Chapter 4 Scheduling

The process scheduling is the activity of the process manager that handles the removal of the running process from the CPU and the selection of another process on the basis of a particular strategy. Process scheduling is an essential part of a Multiprogramming operating systems. Such operating systems allow more than one process to be loaded into the executable memory at a time and the loaded process shares the CPU using time multiplexing.

Objective and criteria of process scheduling

- Max CPU utilization [Keep CPU as busy as possible]
- Fair allocation of CPU.
- Max throughput [Number of processes that complete their execution per time unit]
- Min turnaround time [Time taken by a process to finish execution]
- Min waiting time [Time a process waits in ready queue]
- Min response time [Time when a process produces first response]

Scheduling Level

Schedulers are special system software which handle process scheduling in various ways. Their main task is to select the jobs to be submitted into the system and to decide which process to run. Schedulers are of three levels:

- Long-Term Scheduler
- Short-Term Scheduler
- Medium-Term Scheduler

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. It also controls the degree of multiprogramming.

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 changes 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 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.

	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 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

Preemptive vs Non-Preemptive Scheduling

1. Preemptive Scheduling:

Preemptive scheduling is used when a process switches from running state to ready state or from waiting state to ready state. The resources (mainly CPU cycles) are allocated to the process for the limited amount of time and then is 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 ready queue till it gets next chance to execute.

Algorithms based on preemptive scheduling are: Round Robin (RR), Shortest Job First (SJF preemptive version) and Priority (preemptive version), etc.

2. Non-Preemptive Scheduling:

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

Algorithms based on preemptive scheduling are: First come first serve (FCFS), Priority (non-preemptive version), SJF (non-

preemptive) etc.

Scheduling Techniques

Different time with respect to a process

- **Arrival Time(AT):** Time at which the process arrives in the ready queue.
- **Burst Time(BT):** Time required by a process for CPU execution.
- **Completion Time(CT):** Time at which process completes its execution.
- **Turn Around Time (TAT):** The time interval from the time of submission of a process to the time of the completion of the process.

  OR,

  Time Difference between completion time and arrival time. i.e. **TAT= CT - AT**
- **Waiting Time(WT):** The total time waiting in a ready queue.

  OR**,**

  Time Difference between turnaround time and burst time. i.e.**WT = TAT - BT**
- **Response time (RT):** Amount of time from when a request was submitted until the first response is produced.

- **Quantum size:** It is the specific time interval used to prevent any one process monopolizing the system i.e. can be run exclusively.

A Process Scheduler schedules different processes to be assigned to the CPU based on particular scheduling algorithms**. The rule or set of rules that is followed to schedule the process is known as process scheduling algorithm.** The algorithms are either non-preemptive or preemptive**.**

Some of the algorithm are:

i. **First Come First Serve (FCFS) Scheduling**

- It is a non-preemptive scheduling algorithm.
- The process which arrives first, gets executed first or 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.

A perfect real-life example of FCFS scheduling is **buying tickets at ticket counter**.

<u>Advantages</u>

- FCFS algorithm doesn't include any complex logic, it just

puts the process requests in a queue and executes it one by one. Hence, FCFS is pretty simple and easy to implement.

- Eventually, every process will get a chance to run, so starvation doesn't occur.

Disadvantages

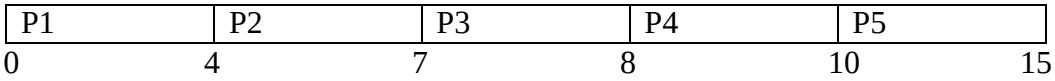
- There is no option for pre-emption of a process. If a process is started, then CPU executes the process until it ends.
- Because there is no pre-emption, if a process executes for a long time, the processes in the back of the queue will have to wait for a long time before they get a chance to be executed.

Example 1: Consider the following set of processes having their arrival time and CPU-burst time. Find the average waiting time and turnaround time using FCFS.

Process	Arrival Time (ms)	Burst Time (ms)
P1	0	4
P2	1	3
P3	2	1
P4	3	2
P5	4	5

Solution:

Preparing Gantt chart using FCFS we get,



We know,

TAT (Turnaround Time) = CT (Completion Time) – AT (Arrival Time)

and WT (Waiting Time) = TAT (Turnaround Time) – BT (Burst Time)

Now finding TAT and WT,

Process	**AT**	**BT**	**CT**	**TAT**	**WT**
P1	0	4	4	4	0
P2	1	3	7	6	3
P3	2	1	8	6	5
P4	3	2	10	7	5
P5	4	5	15	11	6
				∑TAT= 34	**∑WT= 18**

Average Turnaround time (ATAT) = $\sum$**TAT/N** = 34/ 5 = 6.8 ms

Average Waiting Time (AWT) = $\sum$**WT/ N** = 18/5 = 3.6 ms

Note: We can also find throughput and CPU utilization of the system using formula,

Throughput = (Number of process executed / Total time required) = 5/15 = 0.33

CPU Utilization = (Total working time / Total time required) = 15/15 = 1 (100 %)

Example 2: Consider the given processes with arrival and burst time given below. Schedule the given processes using FCFS and find average waiting time and average turn-around time.

PROCESSES	**ARRIVAL TIME**	**BRUST TIME**
A	0	3
B	2	6
C	4	4

D	6	5
E	8	2
F	3	4

SOLUTION:

Applying FCFS Gantt chart for the given processes becomes:

A	B	F	C	D	E

0 3 9 13 17 22 24

Now, from Gantt chart,

Process	Arrival time (AT)	Burst time (BT)	Completion time (CT)	Turnaround time TAT = CT – AT	Waiting time WT=TAT-BT
A	0	3	3	3	0
B	2	6	9	7	1
C	4	4	17	13	9
D	6	5	22	16	11
E	8	2	24	16	14
F	3	4	13	10	6
				∑ TAT=65	**∑ WT=41**

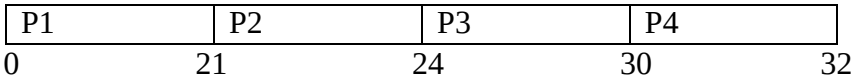
Average turn-around time = ∑(TAT) / n = 5/6= 10.83

Average waiting time = ∑(WT) / n =41/6 = 6.83

Example 3: 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, find the average waiting time using the FCFS scheduling algorithm.

Process	**Burst Time (ms)**
P1	21
P2	3
P3	6
P4	2

Solution:



Now from Gantt chart,

Process	Arrival Time (ms)	Burst Time	Completion Time	Turnaround Time TAT=CT-AT	Waiting Time WT = TAT - BT
P1	0	21	21	21	0
P2	0	3	24	24	21
P3	0	6	30	30	24
P4	0	2	32	32	30

Average WT = (0+21+24+30)/4 = 18.75

i. Shortest Job First (SJF) Scheduling

- It is a non-preemptive scheduling algorithm.
- It is also known as shortest job next (SJN)
- It is a scheduling policy that selects the waiting process with the smallest execution time to execute next.

Advantages.

- The throughput is increased because more processes can be executed in less amount of time.
- Having minimum average waiting time among all scheduling algorithms.

Disadvantages:

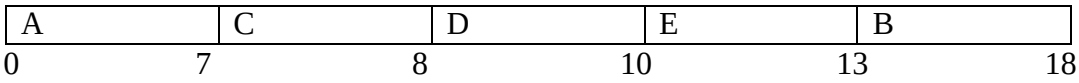
- It is practically infeasible as Operating System may not know burst time and therefore may not sort them.
- Longer processes will have more waiting time, eventually they'll suffer starvation.

Example 1: Consider the given processes with arrival and burst time given below. Schedule the given processes using SJF and find average waiting time (AWT) and average turnaround time (ATAT).

PROCESSES	ARRIVAL TIME	BRUST TIME
A	0	7
B	2	5
C	3	1
D	4	2
E	5	3

Solution:

According to the given question the Gantt chart for SJF given processes becomes:



Now,

Calculating of TAT and WT using: **TAT= CT – AT and WT = TAT - BT**

Process	Arrival time	Burst time	Completion time	Turn-around time	Waiting time
A	0	7	7	7	0
B	2	5	18	16	11
C	3	1	8	5	4
D	4	2	10	6	4
E	5	3	13	8	5
				∑TAT=42	∑WT=24

Average turn-around time = ∑(TAT) / n= 42/5 = 10.83

Average waiting time = ∑(WT) / n =24/5 = 4.8

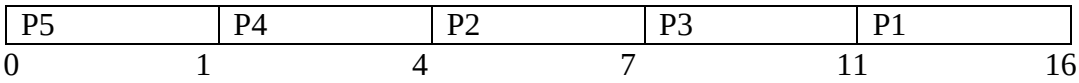
Example 2: Five processes P1,P2,P3,P4 and P5 having burst time 5,3,4,3,1 arrives at CPU . Find the Average TAT and Average WT using Shortest job first scheduling algorithm.

PROCESSES	BRUST TIME (ms)
P1	5
P2	3
P3	4
P4	3
P5	1

Solution

Since there is no any arrival time so it is assumed all the processes arrive initially. i.e. AT=0

The Gantt chart for the above processes becomes:



Now, using Gantt chart above and formula,

TAT = (CT-AT) and WT = (TAT-BT)

Process	Arrival time	Burst time	CT	TAT	WT
P1	0	5	16	16	11
P2	0	3	7	7	4
P3	0	4	11	11	7
P4	0	3	4	4	1
P5	0	1	1	1	0
				∑TAT=39	∑WT=23

Average turn-around time = ∑(TAT) / n = 39/5 = 7.8 ms

Average waiting time = ∑(WT) / n =23/5 = 4.6 ms

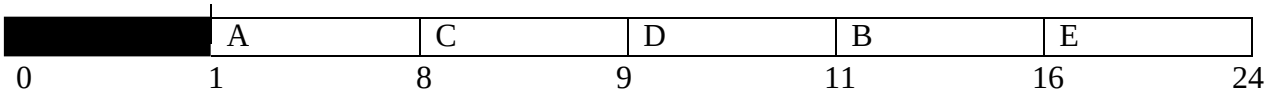
Example 3: Consider the given processes with arrival and burst time given below. Schedule the given processes using SJF and find waiting time and turn-around time.

PROCESSES	ARRIVAL TIME	BRUST TIME
A	1	7
B	2	5
C	3	1
D	4	2
E	5	8

Solution

The Gantt chart for the above processes becomes:

Here no process arrives at time= 0, so CPU stay in idle position.



Now, using Gantt chart

above and formula,

TAT = (CT-AT) and

WT = (TAT-BT)

Process	Arrival time	Burst time	CT	TAT	WT
A	1	7	8	7	0
B	2	5	16	14	9
C	3	1	9	6	5
D	4	2	11	7	5
E	5	8	24	19	11

Here Throughput = (5/24) and CPU Utilization = (23/24) since CPU stay in idle for 1 unit of time.

i. Shortest Remaining Time (SRT) Scheduling

- It is preemptive scheduling algorithm
- It is also called Preemptive shortest job first or Shortest remaining time next or Shortest remaining time first
- In this scheduling algorithm, the process with the smallest amount of time remaining until completion is selected to execute. Since the currently executing process is the one with the shortest amount of time remaining by definition, and since that time should only reduce as execution progresses, processes will always run until they complete or a new process is added that requires a smaller amount of time.

Advantage:

- Short processes are handled very quickly.
- The system also requires very little overhead since it only makes a decision when a process completes or a new process is added.
- When a new process is added, the algorithm only needs to compare the currently executing process with the new process, ignoring all other processes currently waiting to execute.

Disadvantage:

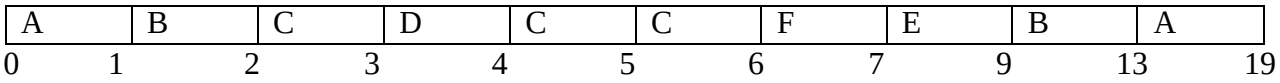
- Like shortest job first, it has the potential for process starvation.
- Long processes may be held off indefinitely if short processes are continually added.

Example 1: Consider the following processes with arrival time and burst time. Schedule them using SRT.

PROCESSES	ARRIVAL TIME(AT)	BRUST TIME (BT)
A	0	7
B	1	5
C	2	3
D	3	1
E	4	2
F	5	1

Solution:

Gantt chart for the above processes becomes:



Now, TAT = (CT-AT) and WT = (TAT-BT)

Process	Arrival time	Burst time	CT	TAT	WT
A	0	7	19	19	12
B	1	5	13	12	7
C	2	3	6	4	1
D	3	1	4	1	0
E	4	2	9	5	3
F	5	1	7	2	1
				∑TAT=43	**∑WT=24**

Average turn-around time = ∑(TAT) / n = 43/6 = 7.16 units
Average waiting time = ∑(WT) / n =24/6 = 4 units

ii. Priority Scheduling

- In this scheduling Priority is assigned for each process.
- Process with highest priority is executed first and so on.
- Processes with same priority are executed in FCFS manner.
- Priority can be decided based on memory requirements, time requirements or any other resource requirement

Advantages of Priority Scheduling:

- The priority of a process can be selected based on memory requirement, time requirement or user preference. For example, a high-end game will have better graphics, that means the process which updates the screen in a game will have higher priority so as to achieve better graphics performance.

Disadvantages:

- A second scheduling algorithm is required to schedule the processes which have same priority.
- In preemptive priority scheduling, a higher priority process

can execute ahead of an already executing lower priority process. If lower priority process keeps waiting for higher priority processes, starvation occurs.

Priority scheduling are of both types: preemptive and non-preemptive.

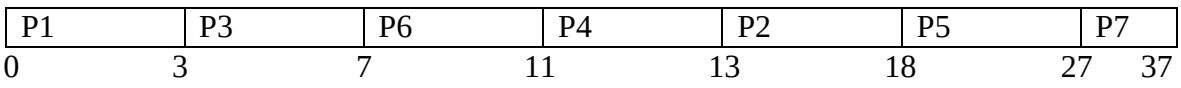
a. Non-Preemptive Priority Scheduling

- 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 1:** There are 7 processes P1, P2, P3, P4, P5, P6 and P7. Their priorities, Arrival Time and burst time are given in the table. Find waiting time and response time using non preemptive priority scheduling. Also find average WT.

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

Solution:

Gantt chart for the process is:



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.

Turn Around Time = Completion Time - Arrival Time

Waiting Time = Turn Around Time - Burst Time

Response time = Time at which process get first response – Arrival Time

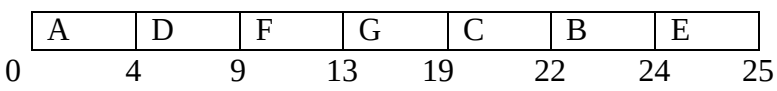
Process	Priority	Arrival Time	Burst Time	Completion Time	Turnaround Time	Waiting Time	Response Time
P1	2	0	3	3	3	0	0
P2	6	2	5	18	16	11	11
P3	3	1	4	7	6	2	2
P4	5	4	2	13	9	7	7
P5	7	6	9	27	21	12	12
P6	4	5	4	11	6	2	2
P7	10	7	10	37	30	20	20

Average Waiting Time = (0+11+2+7+12+2+20)/7 = 54/7 units

Example 2: Consider the given processes below. Schedule the algorithm using non preemptive priority, schedule the given processes. Assume 12 as highest priority and 2 as lowest priority.

Process	AT	BT (ms)	PRIORITY
A	0	4	2(lowest)
B	1	2	4
C	2	3	6
D	3	5	10
E	4	1	3
F	5	4	12(highest)
G	6	6	9

Solution:



a. Preemptive Priority Scheduling

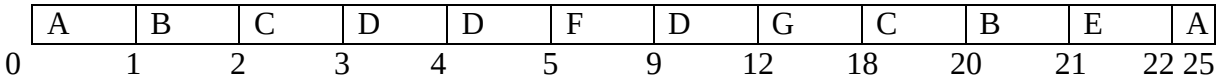
In Preemptive Priority Scheduling, at the time of arrival of a process in the ready queue, its Priority is compared with the priority of the other processes present in the ready queue as well as with the one which is being executed by the CPU at that point of time. The One with the highest priority among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

Example 1: Consider the given processes below. Schedule the algorithm using preemptive priority algorithm and hence find AWT and ATAT. Assume 12 as highest priority and 2 as lowest priority.

Process	AT	BT (ms)	PRIORITY
A	0	4	2(lowest)
B	1	2	4
C	2	3	6
D	3	5	10
E	4	1	3
F	5	4	12(highest)
G	6	6	9

Solution:

The Gantt chart for the given processes becomes: -



Now,

Process	AT	BT	PRIORITY	CT	TAT	WT
A	0	4	2	25	25	21
B	1	2	4	21	20	18
C	2	3	6	20	18	15
D	3	5	10	12	9	4
E	4	1	3	22	18	17
F	5	4	12	9	4	0
G	6	6	9	18	12	6

					∑TAT=106	∑WT=81

Average turn-around time= (∑TAT=106)/7 = 15.14 ms

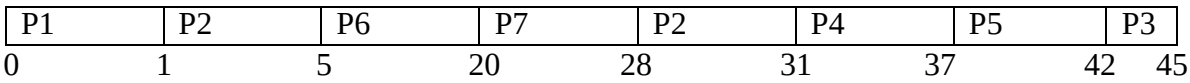
Average waiting time will be = (∑WT=81)/7 =11.57 ms

Example 2: 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. Find average WT using preemptive priority scheduling.

Process Id	Priority	Arrival Time	Burst Time
P1	2(L)	0	1
P2	6	1	7
P3	3	2	3
P4	5	3	6
P5	4	4	5
P6	10(H)	5	15
P7	9	15	8

Solution:

Gantt chart for above process is:



Now,

Process	Priority	Arrival Time	Burst Time	Completion Time	Turnaround Time	Waiting Time
P1	2	0	1	1	1	0
P2	6	1	7	31	30	23
P3	3	2	3	45	43	40
P4	5	3	6	37	34	28
P5	4	4	5	42	38	33
P6	10(H)	5	15	20	15	0
P7	9	6	8	28	22	14

V. Round Robin Scheduling

- CPU is assigned to the process for a fixed amount of time.
- This fixed amount of time is called as time quantum or time slice.
- After the time quantum expires, the running process is preempted and sent to the ready queue.
- Then, the processor is assigned to the next arrived process.
- It is always preemptive scheduling algorithm

Advantages

- It gives the best performance in terms of average response time.
- It is best suited for time sharing system, client server architecture and interactive system.

Disadvantages

- It leads to starvation for processes with larger burst time as they have to repeat the cycle many times.
- Its performance heavily depends on time quantum.
- Priorities cannot be set for the processes.

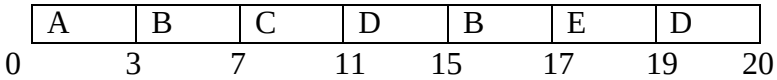
Example 1: Consider the following processes with AT and BT given. Find waiting time and turnaround time using round robin with time quantum = 4**.**

PROCESSES	ARRIVAL TIME(AT)	BRUST TIME (BT)
A	0	3
B	2	6
C	4	4
D	6	5
E	8	2

Solution:

Ready Queue: ABCDBED

Gantt chart:



Now,

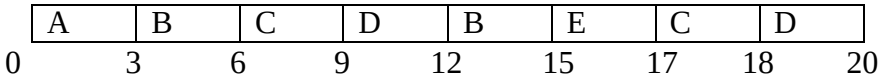
Process	Arrival time	Burst time	CT	TAT	WT
A	0	3	3	3	0
B	2	6	17	15	9
C	4	4	11	7	2
D	6	5	20	14	10
E	8	2	19	11	9

Example 2: Draw the gantt chart of above processes using

round robin with quantum 3 and 2. Solution:

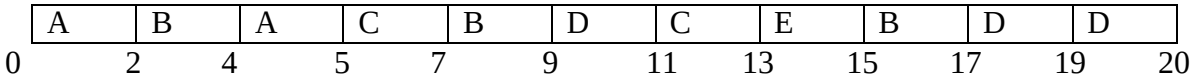
TQ=3

Ready queue: ABCDBECD



Now, TQ = 2

Ready queue: ABACBDCEBDD



i. HRRN (Highest Response Ratio Next)

- Highest Response Ratio Next (HRNN) is one of the most optimal scheduling algorithms.
- This is a **non-preemptive algorithm** in which, the scheduling is done on the basis of an extra parameter called Response Ratio.
- A Response Ratio is calculated for each of the available jobs and the Job with the highest response ratio is given priority over the others.

Response Ratio is calculated by the given formula, Response Ratio = (WT+BT)/BT

Where,

WT → Waiting Time
BT → Service Time or Burst Time

Advantages-

- It performs better than SJF Scheduling.
- It not only favors the shorter jobs but also limits the waiting time of longer jobs.

Disadvantages-

- It cannot be implemented practically. This is because burst time of the processes cannot be known in advance.

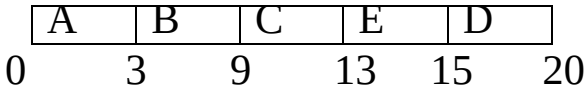
Example: Consider the following processes with AT and BT given. Find waiting time and turnaround time using HRRN.

PROCESSES	ARRIVAL TIME(AT)	BRUST TIME (BT)
A	0	3
B	2	6
C	4	4
D	6	5
E	8	2

Solution:

Gant

t chart:



Here A and B can be executed in FIFO. At, time = 9 C, D, E arrives so RR need to be calculated.

Response Ratio of C $(RR)_C$ = (5+4)/4 = 2.25
Response Ratio of D $(RR)_D$ = (3+5)/5 = 1.6
Response Ratio of E $(RR)_E$ = (1+2)/2 = 1.5

Since $(RR)_C$ is larger than other hence C runs.

Response Ratio of D $(RR)_D = (7+5)/5 = 2.4$
Response Ratio of E $(RR)_E = (5+2)/2 = 3.5$

Since $(RR)_E$ is larger than other hence E runs

Now from the Gantt chart:

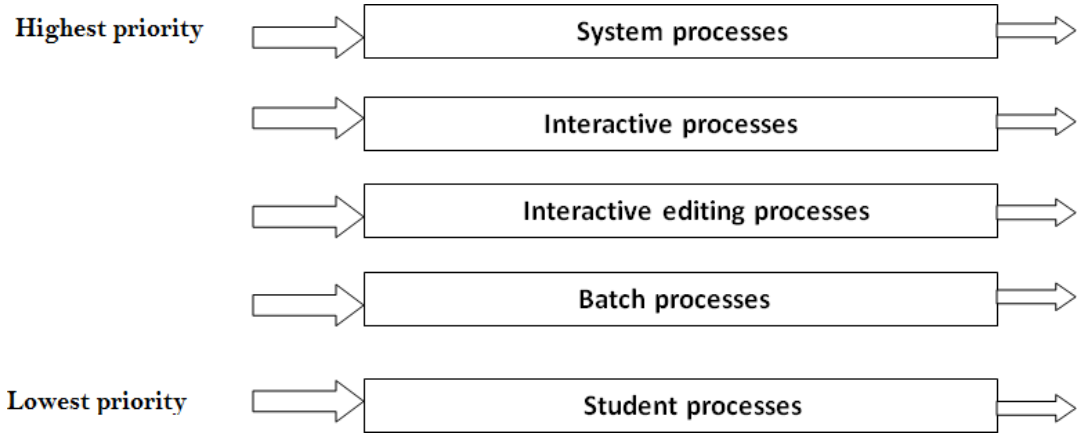
Process	Arrival time (AT)	Burst time (BT)	Completion time (CT)	Turnaround time TAT = CT – AT	Waiting time WT=TAT-BT
A	0	3	3	3	0
B	2	6	9	7	1
C	4	4	13	9	5
D	6	5	20	14	9
E	8	2	15	7	5

iii. Multilevel Queue

- In the multilevel queue scheduling algorithm, the ready queue has divided into separate queues. Based on some priority of the process; like memory size, process priority, or process type these processes are permanently assigned to one queue.
- Each queue has its own scheduling algorithm. For example, some queues are used for the foreground process and some for the background process.
- The foreground queue can be scheduled by using a round-robin algorithm while the background queue is scheduled by a first come first serve algorithm.

Let us take an example of a multilevel queue scheduling algorithm with five queues:

- System process
- Interactive processes
- Interactive editing processes
- Batch processes
- Student processes



iv. Multilevel Feedback Queue

- In multilevel queue scheduling algorithm, processes are permanently stored in one queue in the system and do not move between the queue.
- There is some separate queue for foreground or background processes but the processes do not move from one queue to another queue and these processes do not change their foreground or background nature, these types of arrangement have the advantage of low scheduling but it is inflexible in nature.
- Multilevel feedback queue scheduling, it allows a process to move between the queue. These processes are separated with different

CPU burst time.

- If a process uses too much CPU time, then it will be moved to the lowest priority queue.
- This idea leaves I/O bound and interactive processes in the higher priority queue.
- Similarly, the process which waits too long in a lower priority queue may be moved to a higher priority queue. This form of aging prevents starvation.

The multilevel feedback queue scheduler has the following parameters:

- The number of queues in the system.
- The scheduling algorithm for each queue in the system.
- The method used to determine when the process is upgraded to a higher-priority queue.
- The method used to determine when to demote a queue to a lower - priority queue.
- The method used to determine which process will enter in
- queue and when that process needs service.

i. Earliest Deadline First Algorithm (EDF)

This algorithm takes the approach that tasks with the closest deadlines should be meted out the highest priorities. Likewise, the task with the latest deadline has the lowest priority. Due to this approach, the processor idle time is zero and so 100% utilization can be achieved.