CPU Scheduling Algorithms

Unit-2

Operating System/01CE1401

Department of Computer Engineering

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Topics Covered

- Scheduling Criteria
  - CPU utilization
  - Throughput
  - Turnaround time
  - Waiting time
  - Response time
- Scheduling Algorithm
  - First Come First Served (FCFS)
  - Shortest Job First (SJF)
  - Shortest Remaining next(SRN)
  - Priority Scheduling
  - Round Robin (RR)

Scheduling Criteria

CPU utilization:

- It makes sure that the *CPU* is operating at its peak and is busy.

Throughput:

- A measure of the work done by the CPU is the number of processes being executed and completed per unit of time.
- It is the number of processes that complete their execution per unit of time.

Turnaround time:

- It is the amount of time required to execute a specific process.
- The time elapsed from the time of submission of a process to the time of completion is known as the turnaround time.
- Turn-around time is the sum of times spent waiting to get into memory, waiting in the ready queue, executing in CPU, and waiting for I/O.
- The formula to calculate **Turn Around Time = Completion Time – Arrival Time / Burst Time + Waiting Time**

Scheduling Criteria

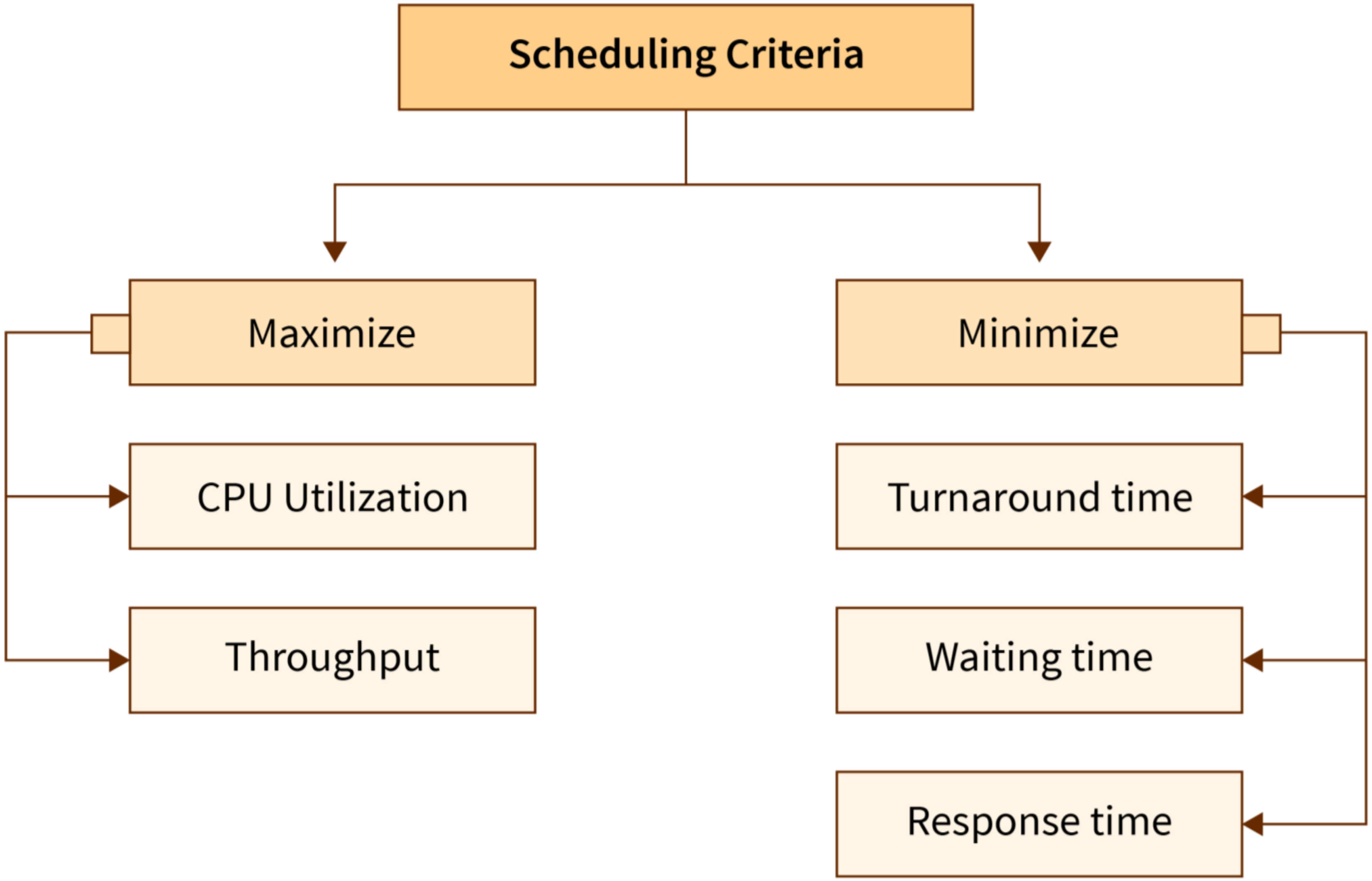
Waiting time:

- It is the amount of waiting time in the queue.
- The formula for calculating **Waiting Time = Turnaround Time – Burst Time**.

Response time:

- Time retired for generating the first request after submission.
- The formula to calculate **Response Time =CPU Allocation Time(when the CPU was allocated for the first) – Arrival Time**

Scheduling Criteria



Preemptive vs Non Preemptive Scheduling

Basis for Comparison	Preemptive Scheduling	Non Preemptive Scheduling
Basic	The resources are allocated to a process for a limited time.	Once resources are allocated to a process, the process holds it till it completes its burst time or switches to waiting state.
Interrupt	Process can be interrupted in between.	Process can not be interrupted till it terminates or switches to waiting state.
Starvation	If a high priority process frequently arrives in the ready queue, low priority process may starve.	If a process with long burst time is running CPU, then another process with less CPU burst time may starve.
Overhead	Preemptive scheduling has overheads of scheduling the processes.	Non-preemptive scheduling does not have overheads.
Flexibility	Preemptive scheduling is flexible.	Non-preemptive scheduling is rigid.
Cost	Preemptive scheduling is cost associated.	Non-preemptive scheduling is not cost associative.

Scheduling Algorithm

- First Come First Served(FCFS)
  - Non-preemptive
- Shortest Job First (SJF)
  - Non-preemptive
  - Preemptive (Shortest Remaining Time First (SRTF)/Shortest Remaining Next(SRN))
- Priority Scheduling (Small Number = High Priority)
  - Non-preemptive
  - Preemptive
- Round Robin (RR)
  - Preemptive

First Come First Served (FCFS)

Working:

- Jobs are executed on first come, first serve basis.
- Its implementation is based on FIFO queue.
- It is Non-preemptive Scheduling Algorithm

Advantage:

- Easy to understand and implement.

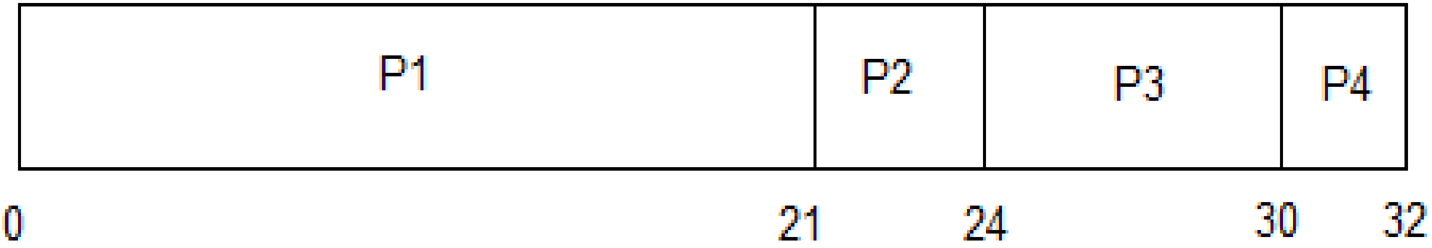
Disadvantage:

- Poor in performance as average wait time is high.
- Lower Device Utilization
- It does not consider the priority or burst time of the processes.
- It suffers from convoy effect. (Convoy Effect - Consider processes with higher burst time arrived before the processes with smaller burst time. Then, smaller processes have to wait for a long time for longer processes to release the CPU.)

First Come First Served (FCFS) Example 1

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



Process	Burst Time	Waiting Time	Turn Around Time (Burst Time+Waiting Time)
P1	21	0	21+0 = 21
P2	3	21	3+21 = 24
P3	6	24	6+24 = 30
p4	2	30	2+30 = 32

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

Average turn around time = (21+24+30+32) / 4 = 26.75

First Come First Served (FCFS) Example 2

Consider the set of 3 processes whose arrival time and burst time are given below. If the CPU scheduling policy is FCFS, calculate the average waiting time and average turn around time.

Process Id	Arrival time	Burst time
P1	0	2
P2	3	1
P3	5	6

Gantt Chart

Turn Around time = Exit time – Arrival time

Waiting time = Turn Around time – Burst time

Process Id	Arrival time	Burst time	Exit time	Turn Around time	Waiting time
P1	0	2	2	2 – 0 = 2	2 – 2 = 0
P2	3	1	4	4 – 3 = 1	1 – 1 = 0
P3	5	6	11	11- 5 = 6	6 – 6 = 0

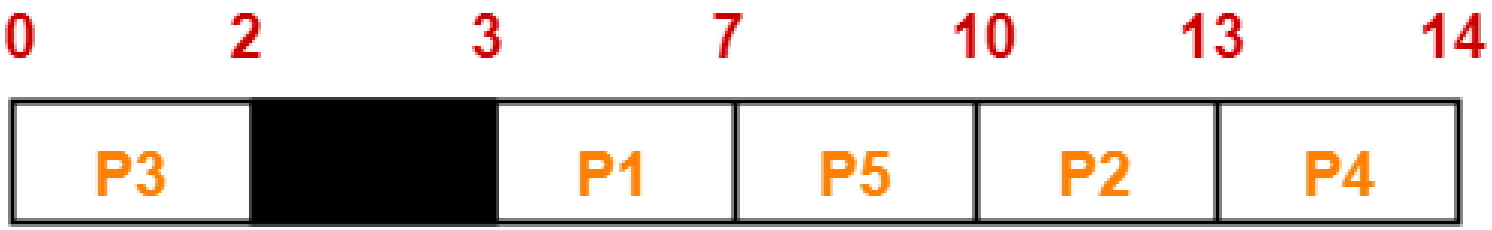
Average Turn Around time = (2 + 1 + 6) / 3 = 9 / 3 = 3 unit

Average waiting time = (0 + 0 + 0) / 3 = 0 / 3 = 0 unit

First Come First Served (FCFS) Example 3

Consider the set of 5 processes whose arrival time and burst time are given below- If the CPU scheduling policy is FCFS, calculate the average waiting time and average turn around time.

Process Id	Arrival time	Burst time
P1	3	4
P2	5	3
P3	0	2
P4	5	1
P5	4	3



Here, black box represents the idle time of CPU.

Gantt Chart

Process Id	Arrival time	Burst time	Exit Time	Turn Around time (Exit Time-Arrival Time)	Waiting Time (Turn Around Time – Burst Time)
P1	3	4	7	7-3 = 4	4 – 4 = 0
P2	5	3	13	13-5=8	8 – 3 = 5
P3	0	2	2	2 – 0 = 2	2 – 2 = 0
P4	5	1	14	14 – 5 = 9	9 – 1 = 8
P5	4	3	10	10 – 4 = 6	6 – 3 = 3

Average Turn Around time = (4 + 8 + 2 + 9 + 6) / 5 = 29 / 5 = 5.8 unit

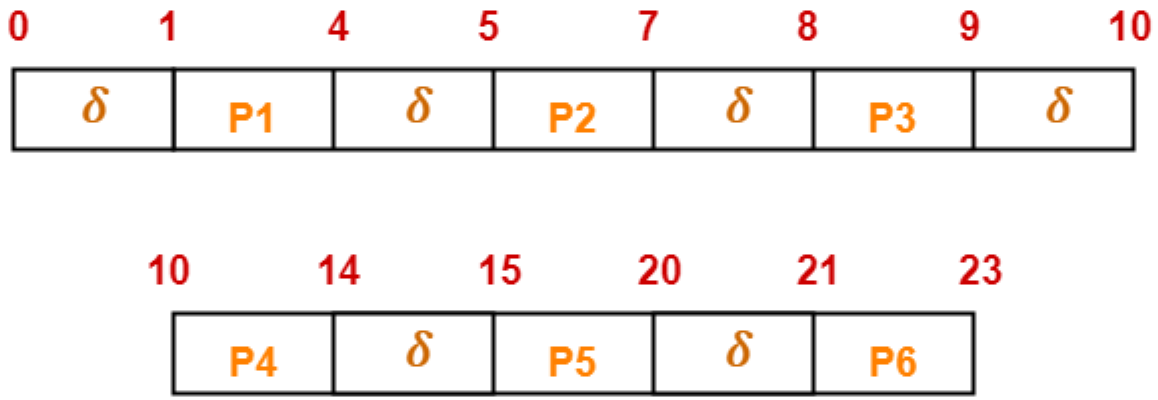
Average waiting time = (0 + 5 + 0 + 8 + 3) / 5 = 16 / 5 = 3.2 unit

First Come First Served (FCFS) Example 4

Consider the set of 6 processes whose arrival time and burst time are given below, If the CPU scheduling policy is FCFS and there is 1 unit of overhead in scheduling the processes, find the efficiency of the algorithm.

Process Id	Arrival time	Burst time
P1	0	3
P2	1	2
P3	2	1
P4	3	4
P5	4	5
P6	5	2

Process Id	Arrival time	Burst time
P1	0	3
P2	1	2
P3	2	1
P4	3	4
P5	4	5
P6	5	2



Gantt Chart

Here, δ denotes the context switching overhead.

Now,

Useless time / Wasted time = 6 x δ = 6 x 1 = 6 unit

Total time = 23 unit

Useful time = 23 unit – 6 unit = 17 unit

Efficiency (η)

= Useful time / Total

= 17 unit / 23 unit

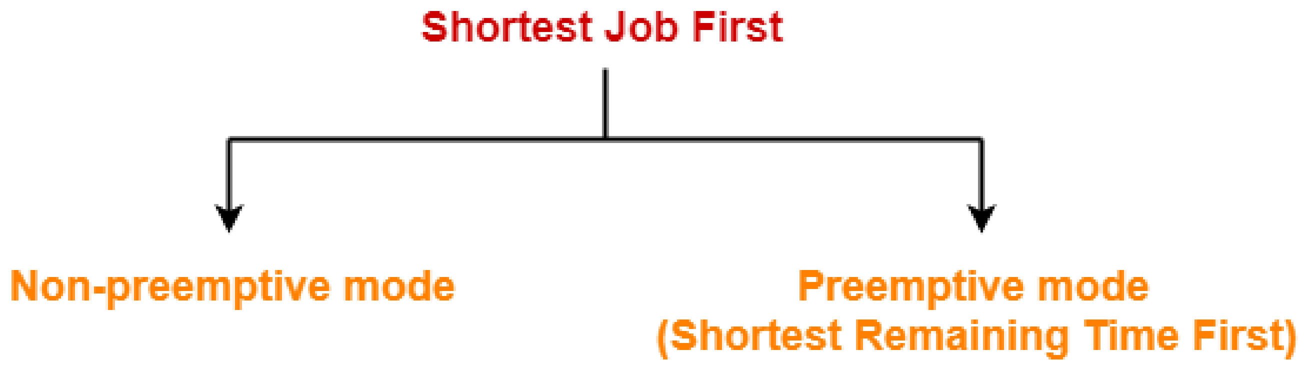
= 0.7391

= 73.91%

Gantt Chart

Shortest Job First

Out of all the available processes, CPU is assigned to the process having smallest burst time



Advantages-

- SRTF is optimal and guarantees the minimum average waiting time.
- It provides a standard for other algorithms since no other algorithm performs better than it.

Disadvantages-

- It can not be implemented practically since burst time of the processes can not be known in advance.
- It leads to starvation for processes with larger burst time.
- Priorities can not be set for the processes.
- Processes with larger burst time have poor response time.

Shortest Job First (SJF) Example 1:

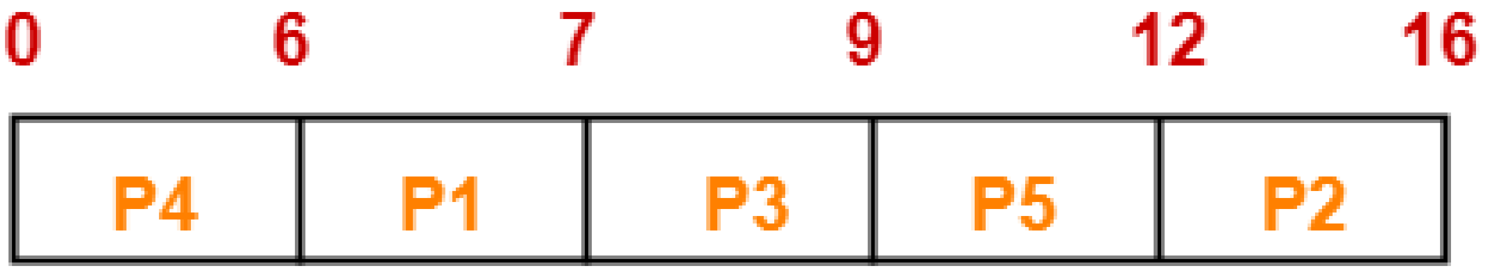
Consider the set of 5 processes whose arrival time and burst time are given below, If the CPU scheduling policy is SJF non-preemptive, calculate the average waiting time and average turn around time.

Process Id	Arrival time	Burst time
P1	3	1
P2	1	4
P3	4	2
P4	0	6
P5	2	3

Shortest Job First (SJF) Example 1:

Arrange process in ascending order of Arrival Time

Process Id	Arrival time	Burst time
P4	0	6
P2	1	4
P5	2	3
P1	3	1
P3	4	2



Gantt Chart

Shortest Job First (SJF) Example 1:

Process Id	Arrival time	Burst time	Exit Time	Turn Around time (Exit Time-Arrival Time)	Waiting Time (Turn Around Time – Burst Time)
P1	3	1	7	7 – 3 = 4	4 – 1 = 3
P2	1	4	16	16 – 1 = 15	15 – 4 = 11
P3	4	2	9	9 – 4 = 5	5 – 2 = 3
P4	0	6	6	6 – 0 = 6	6 – 6 = 0
P5	2	3	12	12 – 2 = 10	10 – 3 = 7

Turn Around time = Exit time – Arrival time

Waiting time = Turn Around time – Burst time

Average Turn Around time = (4 + 15 + 5 + 6 + 10) / 5 = 40 / 5 = 8 unit

Average waiting time = (3 + 11 + 3 + 0 + 7) / 5 = 24 / 5 = 4.8 unit

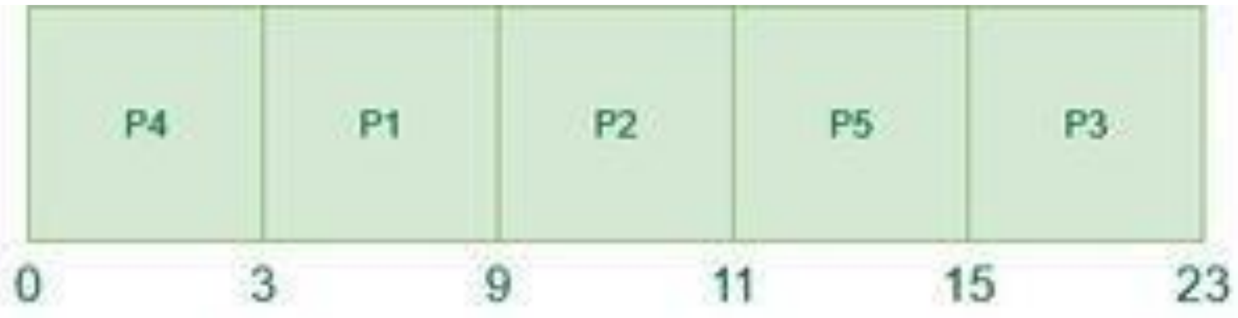
Shortest Job First (SJF) Example 2:

Consider the following table of arrival time and burst time for five processes P1, P2, P3, P4 and P5. calculate the average waiting time.

Process	Burst Time	Arrival Time
P1	6 ms	2 ms
P2	2 ms	5 ms
P3	8 ms	1 ms
P4	3 ms	0 ms
P5	4 ms	4 ms

Shortest Job First (SJF) Example 2:

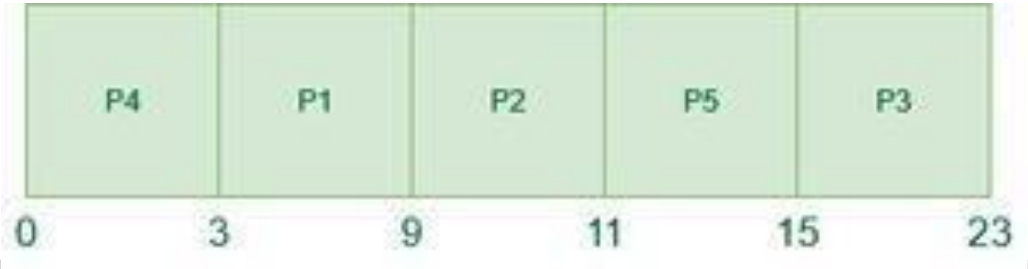
Process	Arrival Time	Burst Time
P4	0 ms	3 ms
P3	1 ms	8 ms
P1	2 ms	6 ms
P5	4 ms	4 ms
P2	5 ms	2 ms



Shortest Job First (SJF) Example 2:

Process	Burst Time	Arrival Time	**Exit Time**	**Turn Around time (Exit Time-Arrival Time)**	**Waiting Time (Turn Around Time – Burst Time)**
P1	6 ms	2 ms	9	9-2=7	7-6=1
P2	2 ms	5 ms	11	11-5=6	6-2=4
P3	8 ms	1 ms	23	23-1=22	22-8=14
P4	3 ms	0 ms	3	3-0=3	3-3=0
P5	4 ms	4 ms	15	15-4=11	11-4=7

Average Waiting Time = 0 + 1 + 4 + 7 + 14/5 = 26/5 = 5.2



Shortest Remaining Time First (SRTF) Example 1:

Marwadi University
Marwadi Chandarana Group
NAAC A+

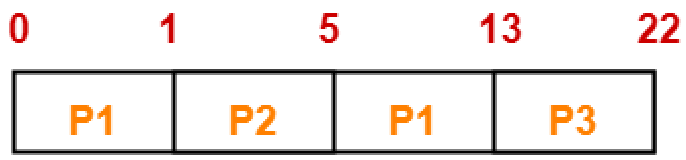
Consider the set of 3 processes whose arrival time and burst time are given below-

Process Id	Arrival time	Burst time
P1	0	9
P2	1	4
P3	2	9

If the CPU scheduling policy is SRTF (Preemptive Shortest Job First - SJF or (Shortest Remaining Time First - SRTF), calculate the average waiting time and average turn around time.

Shortest Remaining Time First (SRTF) Example 1:

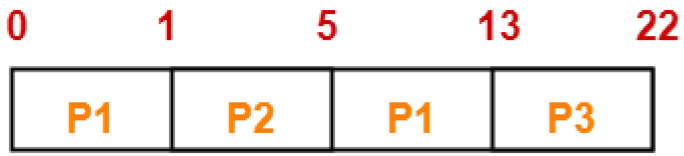
Process Id	Arrival time	Burst time
P1	0	9
P2	1	4
P3	2	9



Gantt Chart

Shortest Remaining Time First (SRTF) Example 1:

Marwadi University
Marwadi Chandarana Group
NAAC A+



Gantt Chart

Process Id	Arrival time	Burst time	Exit time	Turn Around time	Waiting time
P1	0	9	13	13 – 0 = 13	13 – 9 = 4
P2	1	4	5	5 – 1 = 4	4 – 4 = 0
P3	2	9	22	22- 2 = 20	20 – 9 = 11

Now,

Average Turn Around time = (13 + 4 + 20) / 3 = 37 / 3 = 12.33 unit

Average waiting time = (4 + 0 + 11) / 3 = 15 / 3 = 5 unit

Shortest Remaining Time First (SRTF) Example 2:

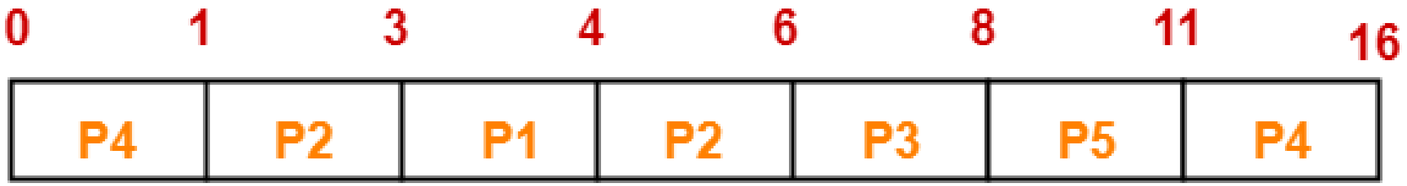
Consider the set of 5 processes whose arrival time and burst time are given below-

Process Id	Arrival time	Burst time
P1	3	1
P2	1	4
P3	4	2
P4	0	6
P5	2	3

If the CPU scheduling policy is SJF preemptive, calculate the average waiting time and average turn around time.

Shortest Remaining Time First (SRTF) Example 2:

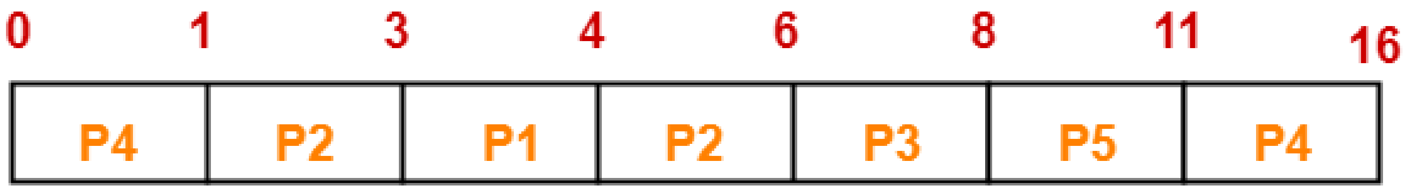
Process Id	Arrival time	Burst time
P4	0	6
P2	1	4
P5	2	3
P1	3	1
P3	4	2



Gantt Chart

Shortest Remaining Time First (SRTF) Example 2:

Process Id	Arrival time	Burst time	Exit time	Turn Around time	Waiting time
P1	3	1	4	4-3 = 1	1-1=0
P2	1	4	6	6-1=5	5-4=1
P3	4	2	8	8-4=4	4-2=2
P4	0	6	16	16-0=16	16-6=10
P5	2	3	11	11-2=9	9-3=6



Gantt Chart

Average Turn Around time = (1 + 5 + 4 + 16 + 9) / 5 = 35 / 5 = 7 unit

Average waiting time = (0 + 1 + 2 + 10 + 6) / 5 = 19 / 5 = 3.8 unit

Shortest Remaining Time First (SRTF) Example 3:

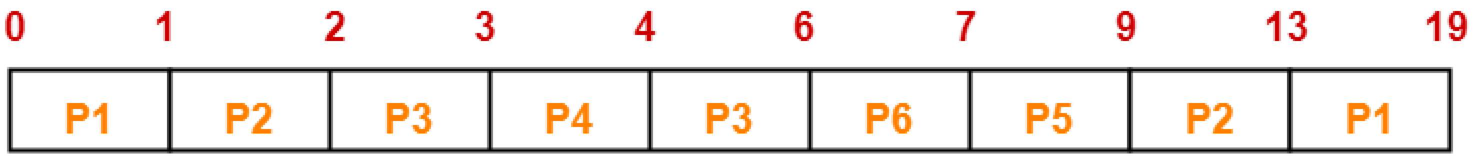
Consider the set of 6 processes whose arrival time and burst time are given below-

Process Id	Arrival time	Burst time
P1	0	7
P2	1	5
P3	2	3
P4	3	1
P5	4	2
P6	5	1

If the CPU scheduling policy is Preemptive shortest remaining time first, calculate the average waiting time and average turn around time.

Shortest Remaining Time First (SRTF) Example 3:

Process Id	Arrival time	Burst time
P1	0	7
P2	1	5
P3	2	3
P4	3	1
P5	4	2
P6	5	1



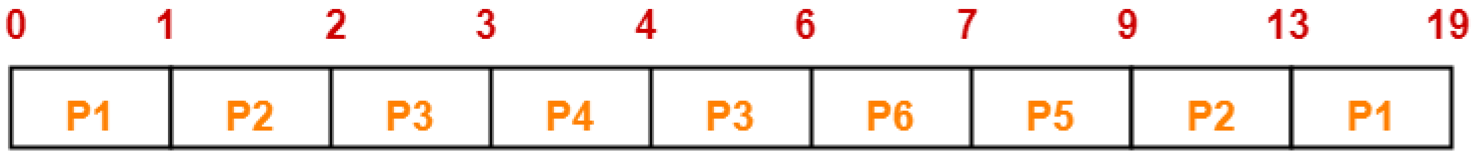
Gantt Chart

Shortest Remaining Time First (SRTF) Example 3:

Process Id	Arrival time	Burst time	Exit time	Turn Around time	Waiting time
P1	0	7	19	19 – 0 = 19	19 – 7 = 12
P2	1	5	13	13 – 1 = 12	12 – 5 = 7
P3	2	3	6	6 – 2 = 4	4 – 3 = 1
P4	3	1	4	4 – 3 = 1	1 – 1 = 0
P5	4	2	9	9 – 4 = 5	5 – 2 = 3
P6	5	1	7	7 – 5 = 2	2 – 1 = 1

Average Turn Around time = (19 + 12 + 4 + 1 + 5 + 2) / 6 = 43 / 6 = 7.17 unit

Average waiting time = (12 + 7 + 1 + 0 + 3 + 1) / 6 = 24 / 6 = 4 unit



Gantt Chart

Shortest Remaining Time First (SRTF) Example 4:

Consider the set of 4 processes whose arrival time and burst time are given below-

Process Id	Arrival time	Burst time
P1	0	20
P2	15	25
P3	30	10
P4	45	15

If the CPU scheduling policy is SRTF, calculate the waiting time of process P2.

Shortest Remaining Time First (SRTF) Example 4:

0	20	30	40	55	70
P1	P2	P3	P2	P4	

Gantt Chart

Process Id	Arrival time	Burst time
P1	0	20
P2	15	25
P3	30	10
P4	45	15

Shortest Remaining Time First (SRTF) Example 4:

Turn Around time = Exit time – Arrival time

Waiting time = Turn Around time – Burst time

Turn Around Time of process P2 = 55 – 15 = 40 unit

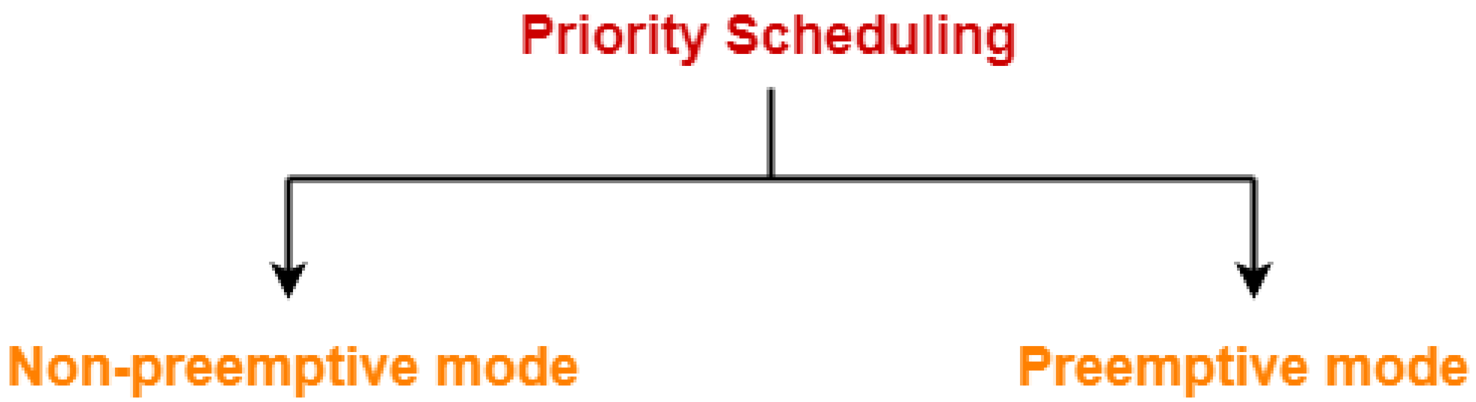
Waiting time of process P2 = 40 – 25 = 15 unit

Priority Scheduling

In Priority Scheduling,

Out of all the available processes, CPU is assigned to the process having the highest priority.

In case of a tie, it is broken by **FCFS Scheduling**.



Priority Scheduling

Advantages-

- It considers the priority of the processes and allows the important processes to run first.
- Priority scheduling in preemptive mode is best suited for real time operating system.

Disadvantages-

- Processes with lesser priority may starve for CPU.
- There is no idea of response time and waiting time.

Non-Preemptive Priority Scheduling Example 1:

Consider the set of 3 processes whose burst time is given below. If the CPU scheduling policy is priority non-preemptive, calculate the average waiting time and average turn around time.(Higher number represents higher priority)

Process	Burst Time	Priority
P1	10	2
P2	5	0
P3	8	1

Non-Preemptive Priority Scheduling Example 1:

Process	Burst Time	Priority
P1	10	2
P2	5	0
P3	8	1

P1	P3	P2

0 10 18 23

Non-Preemptive Priority Scheduling Example 1:

P1	P3	P2

0 10 18 23

Average waiting time = 9.33333

Average turn around time = 17

Process Id	Burst time	Priority	Exit time	Turn Around time	Waiting time
P1	10	2	10	10-0=10	10-10=0
P2	5	0	23	23-0=23	23-5=18
P3	8	1	18	18-0=18	18-8=10

Non-Preemptive Priority Scheduling Example 2:

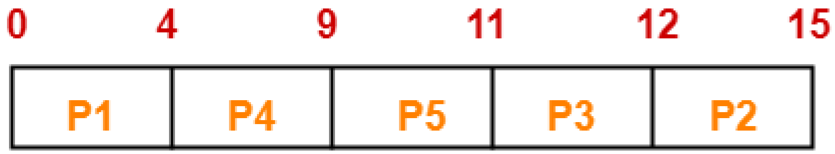
Consider the set of 5 processes whose arrival time and burst time are given below. If the CPU scheduling policy is priority non-preemptive, calculate the average waiting time and average turn around time. (Higher number represents higher priority)

Process Id	Arrival time	Burst time	Priority
P1	0	4	2
P2	1	3	3
P3	2	1	4
P4	3	5	5
P5	4	2	5

Non-Preemptive Priority Scheduling Example 2:

Process Id	Arrival time	Burst time	Priority
P1	0	4	2
P2	1	3	3
P3	2	1	4
P4	3	5	5
P5	4	2	5

(Higher number represents higher priority)



Gantt Chart

Non-Preemptive Priority Scheduling Example 2:

Process Id	Arrival time	Burst time	Priority	Exit time	Turn Around time	Waiting time
P1	0	4	2	4	4 – 0 = 4	4 – 4 = 0
P2	1	3	3	15	15 – 1 = 14	14 – 3 = 11
P3	2	1	4	12	12 – 2 = 10	10 – 1 = 9
P4	3	5	5	9	9 – 3 = 6	6 – 5 = 1
P5	4	2	5	11	11 – 4 = 7	7 – 2 = 5

Average Turn Around time = (4 + 14 + 10 + 6 + 7) / 5 = 41 / 5 = 8.2 unit

Average waiting time = (0 + 11 + 9 + 1 + 5) / 5 = 26 / 5 = 5.2 unit

0 – 4	4 – 9	9 – 11	11 – 12	12 – 15
P1	P4	P5	P3	P2

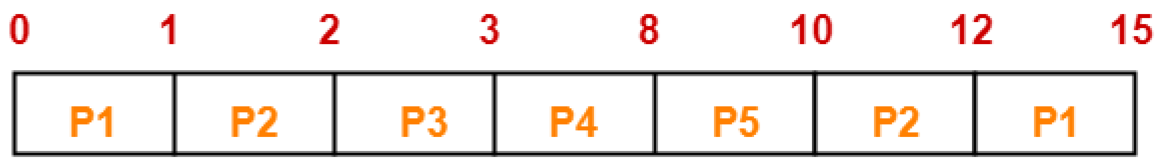
Preemptive Priority Scheduling Example 1:

Consider the set of 5 processes whose arrival time and burst time are given below. If the CPU scheduling policy is priority preemptive, calculate the average waiting time and average turn around time. (Higher number represents higher priority)

Process Id	Arrival time	Burst time	Priority
P1	0	4	2
P2	1	3	3
P3	2	1	4
P4	3	5	5
P5	4	2	5

Preemptive Priority Scheduling Example 1:

Process Id	Arrival time	Burst time	Priority
P1	0	4	2
P2	1	3	3
P3	2	1	4
P4	3	5	5
P5	4	2	5



Gantt Chart

Preemptive Priority Scheduling Example 1:

P1	P2	P3	P4	P5	P2	P1

0, 1, 2, 3, 8, 10, 12, 15

Gantt Chart

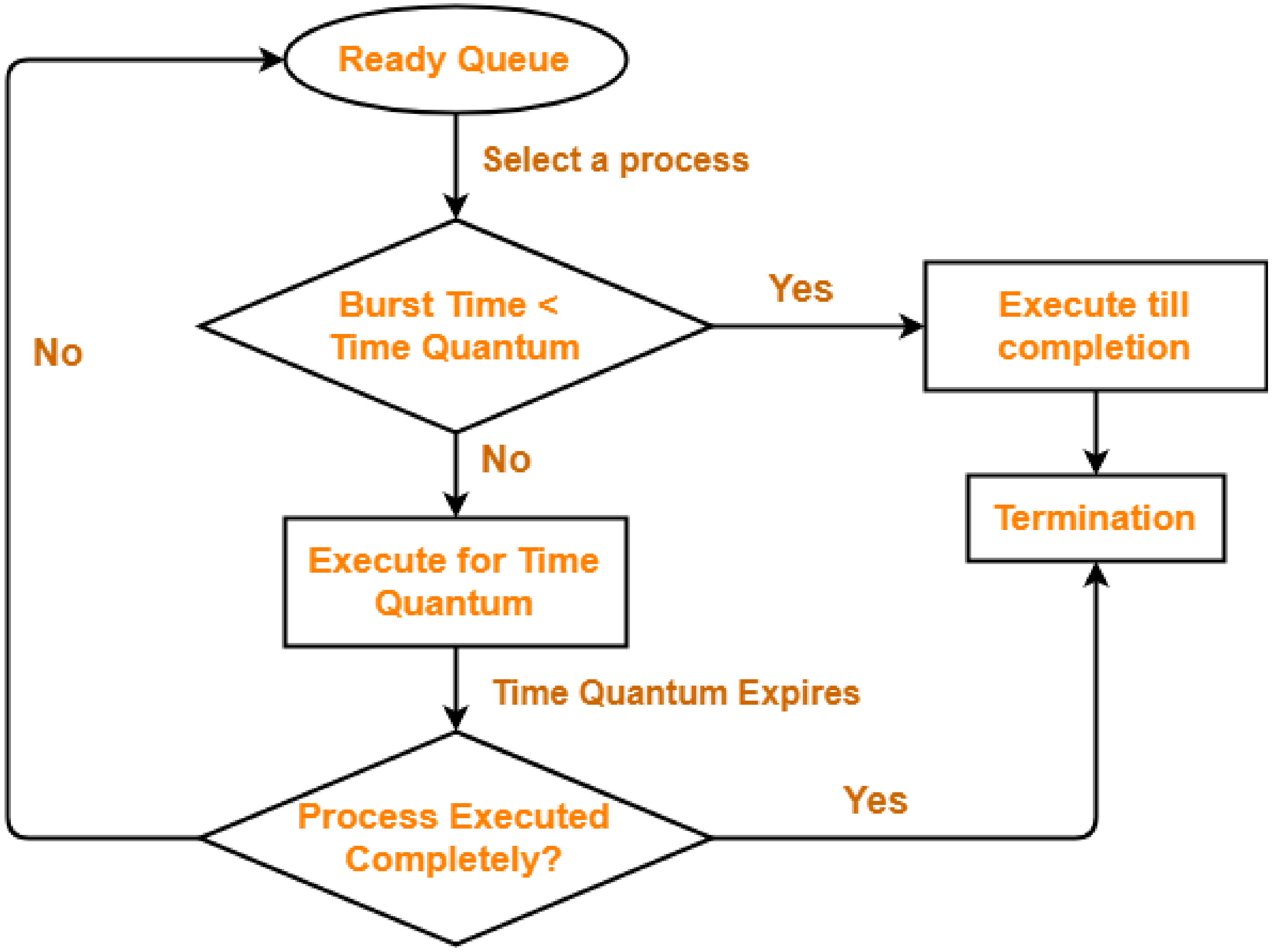
Process Id	Arrival time	Burst time	Priority	Exit time	Turn Around time	Waiting time
P1	0	4	2	15	15 – 0 = 15	15 – 4 = 11
P2	1	3	3	12	12 – 1 = 11	11 – 3 = 8
P3	2	1	4	3	3 – 2 = 1	1 – 1 = 0
P4	3	5	5	8	8 – 3 = 5	5 – 5 = 0
P5	4	2	5	10	10 – 4 = 6	6 – 2 = 4

Average Turn Around time = (15 + 11 + 1 + 5 + 6) / 5 = 38 / 5 = 7.6 unit
Average waiting time = (11 + 8 + 0 + 0 + 4) / 5 = 23 / 5 = 4.6 unit

Round Robin Scheduling

- CPU is assigned to the process on the basis of FCFS 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 in nature.

Round Robin Scheduling



Round Robin Scheduling

Round Robin Scheduling

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 can not be set for the processes.

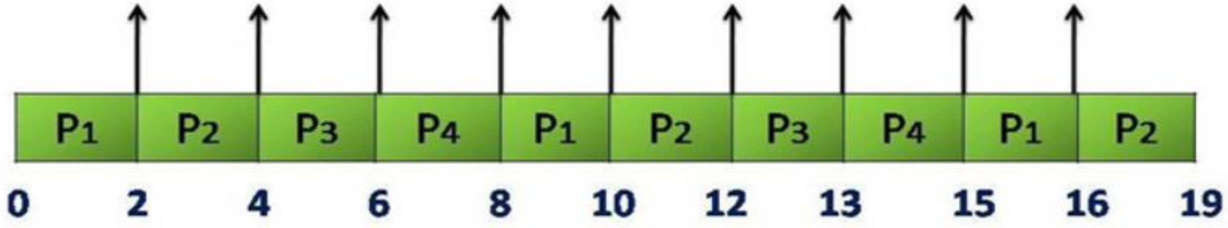
Round Robin Scheduling Example 1:

Consider the set of 4 processes whose arrival time and burst time are given below. If the CPU scheduling policy is Round Robin with time quantum = 2 unit, calculate the average waiting time and average turn around time.

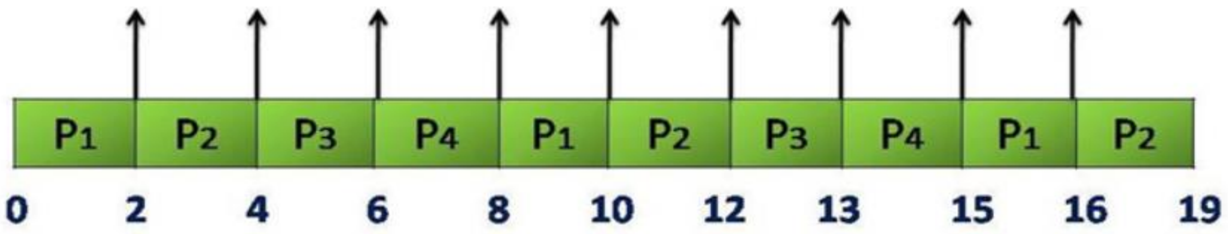
Process Id	Arrival time	Burst time
P1	0	5
P2	1	7
P3	2	3
P4	3	4

Round Robin Scheduling Example 1:

Process Id	Arrival time	Burst time
P1	0	5
P2	1	7
P3	2	3
P4	3	4



Round Robin Scheduling Example 1:



Process Id	Arrival time	Burst time	Exit time	Turn Around time	Waiting time
P1	0	5	16	16 – 0 = 16	16 – 5 = 11
P2	1	7	19	19 – 1 = 18	18 – 7 = 11
P3	2	3	13	13 – 2 = 11	11– 3 = 8
P4	3	4	15	15 – 3 = 12	12– 4 = 8

Average Turn Around time = (16 + 18 + 11 + 12) / 4 = 57 / 4 = 14.25 unit
Average waiting time = (11+ 11 + 8 + 8) / 4 = 38 / 4 = 9.5 unit

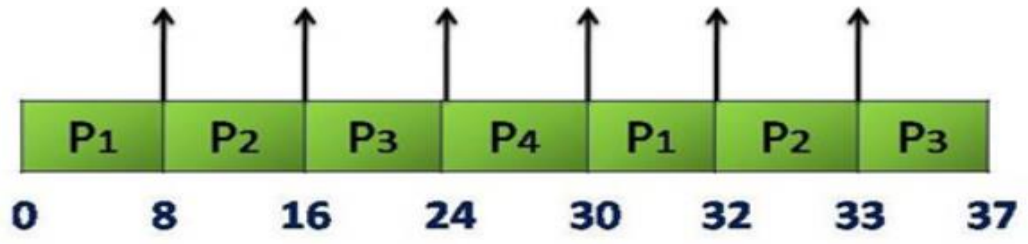
Round Robin Scheduling Example 2:

Consider the set of 4 processes whose arrival time and burst time are given below. If the CPU scheduling policy is Round Robin with time quantum = 8 unit, calculate the average waiting time and average turn around time.

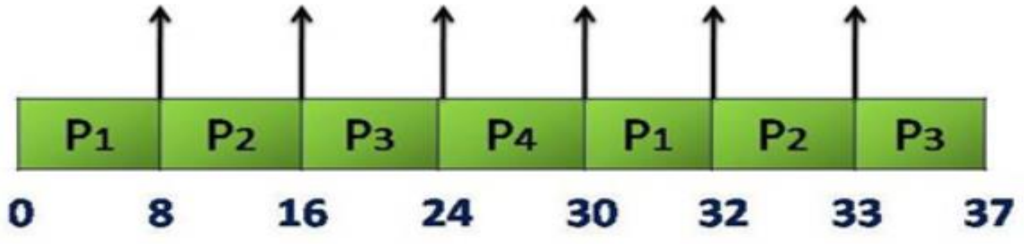
Process Id	Arrival time	Burst time
P1	0	10
P2	1	9
P3	2	12
P4	3	6

Round Robin Scheduling Example 2:

Process Id	Arrival time	Burst time
P1	0	10
P2	1	9
P3	2	12
P4	3	6



Round Robin Scheduling Example 2:



Process Id	Arrival time	Burst time	Exit time	Turn Around time	Waiting time
P1	0	10	32	32 – 0 = 32	32 – 10 = 22
P2	1	9	33	33 – 1 = 32	32 – 9= 23
P3	2	12	37	37 – 2 = 35	35– 12 = 23
P4	3	6	30	30 – 3 = 27	27– 6= 21

Average Turn Around time = (32 + 32 + 35 + 27) / 4 = 126 / 4 = 31.5 unit
Average waiting time = (22+ 23 + 23 + 21) / 4 = 89 / 4 = 22.25 unit

Round Robin Scheduling Example 3:

Consider the set of 6 processes whose arrival time and burst time are given below. If the CPU scheduling policy is Round Robin with time quantum = 2, calculate the average waiting time and average turn around time.

Process Id	Arrival time	Burst time
P1	0	4
P2	1	5
P3	2	2
P4	3	1
P5	4	6
P6	6	3

Round Robin Scheduling Example 3:

Process Id	Arrival time	Burst time
P1	0	4
P2	1	5
P3	2	2
P4	3	1
P5	4	6
P6	6	3

Ready Queue-

P5, P6, P2, P5, P6, P2, P5, P4, P1, P3, P2, P1

0 2 4 6 8 9 11 13 15

P1	P2	P3	P1	P4	P5	P2	P6

15 17 18 19 21

P5	P2	P6	P5

Gantt Chart

Round Robin Scheduling Example 3:

Process Id	Arrival time	Burst time	Exit time	Turn Around time	Waiting time
P1	0	4	8	8 – 0 = 8	8 – 4 = 4
P2	1	5	18	18 – 1 = 17	17 – 5 = 12
P3	2	2	6	6 – 2 = 4	4 – 2 = 2
P4	3	1	9	9 – 3 = 6	6 – 1 = 5
P5	4	6	21	21 – 4 = 17	17 – 6 = 11
P6	6	3	19	19 – 6 = 13	13 – 3 = 10

Average Turn Around time = (8 + 17 + 4 + 6 + 17 + 13) / 6 = 65 / 6 =10.84 unit

Average waiting time = (4 + 12 + 2 + 5 + 11 + 10) / 6 = 44 / 6 = 7.33unit

Round Robin Scheduling Example 4:

Consider the set of 6 processes whose arrival time and burst time are given below. If the CPU scheduling policy is Round Robin with time quantum = 3, calculate the average waiting time and average turn around time.

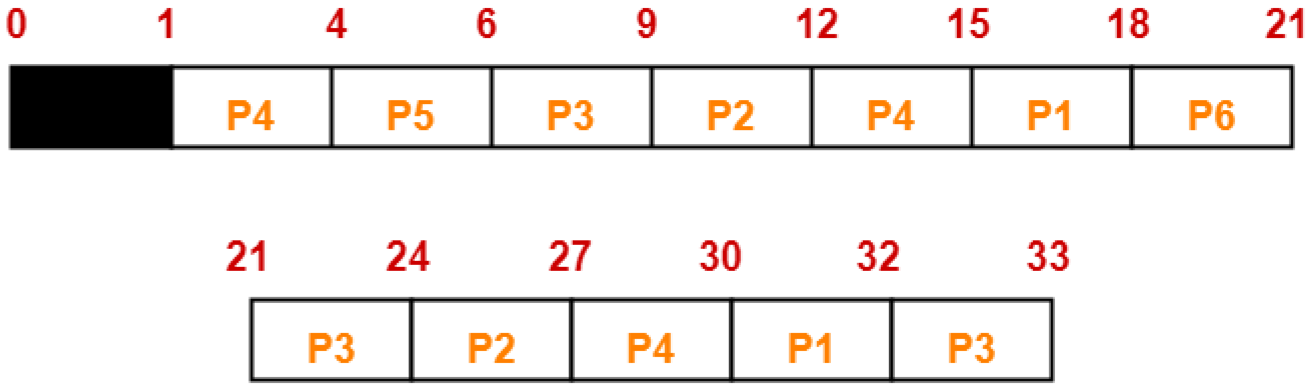
Process Id	Arrival time	Burst time
P1	5	5
P2	4	6
P3	3	7
P4	1	9
P5	2	2
P6	6	3

Round Robin Scheduling Example 4:

Process Id	Arrival time	Burst time
P1	5	5
P2	4	6
P3	3	7
P4	1	9
P5	2	2
P6	6	3

Ready Queue-

P3, P1, P4, P2, P3, P6, P1, P4, P2, P3, P5, P4



Gantt Chart

Round Robin Scheduling Example 4:

Process Id	Arrival time	Burst time	Exit time	Turn Around time	Waiting time
P1	5	5	32	32 – 5 = 27	27 – 5 = 22
P2	4	6	27	27 – 4 = 23	23 – 6 = 17
P3	3	7	33	33 – 3 = 30	30 – 7 = 23
P4	1	9	30	30 – 1 = 29	29 – 9 = 20
P5	2	2	6	6 – 2 = 4	4 – 2 = 2
P6	6	3	21	21 – 6 = 15	15 – 3 = 12

Average Turn Around time = (27 + 23 + 30 + 29 + 4 + 15) / 6 = 128 /6 = 21.33 unit

Average waiting time = (22 + 17 + 23 + 20 + 2 + 12) / 6 = 96 / 6 = 16unit

Round Robin Scheduling Example 5:

Consider the set of 5 processes whose arrival time and burst time are given below-

Process Id	Arrival time	Burst time
P1	0	5
P2	1	3
P3	2	1
P4	3	2
P5	4	3

If the CPU scheduling policy is Round Robin with time quantum = 2 unit, calculate the average waiting time and average turn around time.

Round Robin Scheduling Example 5:

0	2	4	5	7	9	11	12	13	14
P1	P2	P3	P1	P4	P5	P2	P1	P5	

Gantt Chart

Process Id	Exit time	Turn Around time	Waiting time
P1	13	13 – 0 = 13	13 – 5 = 8
P2	12	12 – 1 = 11	11 – 3 = 8
P3	5	5 – 2 = 3	3 – 1 = 2
P4	9	9 – 3 = 6	6 – 2 = 4
P5	14	14 – 4 = 10	10 – 3 = 7

<u>Ready Queue-</u>

P5, P1, P2, P5, P4, P1, P3, P2, P1

Average Turn Around time = (13 + 11 + 3 + 6 + 10) / 5 = 43 / 5 = 8.6 unit

Average waiting time = (8 + 8 + 2 + 4 + 7) / 5 = 29 / 5 = 5.8 unit

Round Robin Scheduling Example 6:

Four jobs to be executed on a single processor system arrive at time 0 in the order A, B, C, D. Their burst CPU time requirements are 4, 1, 8, 1 time units respectively. The completion time of A under round robin scheduling with time slice of one time unit is-

A. 10
B. 4
C. 8
D. 9

Round Robin Scheduling Example 6:

0	1	2	3	4	5	6	7	8	9	14
A	B	C	D	A	C	A	C	A	C	

Gantt Chart

Process Id	Arrival time	Burst time
A	0	4
B	0	1
C	0	8
D	0	1

Ready Queue-

C, A, C, A, C, A, D, C, B, A

Clearly, completion time of process A = 9 unit.
Thus, Option (D) is correct.

THANK YOU