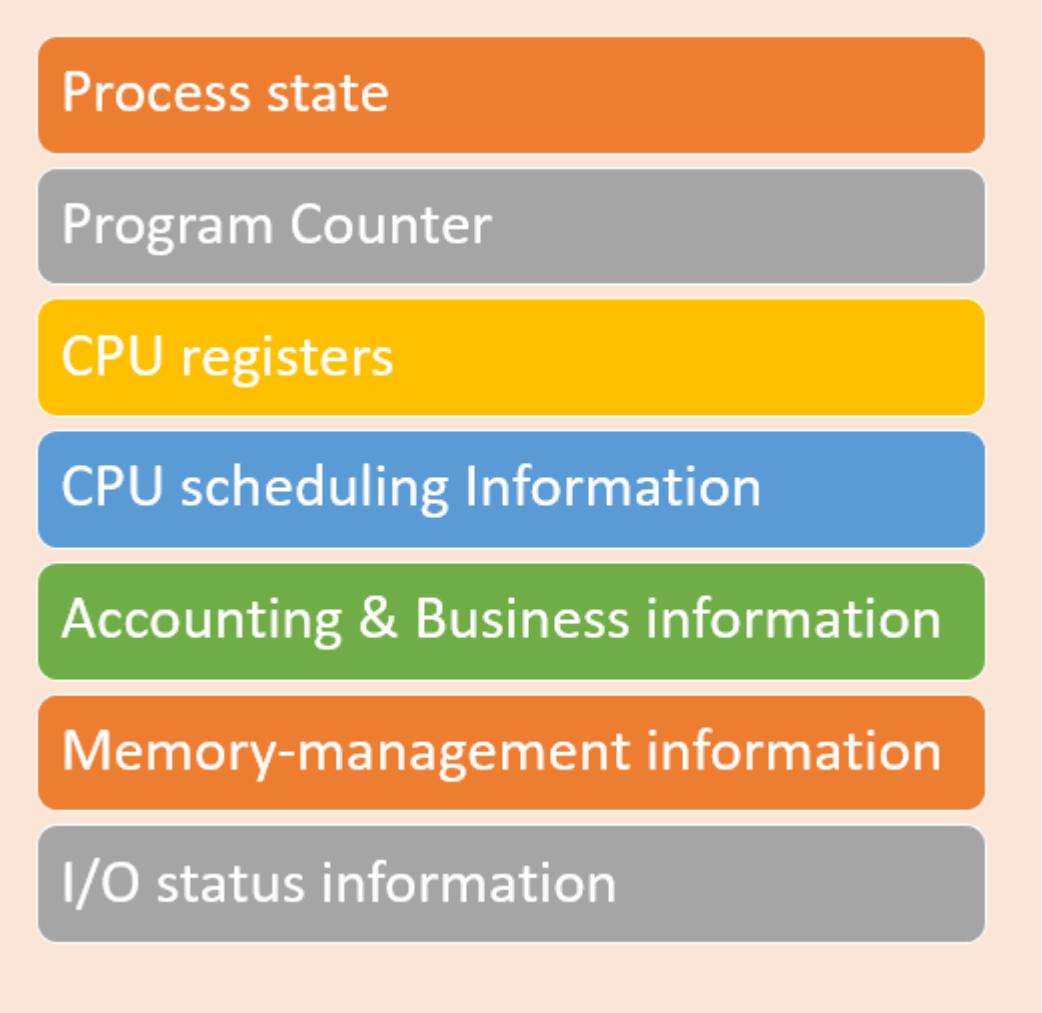
Process Control Block (PCB)

The PCB is a full form of Process Control Block. It is a data structure that is maintained by the Operating System for every process. The PCB should be identified by an integer Process ID (PID). **It helps you to store all the information required to keep track of all the running processes.**

It is also accountable for storing the contents of processor registers. These are saved when the process moves from the running state and then returns back to it. The information is quickly updated in the PCB by the OS as soon as the process makes the state transition.

Every process is represented in the operating system by a process control block, which is also called a task control block.

Here, are important components of PCB

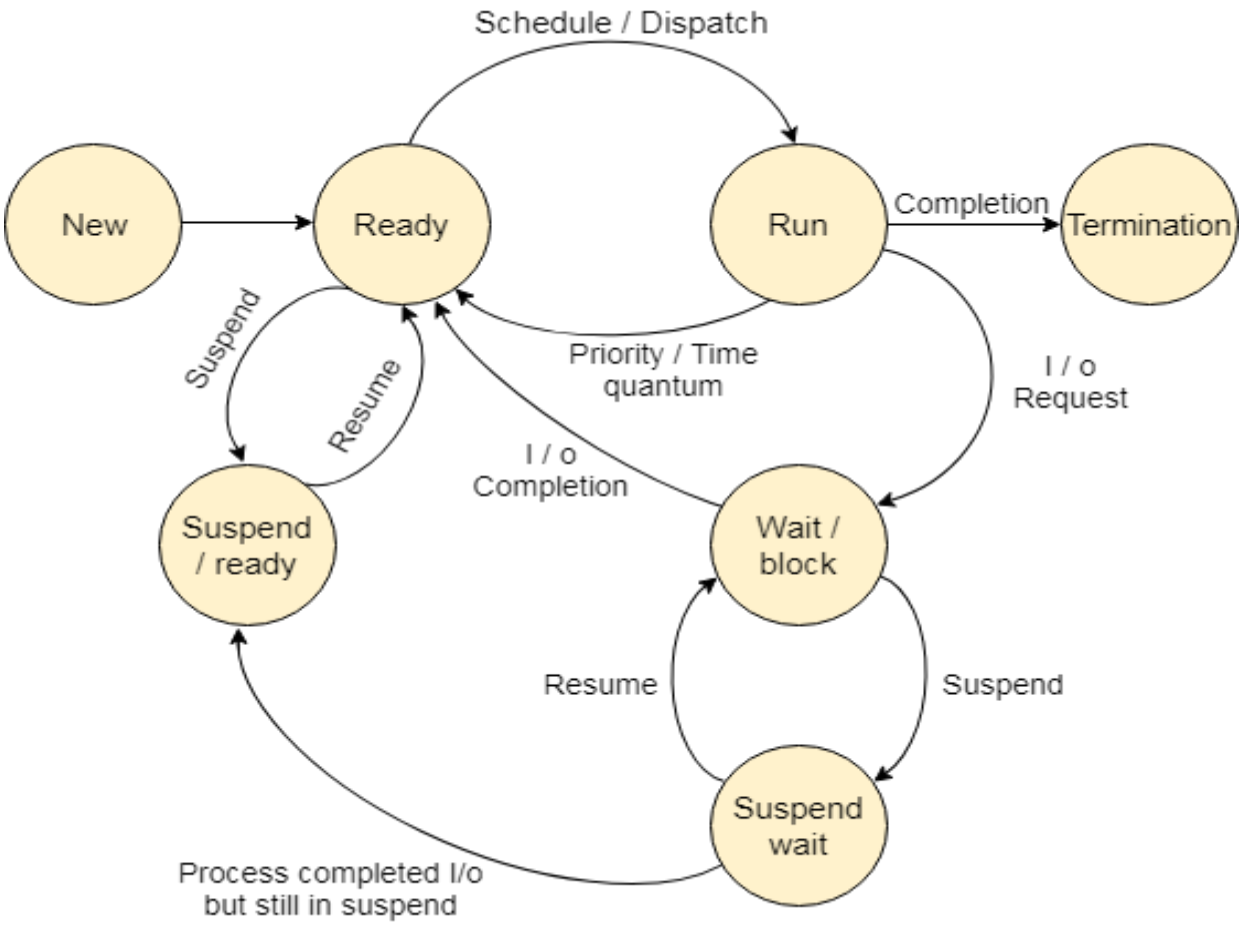


Process Control Block (PCB)

- **Process state:** A process can be new, ready, running, waiting, etc.
- **Program counter:** The program counter lets you know the address of the next instruction, which should be executed for that process.
- **CPU registers:** This component includes accumulators, index and general-purpose registers, and information of condition code.
- **CPU scheduling information:** This component includes a process priority, pointers for scheduling queues, and various other scheduling parameters.
- **Accounting and business information:** It includes the amount of CPU and time utilities like real time used, job or process numbers, etc.
- **Memory-management information:** This information includes the value of the base and limit registers, the page, or segment tables. This depends on the memory system, which is used by the operating system.
- **I/O status information:** This block includes a list of open files, the list of I/O devices that are allocated to the process, etc.

Process States

State Diagram



The process, from its creation to completion, passes through various states. The minimum number of states is five.

The names of the states are not standardized although the process may be in one of the following states during execution.

1. New

A program which is going to be picked up by the OS into the main memory is called a new process.

2. Ready

Whenever a process is created, it directly enters in the ready state, in which, it waits for the CPU to be assigned. The OS picks the new processes from the secondary memory and put all of them in the main memory.

The processes which are ready for the execution and reside in the main memory are called ready state processes. There can be many processes present in the ready state.

3. Running

One of the processes from the ready state will be chosen by the OS depending upon the scheduling algorithm. Hence, if we have only one CPU in our system, the number of running processes for a particular time will always be one. If we have n processors in the system then we can have n processes running simultaneously.

4. Block or wait

From the Running state, a process can make the transition to the block or wait state depending upon the scheduling algorithm or the intrinsic behaviour of the process.

When a process waits for a certain resource to be assigned or for the input from the user then the OS move this process to the block or wait state and assigns the CPU to the other processes.

5. Completion or termination

When a process finishes its execution, it comes in the termination state. All the context of the process (Process Control Block) will also be deleted the process will be terminated by the Operating system.

6. Suspend ready

A process in the ready state, which is moved to secondary memory from the main memory due to lack of the resources (mainly primary memory) is called in the suspend ready state.

If the main memory is full and a higher priority process comes for the execution then the OS have to make the room for the process in the main memory by throwing the lower priority process out into the secondary memory. The suspend ready processes remain in the secondary memory until the main memory gets available.

7. Suspend wait

Instead of removing the process from the ready queue, it's better to remove the blocked process which is waiting for some resources in the main memory. Since it is already waiting for some resource to get available hence it is better if it waits in the secondary memory and make room for the higher priority process. These processes complete their execution once the main memory gets available and their wait is finished.

Types of Schedulers

There are three types of schedulers available:

1. **Long Term Scheduler**
2. **Short Term Scheduler**
3. **Medium Term Scheduler**

Let's discuss about all the different types of Schedulers in detail:

Long Term Scheduler

It is also called a **job scheduler**. A long-term scheduler determines which programs are admitted to the system for processing. It selects processes from the queue and loads them into memory for execution. Process loads into the memory for CPU scheduling.

The primary objective of the job scheduler is to provide a balanced mix of jobs, such as I/O bound and processor bound. It also controls the degree of multiprogramming. If the degree of multiprogramming is stable, then the average rate of process creation must be equal to the average departure rate of processes leaving the system.

On some systems, the long-term scheduler may not be available or minimal. Time-sharing operating systems have no long term scheduler. When a process changes the state from new to ready, then there is use of long-term scheduler.

Short Term Scheduler

It is also called as **CPU scheduler**. Its main objective is to increase system performance in accordance with the chosen set of criteria. It is the change of ready state to running state of the process. CPU scheduler selects a process among the processes that are ready to execute and allocates CPU to one of them.

Short-term schedulers, also known as dispatchers, make the decision of which process to execute next. Short-term schedulers are faster than long-term schedulers.

Medium Term Scheduler

Medium-term scheduling is a part of **swapping**. It removes the processes from the memory. It reduces the degree of multiprogramming. The medium-term scheduler is in-charge of handling the swapped out-processes.

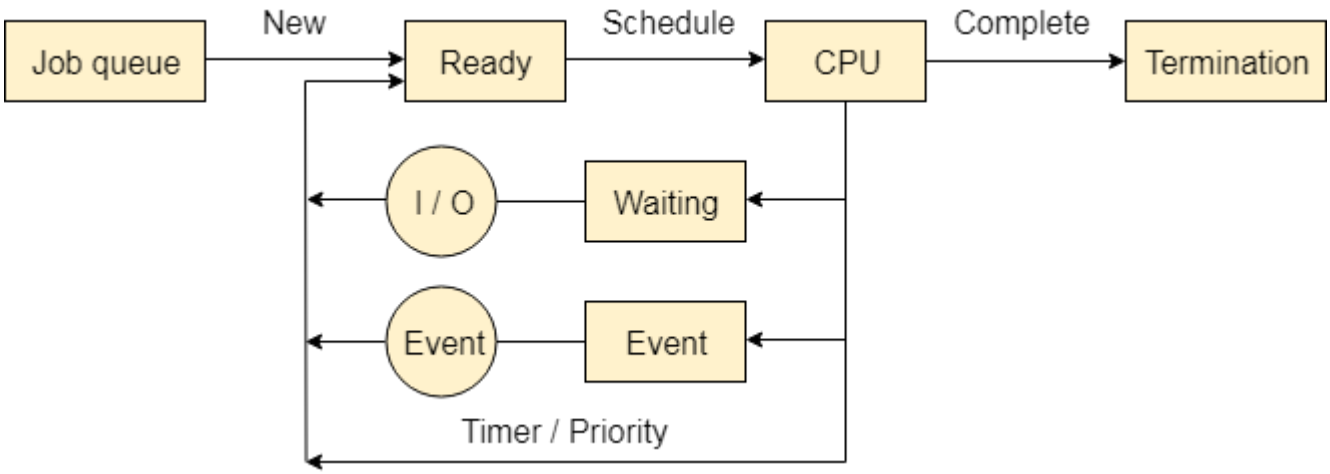
A running process may become suspended if it makes an I/O request. A suspended process cannot make any progress towards completion. In this condition, to remove the process from memory and make space for other processes, the suspended process is moved to the secondary storage. This process is called **swapping**, and the process is said to be swapped out or rolled out. Swapping may be necessary to improve the process mix.

Comparison among Scheduler

S.N.	Long-Term Scheduler	Short-Term Scheduler	Medium-Term Scheduler
1	It is a job scheduler	It is a CPU scheduler	It is a process swapping scheduler.
2	Speed is lesser than short term scheduler	Speed is fastest among other two	Speed is in between both short and long term scheduler.
3	It controls the degree of multiprogramming	It provides lesser control over degree of multiprogramming	It reduces the degree of multiprogramming.

4	It is almost absent or minimal in time sharing system	It is also minimal in time sharing system	It is a part of Time sharing systems.
5	It selects processes from pool and loads them into memory for execution	It selects those processes which are ready to execute	It can re-introduce the process into memory and execution can be continued.

Various Queues:



There are the following queues maintained by the Operating system.

1. Job Queue

In starting, all the processes get stored in the job queue. It is maintained in the secondary memory. The long term scheduler (Job scheduler) picks some of the jobs and put them in the primary memory.

2. Ready Queue

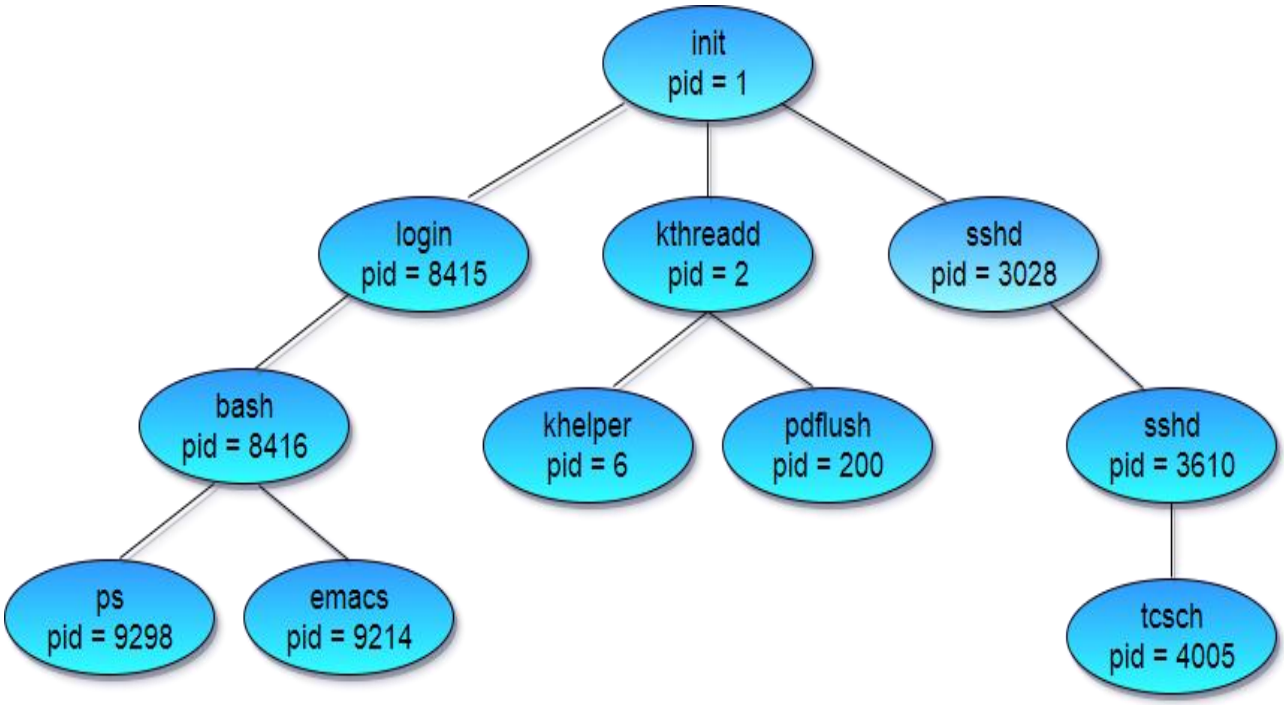
Ready queue is maintained in primary memory. The short term scheduler picks the job from the ready queue and dispatch to the CPU for the execution.

3. Waiting Queue

When the process needs some IO operation in order to complete its execution, OS changes the state of the process from running to waiting. The context (PCB) associated with the process gets stored on the waiting queue which will be used by the Processor when the process finishes the IO.

CPU-Bound Vs. I/O-Bound Processes:
A CPU-bound process requires more CPU time or spends more time in the running state.
An I/O-bound process requires more I/O time and less CPU time. An I/O-bound process spends more time in the waiting state.

Operations on Process



Process Creation

A process may create several new processes, during the course of execution.

The creating process is called a parent process, whereas the new processes are called the children of that process.

When a process creates a new process, two possibilities exist in terms of execution:

- The parent continues to execute concurrently with its children.
- The parent waits until some or all of its children have terminated.

There are also two possibilities in terms of the address space of the new process:

- The child process is a duplicate of the parent process.

- The child process has a program loaded into it.

Two types of modes: 1. User mode
2. OS mode(kernel mode)

In UNIX, each process is identified by its process identifier, which is a unique integer.

A new process is created by the fork()

Process Termination

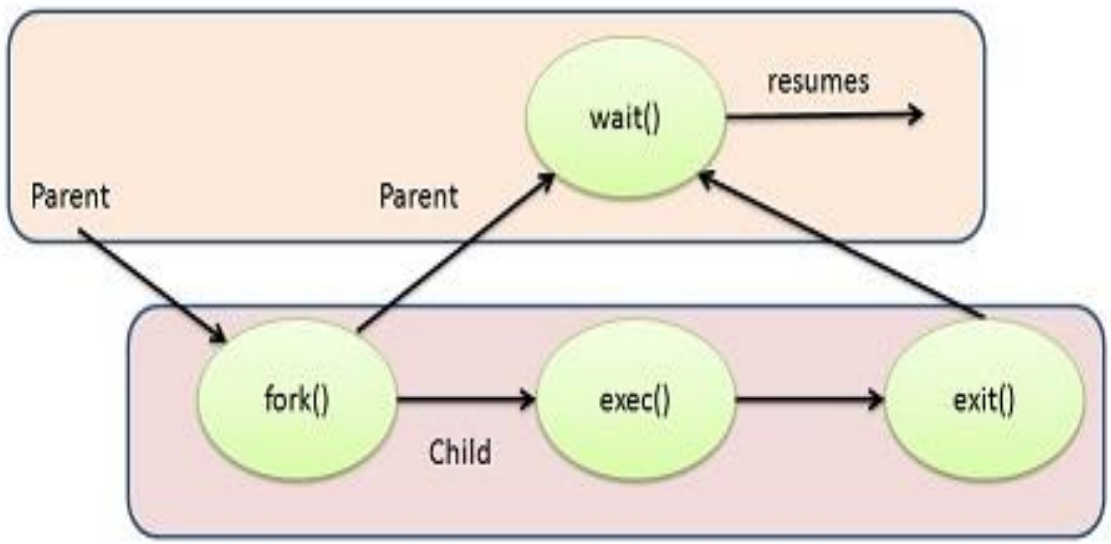
- A process terminates when it finishes executing its final statement and asks the operating system to delete it by using the exit system call.

- At that point, the process may return data (output) to its parent process (via the wait system call).
- A process can cause the termination of another process via an appropriate system call.
- A parent may terminate the execution of one of its children for a variety of reasons, such as these:
- The child has exceeded its usage of some of the resources that it has been allocated.
- The task assigned to the child is no longer required.
- The parent is exiting, and the operating system does not allow a child to continue if its parent terminates.

  On such systems, if a process terminates (either normally or abnormally), then all its children must also be terminated. This phenomenon, referred to as **cascading termination**, is normally initiated by the operating system.

Process Cycle using System Calls

- A parent process creates a sub process by making a **fork()** system call.
- After the fork(), **exec()** system call is used to load the binary file of child process into memory and start its execution.
- While the child process is executed, the parent process can create more children. If parent process has nothing to do, it just issues the **wait()** system call and waits until the child processes exit.
- **exit()** system call terminates the process. When it is used on the child process, it exists and parent is notified to resume



Creation of Process

Process Creation - fork() System Call

The process can create the new process by using the fork() system call. The creating process is known as parent process whereas the newly created process is known as child process.

Process ID

In general, each process has a unique process identification number called process id(i.e pid). Most of the operating system use this pid to identify the process.

Required Resources

Usually the process requires some resources (CPU time, file, memory, I/O device) to complete its task. When a process creates several new processes,

that child processes may able to get its resources from operating system. That means, the parent process may assign some resources to its children or it may have to share some resources with its children.

Process Address Space

In terms of address space, There are also two possibilities:

1. The child process is a duplicate of the parent process that means, the child has the same program and data as the parent.
2. The child process has a new program loaded into it.

Process Execution - exec() System Call

When a process creates a new process, then there are two possibilities in terms of execution:

1. The parent process continues to execute concurrently with its children.
2. The parent process waits until some or all of its children have terminated.

exec() system call is used to load the binary file of child process into memory and start its execution.

Process Blocking - wait() System Call

wait() system call is called to make a process wait until something else happens.

Process Termination - exit() System call

The **exit()** system call is used to terminate the process. Once the process completes its execution of final statement, it asks the operating system to delete the process from memory and deallocates its all resources. After the termination, the child may return their status code to its parent.

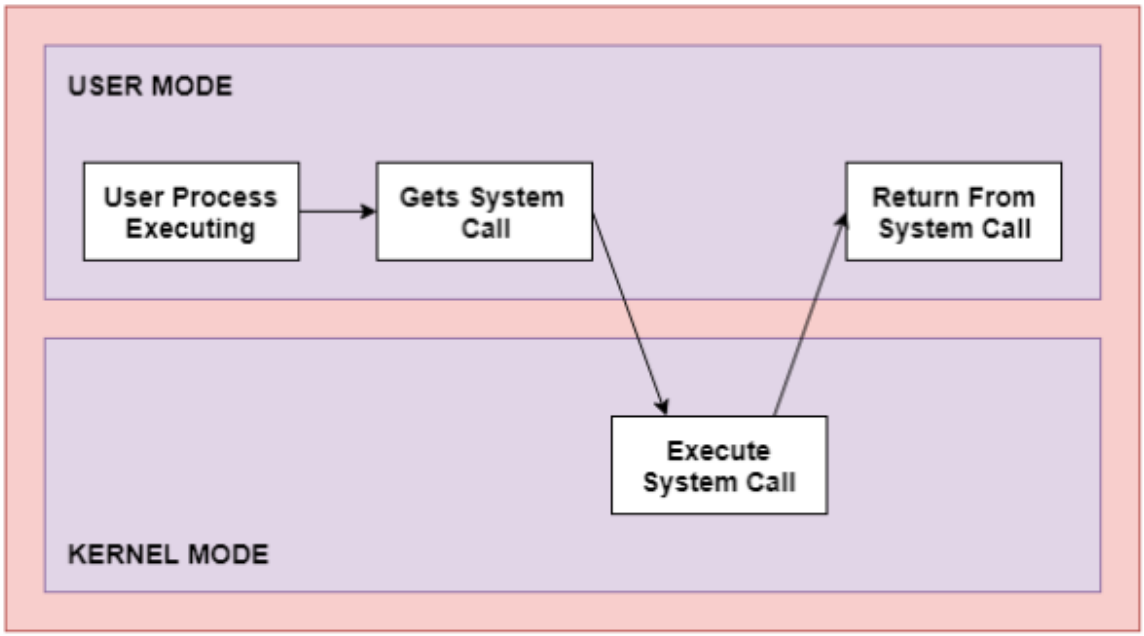
Parent may terminate their children due to the following reasons:

- The child has exceeded its usage of some of the resources that it has been allocated.
- The work assigned to the child is no longer required
- If the parent terminates, the operating system may not allow a child to continue its execution.

System calls:

The interface between a process and an operating system is provided by system calls. In general, system calls are available as assembly language instructions. They are also included in the manuals used by the assembly level programmers. System calls are usually made when a process in user mode requires access to a resource. Then it requests the kernel to provide the resource via a system call.

A figure representing the execution of the system call is given as follows −



As can be seen from this diagram, the processes execute normally in the user mode until a system call interrupts this. Then the system call is executed on a priority basis in the kernel mode. After the execution of the system call, the control returns to the user mode and execution of user processes can be resumed.

In general, system calls are required in the following situations −

- If a file system requires the creation or deletion of files. Reading and writing from files also require a system call.
- Creation and management of new processes.
- Network connections also require system calls. This includes sending and receiving packets.
- Access to a hardware devices such as a printer, scanner etc. requires a system call.

Inter Process Communication (IPC) refers to a mechanism, where the operating systems allow various processes to communicate with each other. This involves synchronizing their actions and managing shared data.

A process can be of two types:

- Independent process.
- Co-operating process.

An independent process is not affected by the execution of other processes while a co-operating process can be affected by other executing processes. Though one can think that those processes, which are running independently, will execute very efficiently, in reality, there are many situations when co-operative nature can be utilised for increasing computational speed, convenience and modularity.

Inter process communication (IPC) is a mechanism which allows processes to communicate with each other and synchronize their actions. The communication between these processes can be seen as a method of co-operation between them. Processes can communicate with each other through both:

1. **Shared Memory**
2. **Message passing**

The Figure 1 below shows a basic structure of communication between processes via the shared memory method and via the message passing method.

An operating system can implement both method of communication. First, we will discuss the shared memory methods of communication and then message passing.

Communication between processes using shared memory requires processes to share some variable and it completely depends on how programmer will implement it. One way of communication using shared memory can be imagined like this:

- Suppose process1 and process2 are executing simultaneously and they share some resources or use some information from another process. Process1 generate information about certain computations or resources being used and keeps it as a record in shared memory.
- When process2 needs to use the shared information, it will check in the record stored in shared memory and take note of the information generated by process1 and act accordingly. Processes can use shared memory for extracting information as a record from another process as well as for delivering any specific information to other processes.
  Let's discuss an example of communication between processes using shared memory method.

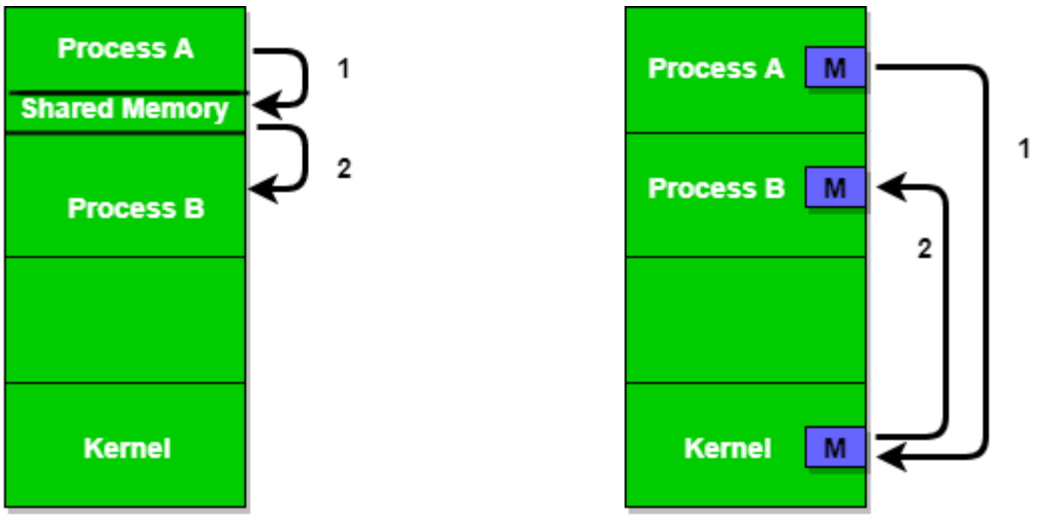


Figure 1 - Shared Memory and Message Passing

i) Shared Memory Method

Ex: Producer-Consumer problem

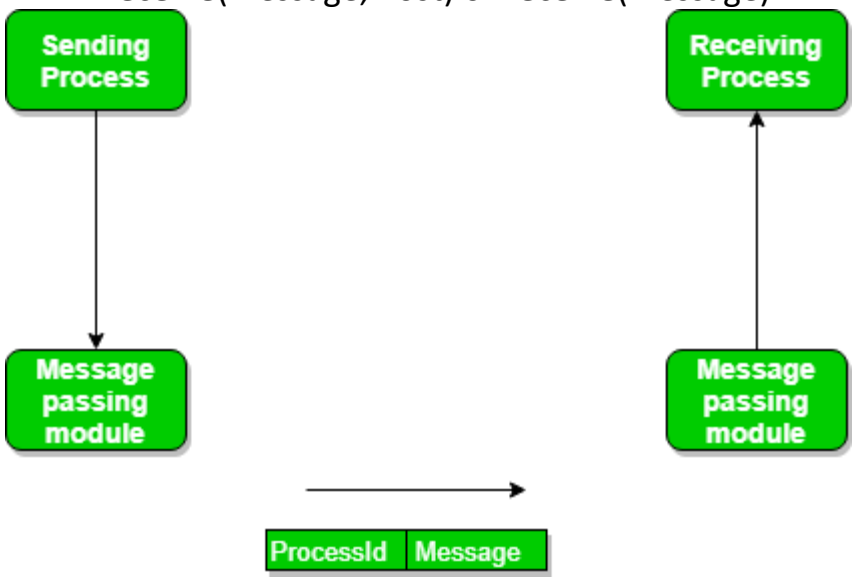
There are two processes: Producer and Consumer. Producer produces some item and Consumer consumes that item. The two processes share a common space or memory location known as a buffer where the item produced by Producer is stored and from which the Consumer consumes the item, if needed. There are two versions of this problem:

- the first one is known as **unbounded buffer problem** in which Producer can keep on producing items and there is no limit on the size of the buffer
- the second one is known as the **bounded buffer** problem in which Producer can produce up to a certain number of items before it starts waiting for Consumer to consume it.
- We will discuss the bounded buffer problem. First, the Producer and the Consumer will share some common memory, then producer will start producing items. If the total produced item is equal to the size of buffer, producer will wait to get it consumed by the Consumer.
- Similarly, the consumer will first check for the availability of the item. If no item is available, Consumer will wait for Producer to produce it. If there are items available, Consumer will consume it. The pseudo code to demonstrate is provided below:

ii) Messaging Passing Method

In this method, processes communicate with each other without using any kind of shared memory. If two processes p1 and p2 want to communicate with each other, they proceed as follows:

- Establish a communication link (if a link already exists, no need to establish it again.)
- Start exchanging messages using basic primitives.
  We need at least two primitives:
  – **send**(message, destinaion) or **send**(message)
  – **receive**(message, host) or **receive**(message)



The message size can be of fixed size or of variable size. If it is of fixed size, it is easy for an OS designer but complicated for a programmer and if it is of variable size then it is easy for a programmer but complicated for the OS designer. A standard message can have two parts: **header and body.**
The **header part** is used for storing message type, destination id, source id, message length, and control information. The control information contains information like what to do if runs out of buffer space, sequence number, priority. Generally, message is sent using FIFO style.

While implementing the link, there are some questions which need to be kept in mind like:

1. How are links established?
2. Can a link be associated with more than two processes?
3. How many links can there be between every pair of communicating processes?
4. What is the capacity of a link? Is the size of a message that the link can accommodate fixed or variable?
5. Is a link unidirectional or bi-directional?

A link has some capacity that determines the number of messages that can reside in it temporarily for which every link has a queue associated with it which can be of zero capacity, bounded capacity, or unbounded capacity.
In zero capacity, the sender waits until the receiver informs the sender that it has received the message. In non-zero capacity cases, a process does not know whether a message has been received or not after the send operation.
For this, the sender must communicate with the receiver explicitly.
Implementation of the link depends on the situation; it can be either a direct communication link or an in-directed communication link.
1. Direct Communication links are implemented when the process uses a specific process identifier for the communication, but it is hard to identify the sender ahead of time.
For example: the print server.

In-direct Communication is done via a shared mailbox (port), which consists of a queue of messages. The sender keeps the message in mailbox and the receiver picks them up.
In Indirect message passing, processes use mailboxes (also referred to as ports) for sending and receiving messages. Each mailbox has a unique id and processes can communicate only if they share a mailbox. Link established only if processes share a common mailbox and a single link can be associated with many processes. Each pair of processes can share several communication links and these links may be unidirectional or bi-directional. Suppose two processes want to communicate though indirect message passing, the required operations are: create a mail box, use this mail box for sending and receiving messages, and then destroy the mail box. The standard primitives used are: **send (A, message)** which means send the message to mailbox A. The primitive for the receiving the message also works in the same way e.g. **receive(A, message)**.
There is a problem in this mailbox implementation. Suppose there are more than two processes sharing the same mailbox and suppose the process p1 sends a message to the mailbox, which process will be the receiver? This can be solved by either enforcing that only two processes can share a single mailbox or enforcing that only one process is allowed to execute the receive at a given time or select any process randomly and notify the sender about the receiver. A mailbox can be made private to a single sender/receiver pair and can also be shared between multiple sender/receiver pairs. Port is an implementation of such mailbox which can have multiple sender and single receiver. It is used in client/server applications (in this case the server is the receiver). The port is owned by the receiving process and created by OS on the request of the receiver process and can be destroyed either on request of the same receiver

process or when the receiver terminates itself. Enforcing that only one process is allowed to execute the receive can be done using the concept of mutual exclusion.

Message Passing through Exchanging the Messages

2.Synchronous and Asynchronous Message Passing:

A process that is blocked is one that is waiting for some event, such as a resource becoming available or the completion of an I/O operation. IPC is possible between the processes on same computer as well as on the processes running on different computer i.e. in networked/distributed system. In both cases, the process may or may not be blocked while sending a message or attempting to receive a message so message passing may be blocking or non-blocking.

Blocking is considered **synchronous** and **blocking send** means the sender will be blocked until the message is received by receiver. Similarly, **blocking receive** has the receiver block until a message is available. Non-blocking is considered **asynchronous** and Non-blocking send has the sender sends the message and continue.

Similarly, Non-blocking receive has the receiver receive a valid message or null. After a careful analysis, we can come to a conclusion that for a sender it is more natural to be non-blocking after message passing as there may be a need to send the message to different processes. However, the sender expects acknowledgement from the receiver in case the send fails.

Similarly, it is more natural for a receiver to be blocking after issuing the receive as the information from the received message may be used for further execution. At the same time, if the messages send keep on failing, the receiver will have to wait indefinitely. That is why we also consider the other possibility of message passing. There are basically three preferred combinations:

- Blocking send and blocking receive
- Non-blocking send and Non-blocking receive
- Non-blocking send and Blocking receive (Mostly used)

3. Automatic and Explicit Buffering:

Zero capacity –no buffering

Bounded capacity -automatic buffering

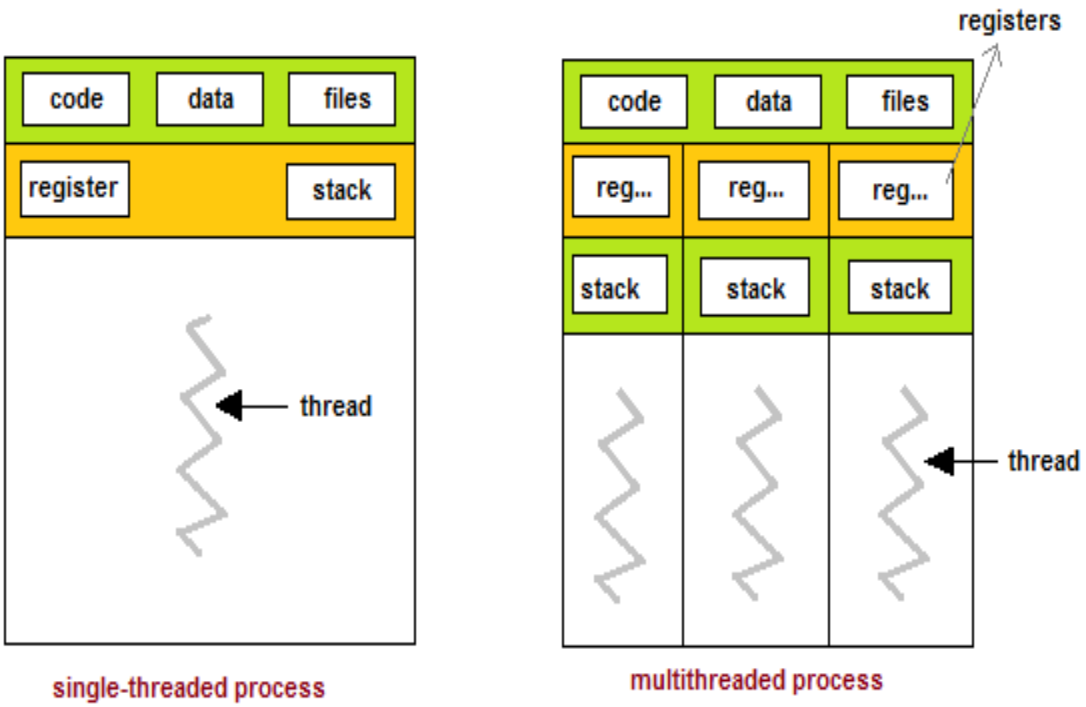
Unbounded capacity queue-automatic buffering

Context Switch

Context Switching involves storing the context or state of a process so that it can be reloaded when required and execution can be resumed from the same point as earlier. This is a feature of a multitasking operating system and allows a single CPU to be shared by multiple processes. The Context switching is a technique or method used by the operating system to switch a process from one state to another to execute its function using CPUs in the system. When switching performs in the system, it stores the old running process's status in the form of registers and assigns the CPU to a new process to execute its tasks. While a new process is running in the system, the previous process must wait in a ready queue. The execution of the old process starts at that point where another process stopped it. It defines the characteristics of a multitasking operating system in which multiple processes shared the same CPU to perform multiple tasks without the need for additional processors in the system.

Threads is an execution unit which consists of its own program counter, a stack, and a set of registers. Threads are also known **as Lightweight processes**. The CPU switches rapidly back and forth among the threads giving illusion that the threads are running in parallel.

As each thread has its own independent resource for process execution, multiple processes can be executed parallel by increasing number of threads.



Types of Thread

There are two types of threads:

1. User level Threads
2. Kernel level Threads

User threads are above the kernel and without kernel support. These are the threads that application programmers use in their programs.

Kernel threads are supported within the kernel of the OS itself. All modern OS support kernel level threads, allowing the kernel to perform multiple simultaneous tasks and/or to service multiple kernel system calls simultaneously.

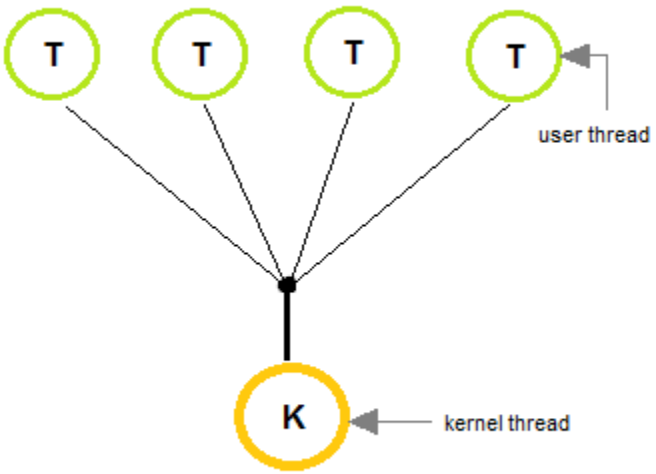
Multithreading Models

The user threads must be mapped to kernel threads, by one of the following strategies:

- Many to One Model
- One to One Model
- Many to Many Model

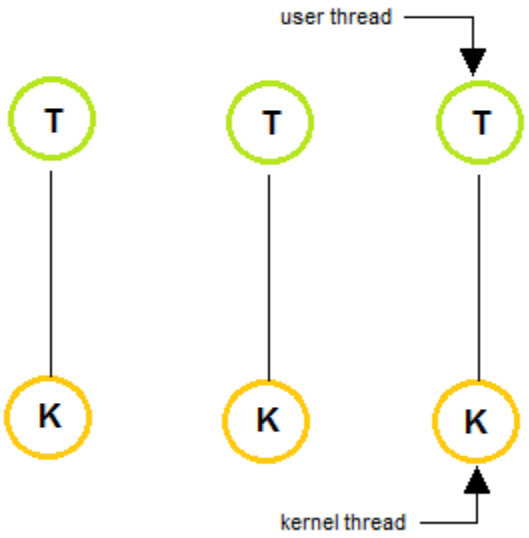
Many to One Model

- In the **many to one** model, many user-level threads are all mapped onto a single kernel thread.
- Thread management is handled by the thread library in user space, which is efficient in nature.



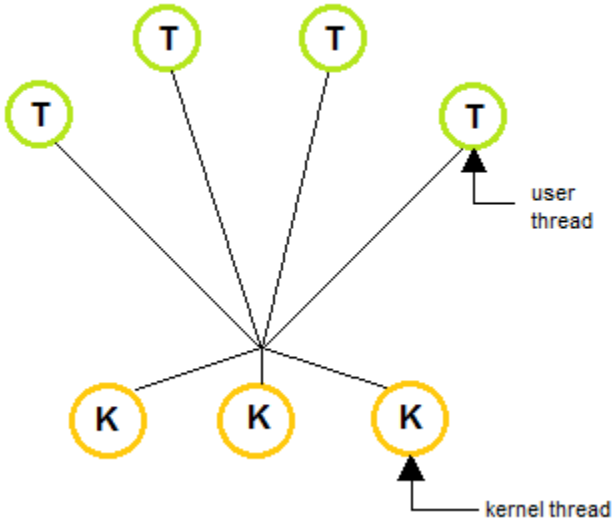
One to One Model

- The **one to one** model creates a separate kernel thread to handle each and every user thread.
- Most implementations of this model place a limit on how many threads can be created.
- Linux and Windows from 95 to XP implement the one-to-one model for threads.



Many to Many Model

- The **many to many** model multiplexes any number of user threads onto an equal or smaller number of kernel threads, combining the best features of the one-to-one and many-to-one models.
- Users can create any number of the threads.
- Blocking the kernel system calls does not block the entire process.
- Processes can be split across multiple processors.



Benefits of Multithreading

1. Responsiveness
2. Resource sharing, hence allowing better utilization of resources.
3. Economy. Creating and managing threads becomes easier.
4. Scalability. One thread runs on one CPU. In Multithreaded processes, threads can be distributed over a series of processors to scale.
5. Context Switching is smooth. Context switching refers to the procedure followed by CPU to change from one task to another.

CPU Scheduling is a process of determining which process will own CPU for execution while another process is on hold. The main task of CPU scheduling is to make sure that whenever the CPU remains idle, the OS at least select one of the processes available in the ready queue for execution. The selection process will be carried out by the CPU scheduler. It selects one of the processes in memory that are ready for execution.

Why do we need Scheduling?

In Multiprogramming, if the long term scheduler picks more I/O bound processes then most of the time, the CPU remains idol. The task of Operating system is to optimize the utilization of resources.

If most of the running processes change their state from running to waiting then there may always be a possibility of deadlock in the system. Hence to reduce this overhead, the OS needs to schedule the jobs to get the optimal utilization of CPU and to avoid the possibility to deadlock.

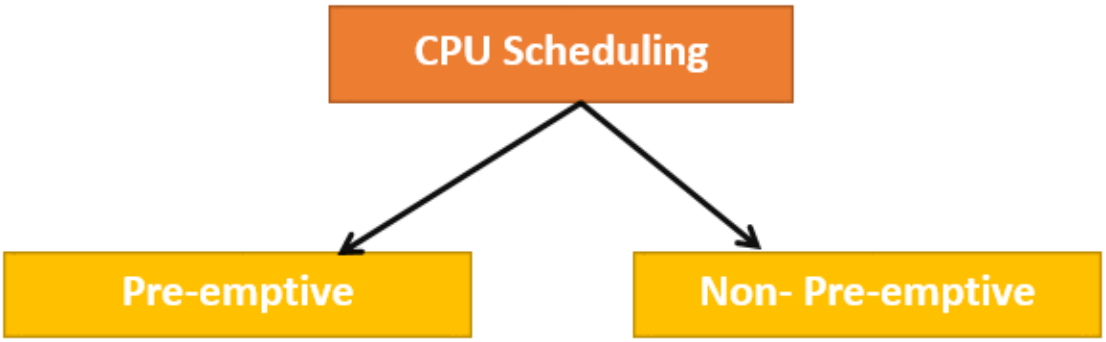
What is Dispatcher?

It is a module that provides control of the CPU to the process. The Dispatcher should be fast so that it can run on every context switch. Dispatch latency is the amount of time needed by the CPU scheduler to stop one process and start another.

Functions performed by Dispatcher:

- Context Switching
- Switching to user mode
- Moving to the correct location in the newly loaded program.

Types of CPU Scheduling



Preemptive Scheduling

In Preemptive Scheduling, the tasks are mostly assigned with their priorities. Sometimes it is important to run a task with a higher priority before another lower priority task, even if the lower priority task is still running. The lower priority task holds for some time and resumes when the higher priority task finishes its execution.

Non-Preemptive Scheduling

In this type of scheduling method, the CPU has been allocated to a specific process. The process that keeps the CPU busy will release the CPU either by switching context or terminating. It is the only method that can be used for various hardware platforms. That's because it doesn't need special hardware (for example, a timer) like preemptive scheduling.

When scheduling is Preemptive or Non-Preemptive?

To determine if scheduling is preemptive or non-preemptive, consider these four parameters:

1. A process switches from the running to the waiting state.
2. Specific process switches from the running state to the ready state.
3. Specific process switches from the waiting state to the ready state.
4. Process finished its execution and terminated.

Only conditions 1 and 4 apply, the scheduling is called non- preemptive.

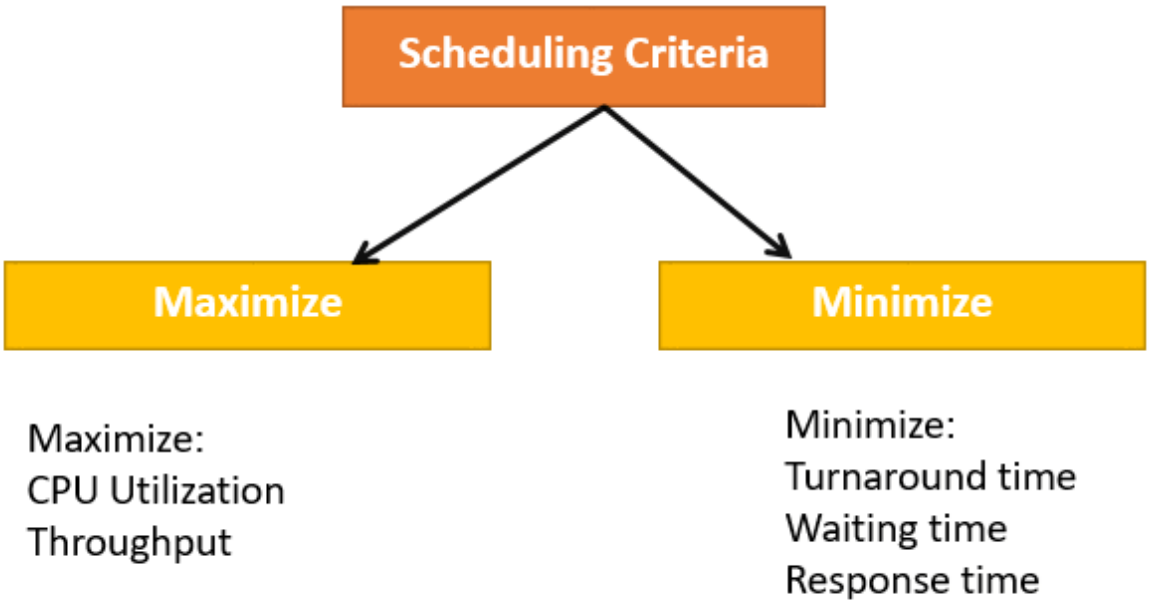
All other scheduling are preemptive.

Important CPU scheduling Terminologies

- **Burst Time/Execution Time:** It is a time required by the process to complete execution. It is also called running time.
- **Arrival Time:** when a process enters in a ready state
- **Finish Time:** when process complete and exit from a system
- **Multiprogramming:** A number of programs which can be present in memory at the same time.
- **Jobs:** It is a type of program without any kind of user interaction.
- **User:** It is a kind of program having user interaction.
- **Process:** It is the reference that is used for both job and user.
- **CPU/IO burst cycle:** Characterizes process execution, which alternates between CPU and I/O activity. CPU times are usually shorter than the time of I/O.

CPU Scheduling Criteria

A CPU scheduling algorithm tries to maximize and minimize the following:



Maximize:

CPU utilization: CPU utilization is the main task in which the operating system needs to make sure that CPU remains as busy as possible. It can range from 0 to 100 percent. However, for the RTOS, it can be range from 40 percent for low-level and 90 percent for the high-level system.

Throughput: The number of processes that finish their execution per unit time is known Throughput. So, when the CPU is busy executing the process, at that time, work is being done, and the work completed per unit time is called Throughput.

Minimize:

Waiting time: Waiting time is an amount that specific process needs to wait in the ready queue.

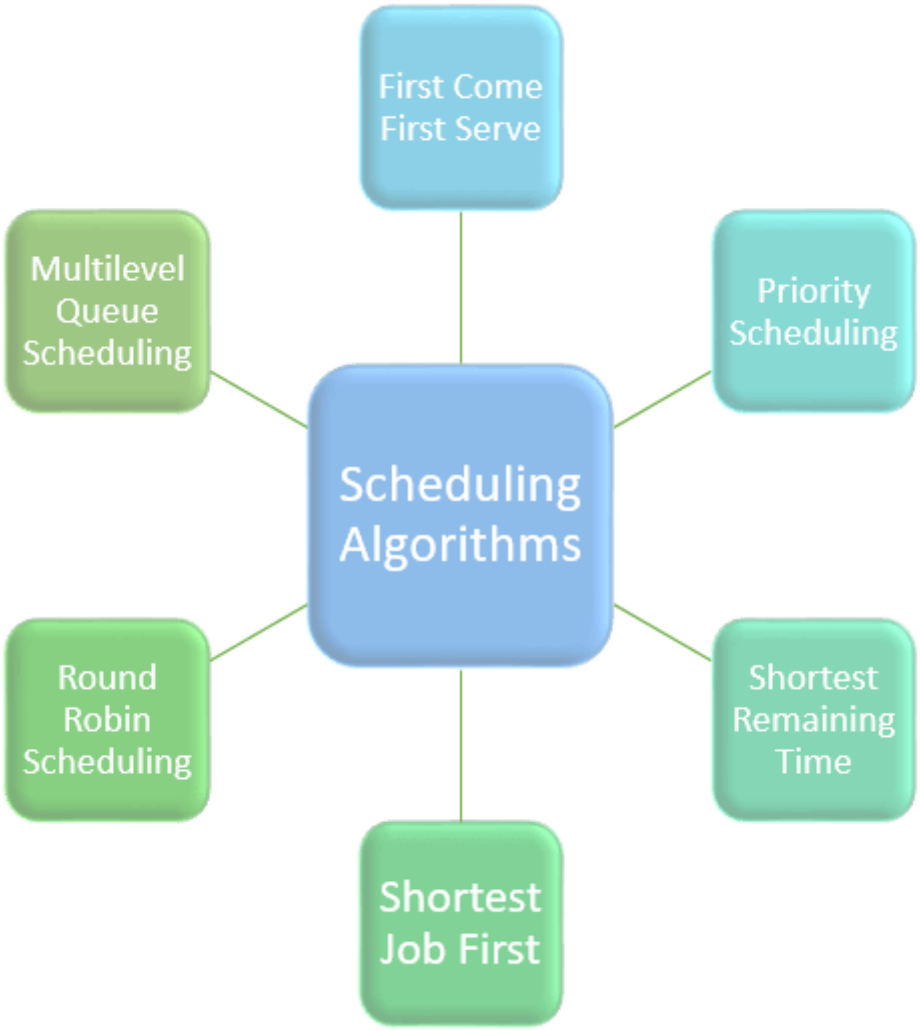
Response time: It is an amount to time in which the request was submitted until the first response is produced.

Turnaround Time: Turnaround time is an amount of time to execute a specific process. It is the calculation of the total time spent waiting to get into the memory, waiting in the queue and, executing on the CPU. The period between the time of process submission to the completion time is the turnaround time.

Types of CPU scheduling Algorithm

There are mainly six types of process scheduling algorithms

1. First Come First Serve (FCFS)
2. Shortest-Job-First (SJF) Scheduling
3. Shortest Remaining Time
4. Priority Scheduling
5. Round Robin Scheduling
6. Multilevel Queue Scheduling



1. **First Come First Serve Scheduling**

In the "First come first serve" scheduling algorithm, as the name suggests, **the process which arrives first, gets executed first**, or we can say that the process which requests the CPU first, gets the CPU allocated first.

- First Come First Serve is just like **FIFO** (First in First out) Queue data structure, where the data element which is added to the queue first, is the one who leaves the queue first.
- This is used in Batch Systems.
- It's **easy to understand and implement** programmatically, using a Queue data structure, where a new process enters through the **tail** of the queue, and the scheduler selects process from the **head** of the queue.
- A perfect real life example of FCFS scheduling is **buying tickets at ticket counter**.

Calculating Average Waiting Time

For every scheduling algorithm, **Average waiting time** is a crucial parameter to judge it's performance.

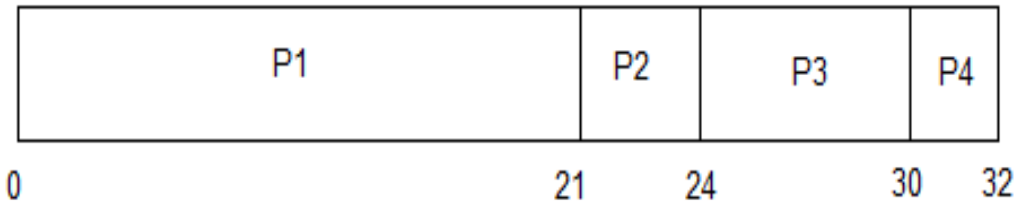
AWT or Average waiting time is the average of the waiting times of the processes in the queue, waiting for the scheduler to pick them for execution.

Lower the Average Waiting Time, better the scheduling algorithm.

Consider the processes P1, P2, P3, P4 given in the below table, arrives for execution in the same order, with **Arrival Time 0** and given **Burst Time**, let's find the average waiting time using the FCFS scheduling algorithm.

PROCESS	BURST TIME
P1	21
P2	3
P3	6
P4	2

The average waiting time will be = (0 + 21 + 24 + 30)/4 = 18.75 ms



This is the GANTT chart for the above processes

CT	TAT=CT-AT	WT=TAT-BT
21	21	0
24	24	21
30	30	24
32	32	30

The average waiting time will be 18.75 ms

For the above given proccesses, first **P1** will be provided with the CPU resources,

- Hence, waiting time for **P1** will be 0

- **P1** requires 21 ms for completion, hence waiting time for **P2** will be 21 ms
- Similarly, waiting time for process **P3** will be execution time of **P1** + execution time for **P2**, which will be (21 + 3) ms = 24 ms.

Problems with FCFS Scheduling

Below we have a few shortcomings or problems with the FCFS scheduling algorithm:

1. It is **Non Pre-emptive** algorithm, which means the **process priority** doesn't matter.

   If a process with very least priority is being executed, more like **daily routine backup** process, which takes more time, and all of a sudden some other high priority process arrives, like **interrupt to avoid system crash**, the high priority process will have to wait, and hence in this case, the system will crash, just because of improper process scheduling.

   Due to the non-preemptive nature of the algorithm, the problem of starvation may occur.

2. Not optimal Average Waiting Time.
3. Resources utilization in parallel is not possible, which leads to **Convoy Effect**, and hence poor resource (CPU, I/O etc) utilization.

Let's take an example of The FCFS scheduling algorithm. In the Following schedule, there are 5 processes with process ID **P0, P1, P2, P3 and P4**. P0 arrives at time 0, P1 at time 1, P2 at time 2, P3 arrives at time 3 and Process P4 arrives at time 4 in the ready queue. The processes and their respective Arrival and Burst time are given in the following table.

The Turnaround time and the waiting time are calculated by using the following formula.

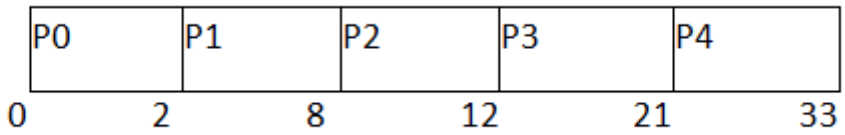
1. Turn Around Time = Completion Time - Arrival Time

2. Waiting Time = Turnaround time - Burst Time

   The average waiting Time is determined by summing the respective waiting time of all the processes and divided the sum by the total number of processes.

Process	Arrival Time	Burst Time	Completion Time	Turn Around Time	Waiting Time
P0	**0**	**2**	**2**	2	0
P1	1	6	8	7	1
P2	2	4	12	8	4
P3	3	9	21	18	9
P4	4	12	33	29	17

Avg Waiting Time=31/5

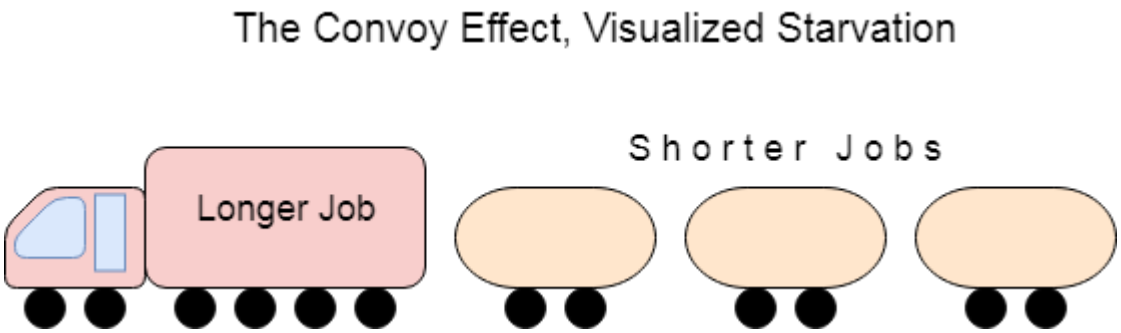


(Gantt chart)

Convoy Effect in FCFS

FCFS may suffer from the **convoy effect** if the burst time of the first job is the highest among all. As in the real life, if a convoy is passing through the road then the other persons may get blocked until it passes completely. This can be simulated in the Operating System also.

If the CPU gets the processes of the higher burst time at the front end of the ready queue then the processes of lower burst time may get blocked which means they may never get the CPU if the job in the execution has a very high burst time. This is called **convoy effect** or **starvation**.



Solution: Change the order of execution of processes.

Shortest Job First (SJF) Scheduling (shorter burst time process would run)---NON -PREEMPTIVE

Till now, we were scheduling the processes according to their arrival time (in FCFS scheduling). However, SJF scheduling algorithm, schedules the processes according to their burst time.

In SJF scheduling, the process with the lowest burst time, among the list of available processes in the ready queue, is going to be scheduled next.

However, it is very difficult to predict the burst time needed for a process hence this algorithm is very difficult to implement in the system.

Advantages of SJF

1. Maximum throughput
2. Minimum average waiting and turnaround time

Disadvantages of SJF

1. May suffer with the problem of starvation
2. It is not implementable because the exact Burst time for a process can't be known in advance.

There are different techniques available by which, the CPU burst time of the process can be determined. We will discuss them later in detail.

Example

In the following example, there are five jobs named as P1, P2, P3, P4 and P5. Their arrival time and burst time are given in the table below.

Process	Arrival Time	Burst Time	Completion Time	Turn Around Time	Waiting Time
P1	1	7	8	7	0
P2	3	3	13	10	7
P3	6	2	10	4	2
P4	7	10	31	24	14
P5	9	8	21	12	4

Since, No Process arrives at time 0 hence; there will be an empty slot in the **Gantt chart** from time 0 to 1 (the time at which the first process arrives).

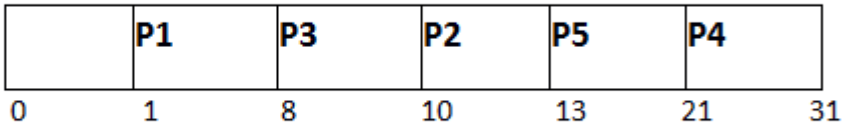
According to the algorithm, the OS schedules the process which is having the lowest burst time among the available processes in the ready queue.

Till now, we have only one process in the ready queue hence the scheduler will schedule this to the processor no matter what is its burst time.

This will be executed till 8 units of time. Till then we have three more processes arrived in the ready queue hence the scheduler will choose the process with the lowest burst time.

Among the processes given in the table, P3 will be executed next since it is having the lowest burst time among all the available processes.

So that's how the procedure will go on in **shortest job first (SJF)** scheduling algorithm.



Avg Waiting Time = 27/5

Shortest Remaining Time First (SRTF) Scheduling Algorithm

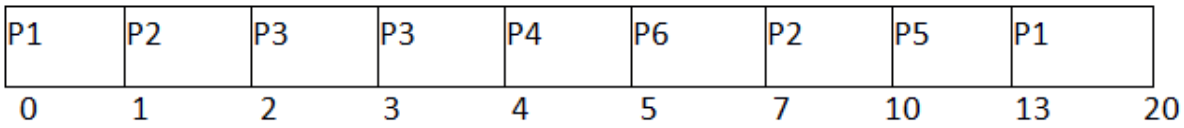
This Algorithm is the **pre-emptive version** of **SJF scheduling**. In SRTF, the execution of the process can be stopped after certain amount of time. At the arrival of every process, the short term scheduler schedules the process with the least remaining burst time among the list of available processes and the running process.

Once all the processes are available in the **ready queue**, No preemption will be done and the algorithm will work as **SJF scheduling**. The context of the process is saved in the **Process Control Block** when the process is removed from the execution and the next process is scheduled. This PCB is accessed on the **next execution** of this process.

Example

In this Example, there are five jobs P1, P2, P3, P4, P5 and P6. Their arrival time and burst time are given below in the table.

Process ID	Arrival Time	Burst Time	Completion Time	Turn Around Time	Waiting Time	Response Time
P1	0	8-1=7	20	20	12	0
P2	1	4-1=3	10	9	5	1
P3	2	2-1=1-1=0	4	2	0	2
P4	3	1-1=0	5	2	1	4
P5	4	3	13	9	6	10
P6	5	2	7	2	0	5



Avg Waiting Time = 24/6

The Gantt chart is prepared according to the arrival and burst time given in the table.

1. Since, at time 0, the only available process is P1 with CPU burst time 8. This is the only available process in the list therefore it is scheduled.
2. The next process arrives at time unit 1. Since the algorithm we are using is SRTF which is a preemptive one, the current execution is stopped and the scheduler checks for the process with the least burst time.
   Till now, there are two processes available in the ready queue. The OS has executed P1 for one unit of time till now; the remaining burst time of P1 is 7 units. The burst time of Process P2 is 4 units. Hence Process P2 is scheduled on the CPU according to the algorithm.
3. The next process P3 arrives at time unit 2. At this time, the execution of process P3 is stopped and the process with the least remaining burst

time is searched. Since the process P3 has 2 unit of burst time hence it will be given priority over others.

4. The Next Process P4 arrives at time unit 3. At this arrival, the scheduler will stop the execution of P4 and check which process is having least burst time among the available processes (P1, P2, P3 and P4). P1 and P2 are having the remaining burst time 7 units and 3 units respectively.

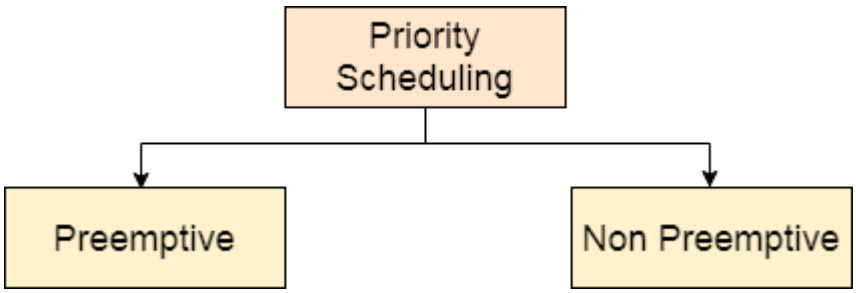
   P3 and P4 are having the remaining burst time 1 unit each. Since, both are equal hence the scheduling will be done according to their arrival time. P3 arrives earlier than P4 and therefore it will be scheduled again.
5. The Next Process P5 arrives at time unit 4. Till this time, the Process P3 has completed its execution and it is no more in the list. The scheduler will compare the remaining burst time of all the available processes. Since the burst time of process P4 is 1 which is least among all hence this will be scheduled.
6. The Next Process P6 arrives at time unit 5, till this time, the Process P4 has completed its execution. We have 4 available processes till now, that are P1 (7), P2 (3), P5 (3) and P6 (2). The Burst time of P6 is the least among all hence P6 is scheduled. Since, now, all the processes are available hence the algorithm will now work same as SJF. P6 will be executed till its completion and then the process with the least remaining time will be scheduled.

Once all the processes arrive, No pre-emption is done and the algorithm will work as SJF.

Priority Scheduling

In Priority scheduling, there is a **priority number** assigned to each process. In some systems, the lower the number, the higher the priority. While, in the others, the higher the number, the higher will be the priority.

There are two types of priority scheduling algorithm exists. One is **Preemptive** priority scheduling while the other is **Non Preemptive** Priority scheduling.



The priority number assigned to each of the process may or may not vary. If the priority number doesn't change itself throughout the process, it is called **static priority**, while if it keeps changing itself at the regular intervals, it is called **dynamic priority**.

Non Preemptive Priority Scheduling

In the Non Preemptive Priority scheduling, The Processes are scheduled according to the priority number assigned to them. Once the process gets scheduled, it will run till the completion. Generally, the **lower the priority number, the higher is the priority of the process.**

Example

In the Example, there are 7 processes P1, P2, P3, P4, P5, P6 and P7. Their priorities, Arrival Time and burst time are given in the table.

Process ID	Priority	Arrival Time	Burst Time
P1	2(high)	0	3
P2	6	1	5
P3	3	1	4
P4	5	4	2
P5	7	6	9
P6	4	5	4
P7	10(low)	7	10

We can prepare the Gantt chart according to the Non Preemptive priority scheduling.

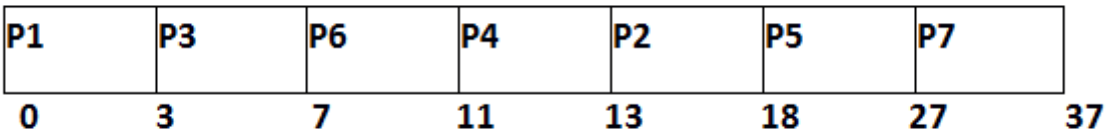
The Process P1 arrives at time 0 with the burst time of 3 units and the priority number 2. Since No other process has arrived till now hence the OS will schedule it immediately.

Meanwhile the execution of P1, two more Processes P2 and P3 are arrived. Since the priority of P3 is 3 hence the CPU will execute P3 over P2.

Meanwhile the execution of P3, All the processes get available in the ready queue. The Process with the lowest priority number will be given the priority. Since P6 has priority number assigned as 4 hence it will be executed just after P3.

After P6, P4 has the least priority number among the available processes; it will get executed for the whole burst time.

Since all the jobs are available in the ready queue hence All the Jobs will get executed according to their priorities. If two jobs have similar priority number assigned to them, the one with the least arrival time will be executed.



From the GANTT Chart prepared, we can determine the completion time of every process. The turnaround time, waiting time and response time will be determined.

1. Turn Around Time = Completion Time - Arrival Time
2. Waiting Time = Turn Around Time - Burst Time

Process Id	Priority	Arrival Time	Burst Time	Completion Time	Turnaround Time	Waiting Time	Response Time
1	2	0	3	3	3	0	0
2	6	2	5	18	16	11	13
3	3	1	4	7	6	2	3
4	5	4	2	13	9	7	11
5	7	6	9	27	21	12	18
6	4	5	4	11	6	2	7
7	10	7	10	37	30	18	27

Avg Waiting Time = (0+11+2+7+12+2+18)/7 = 52/7 units

Preemptive Priority Scheduling

In Preemptive Priority Scheduling, at the time of arrival of a process in the ready queue, its Priority is compared with the priority of the other processes present in the ready queue as well as with the one which is being executed by the CPU at that point of time. The One with the highest priority among all the available processes will be given the CPU next.

The difference between preemptive priority scheduling and non preemptive priority scheduling is that, in the preemptive priority scheduling, the job which is being executed can be stopped at the arrival of a higher priority job.

Once all the jobs get available in the ready queue, the algorithm will behave as non-preemptive priority scheduling, which means the job scheduled will run till the completion and no preemption will be done.

Example

There are 7 processes P1, P2, P3, P4, P5, P6 and P7 given. Their respective priorities, Arrival Times and Burst times are given in the table below.

Process Id	Priority	Arrival Time	Burst Time
1	2(L)	0	1-1=0
2	6	1	7-4=3
3	3	2	3
4	5	3	6
5	4	4	5
6	10(H)	5	15
7	9	15	8

P1

0---1

P2---1-5

P6 5---20

P7 20- 28

P2 28-31

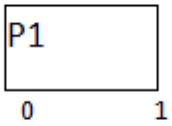
P4 31-37

P537-42

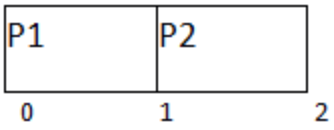
P3 42-45

GANTT chart Preparation

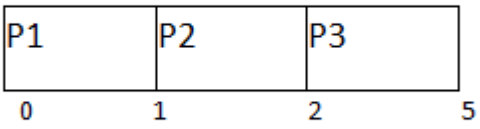
At time 0, P1 arrives with the burst time of 1 units and priority 2. Since no other process is available hence this will be scheduled till next job arrives or its completion (whichever is lesser).



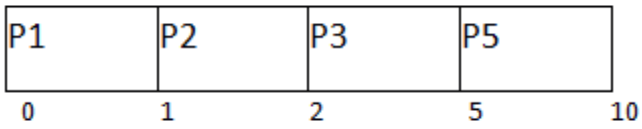
At time 1, P2 arrives. P1 has completed its execution and no other process is available at this time hence the Operating system has to schedule it regardless of the priority assigned to it.



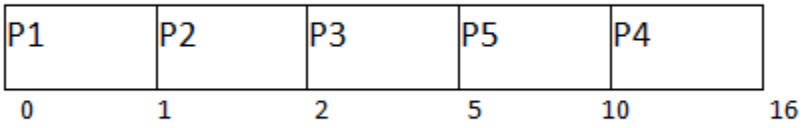
The Next process P3 arrives at time unit 2, the priority of P3 is higher to P2. Hence the execution of P2 will be stopped and P3 will be scheduled on the CPU.



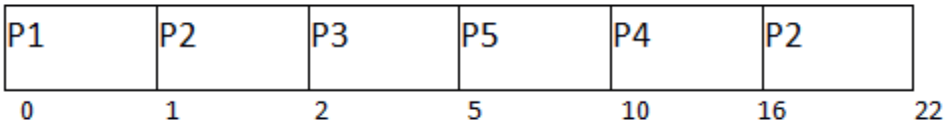
During the execution of P3, three more processes P4, P5 and P6 becomes available. Since, all these three have the priority lower to the process in execution so PS can't preempt the process. P3 will complete its execution and then P5 will be scheduled with the priority highest among the available processes.



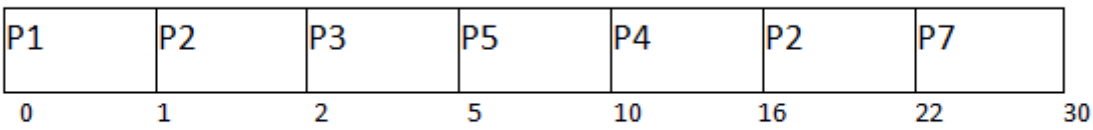
Meanwhile the execution of P5, all the processes got available in the ready queue. At this point, the algorithm will start behaving as Non Preemptive Priority Scheduling. Hence now, once all the processes get available in the ready queue, the OS just took the process with the highest priority and execute that process till completion. In this case, P4 will be scheduled and will be executed till the completion.



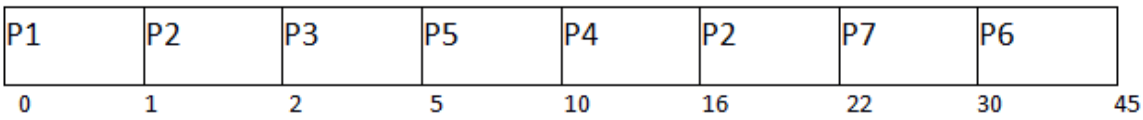
Since P4 is completed, the other process with the highest priority available in the ready queue is P2. Hence P2 will be scheduled next.



P2 is given the CPU till the completion. Since its remaining burst time is 6 units hence P7 will be scheduled after this.



The only remaining process is P6 with the least priority, the Operating System has no choice unless of executing it. This will be executed at the last.



The Completion Time of each process is determined with the help of GANTT chart. The turnaround time and the waiting time can be calculated by the following formula.

1. Turnaround Time = Completion Time - Arrival Time
2. Waiting Time = Turn Around Time - Burst Time

Process Id	Priority	Arrival Time	Burst Time	Completion Time	Turn around Time
1	2	0	1	1	1
2	6	1	7	22	21
3	3	2	3	5	3
4	5	3	6	16	13
5	4	4	5	10	6
6	10	5	15	45	40
7	9	6	8	30	24

Avg Waiting Time = (0+14+0+7+1+25+16)/7 = 63/7 = 9 units

Problem with Priority Scheduling Algorithm

In priority scheduling algorithm, the chances of **indefinite blocking** or **starvation**.

A process is considered blocked when it is ready to run but has to wait for the CPU as some other process is running currently.

But in case of priority scheduling if new higher priority processes keeps coming in the ready queue then the processes waiting in the ready queue with lower priority may have to wait for long durations before getting the CPU for execution.

In 1973, when the IBM 7904 machine was shut down at MIT, a low-priority process was found which was submitted in 1967 and had not yet been run.

Using Aging Technique with Priority Scheduling

To prevent starvation of any process, we can use the concept of **aging** where we keep on increasing the priority of low-priority process based on its waiting time.

For example, if we decide the aging factor to be **0.5** for each day of waiting, then if a process with priority **20**(which is comparatively low priority) comes in the ready queue. After one day of waiting, its priority is increased to **19.5** and so on.

Doing so, we can ensure that no process will have to wait for indefinite time for getting CPU time for processing.