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TECHNOLOGY, RESEARCH, SOCIAL INNOVATION & PARTNERSHIPS

Scheduling

Module 2

Process Management

- **Process:** Concept of a Process, Process States, Process Control - creation, new program execution, termination. Interposes communication(IPC). Examples of IPC.

- **Threads:** Differences between Threads and Processes. Concept of Threads, Concurrency. Multi- threading, Types of Threads. POSIX Threads functions.

- **Scheduling:** Concept of Scheduler, Scheduling Algorithms: FCFS, SJF, SRTN, Priority, Round Robin.

Scheduling

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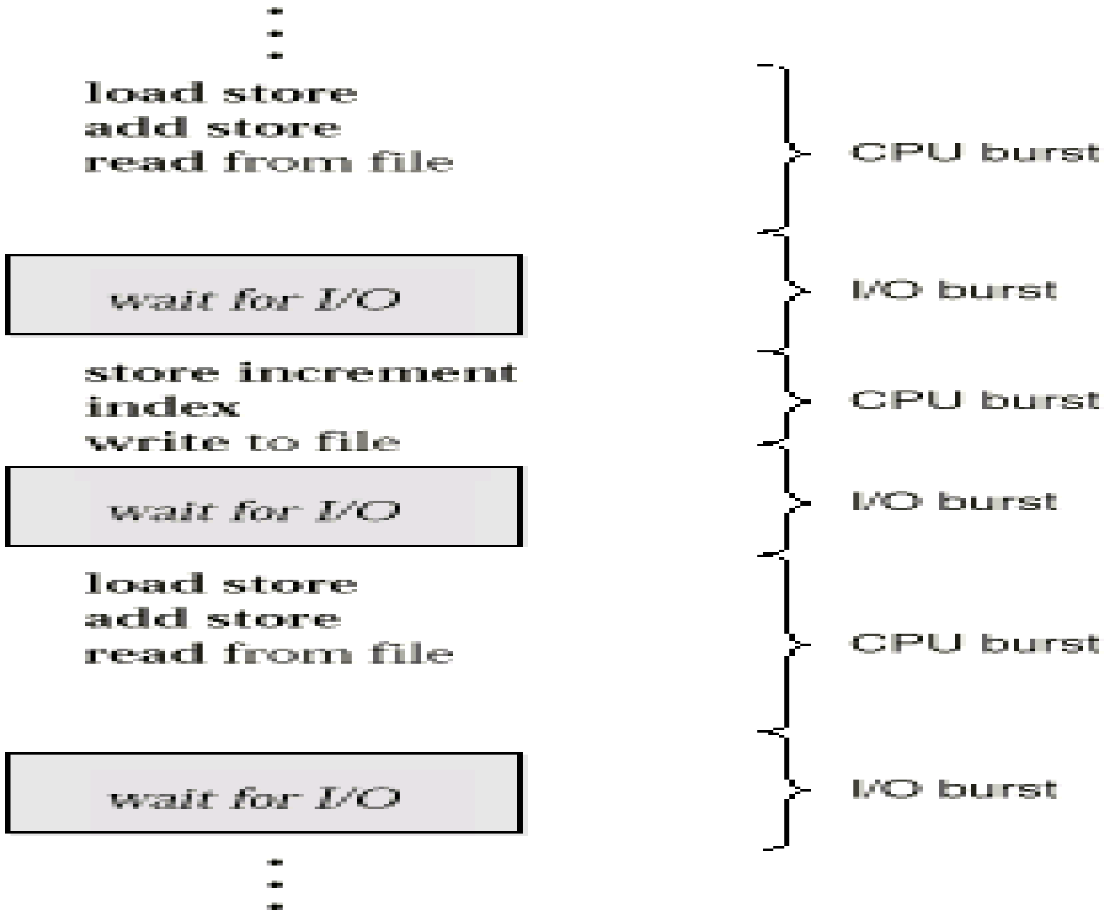
Scheduling

- Maximum CPU utilization obtained with multiprogramming

- CPU–I/O Burst Cycle – Process execution consists of a *cycle* of CPU execution and I/O wait.

Alternating Sequence of CPU And I/O Bursts



CPU / Process Scheduler

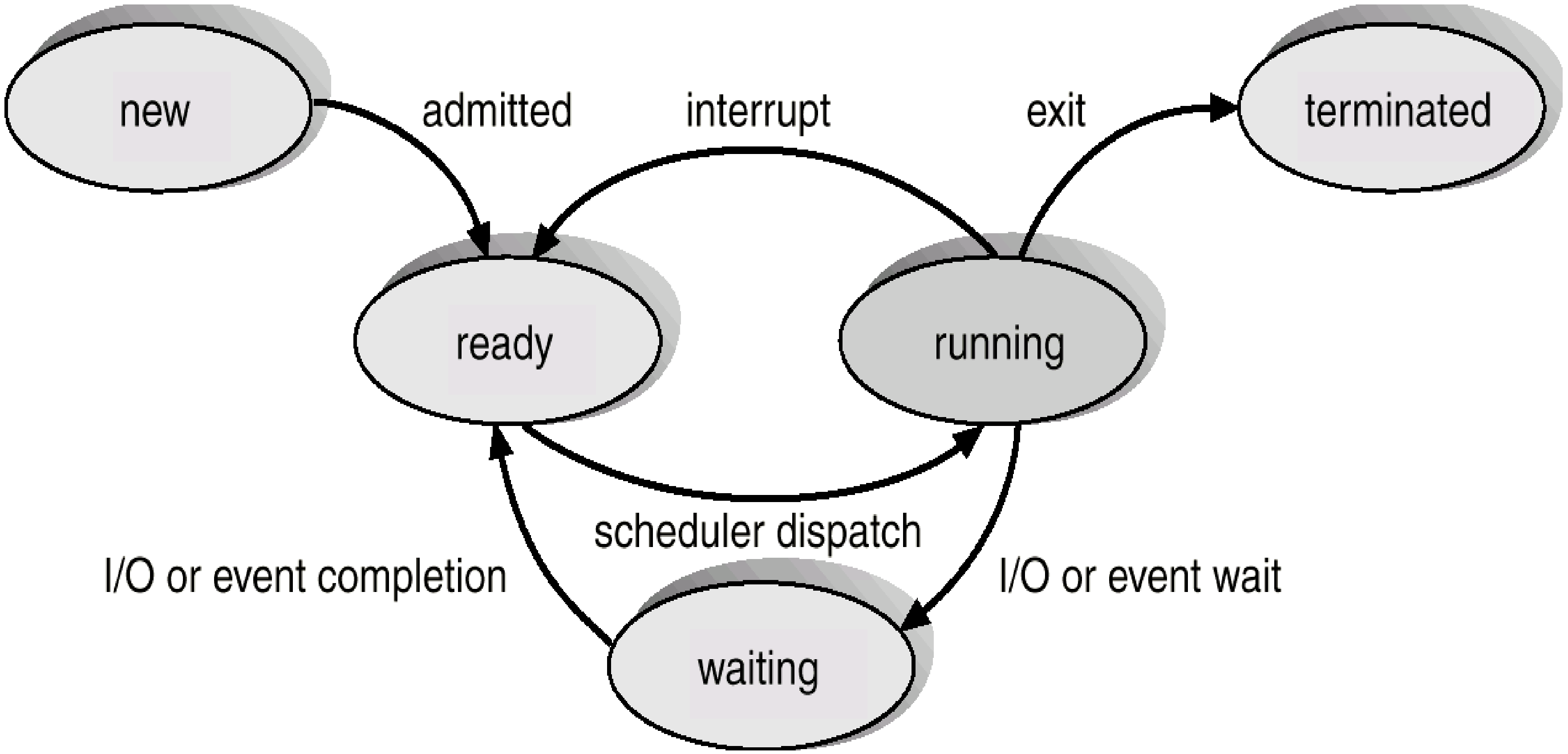
- Selects from among the processes in memory that are ready to execute, and allocates the CPU to one of them.

- Scheduling may be *preemptive or non-preemptive*
- ***Non-preemptive*** – If CPU allocated to a process, it keeps the CPU until it releases it by terminating or switching to waiting state
- ***Preemptive*** - If CPU allocated to a process, it may be released if high priority process needs the CPU

Scheduler

- CPU scheduling decisions may take place when a process:
  1.Switches from running to waiting state
  2.Switches from running to ready state
  3.Switches from waiting to ready state
  4.Terminates
- Scheduling under 1 and 4 is *non-preemptive*
- All other scheduling is *preemptive*

Diagram for Process States



Scheduling Algorithms

They deal with the problem of deciding which of the processes in ready queue is to be allocated the CPU

Algorithm compared based on following criteria

- **CPU utilization** – keep the CPU as busy as possible
- **Throughput** – number of processes completed or amount of work done per unit time
- **Turnaround time** – time of submission of a process to the time of completion
- **Waiting time** – amount of time a process has been waiting in the ready queue
- **Response time** – amount of time it takes from when a request was submitted until the first response is produced

Optimization Criteria

- Max CPU utilization
- Max throughput
- Min turnaround time
- Min waiting time
- Min response time

Types of process schedulers / Scheduling categories

Scheduling is broken down into three categories:

1. Long term scheduling:

- Is performed when a new process is created.
- Long-term scheduler (or job scheduler) – selects which processes should be brought into the ready queue.
- Long-term scheduler is invoked very infrequently (seconds, minutes) $\Rightarrow$ (may be slow)
- The long-term scheduler controls the *degree of multiprogramming*.

Types of process schedulers / Scheduling categories

2. Medium term scheduling:

- Part of the swapping function
- Swapping-in decisions are taken by medium term scheduler
- Based on the need to manage the degree of multiprogramming

Types of process schedulers / Scheduling categories

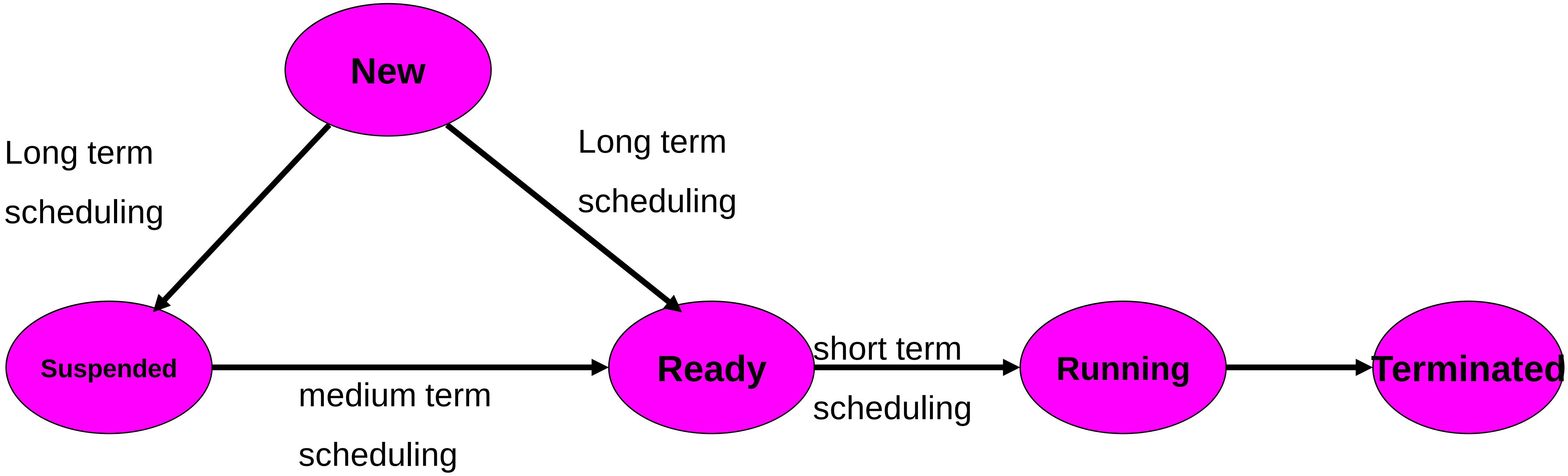
3.Short term scheduling:

- Determines which ready process will be assigned the CPU when it next becomes available and actually assign the CPU to this process **.**

- Short-term scheduler (or CPU scheduler) – selects which process should be executed next and allocates CPU.

- Short-term scheduler is invoked very frequently (milliseconds)$\Rightarrow$ (must be fast).

Types of process schedulers / Scheduling categories



Scheduling Algorithms

- **FCFS (First Come First Serve)**
- **SJF (Shortest Job First)**
- **Priority scheduling**
- **Round Robin scheduling**

FCFS Scheduling: Characteristics

Selection Function: max(w), selects the process which is waiting in the ready queue for maximum time.

Decision Mode : Non_preemptive

Throughput: Not emphasized

Response Time: May be high, especially if there is a large variance in the process execution times.

Overhead: Minimum

Effect on Processes: Penalizes short processes

Starvation: No

- **Completion Time**

  Time at which process completes its execution.
- **Turn Around Time**

  Time Difference between completion time and arrival time.

  Turn Around Time = Completion Time – Arrival Time
- **Waiting Time(W.T)**

  Time Difference between turn around time and burst time.

  Waiting Time = Turn Around Time – Burst Time

Process	**Burst Time**
P1	24
P2	3
P3	3

- Suppose that the processes arrive in the order: *P1* , *P2* , *P3*

The Gantt Chart for the schedule is:

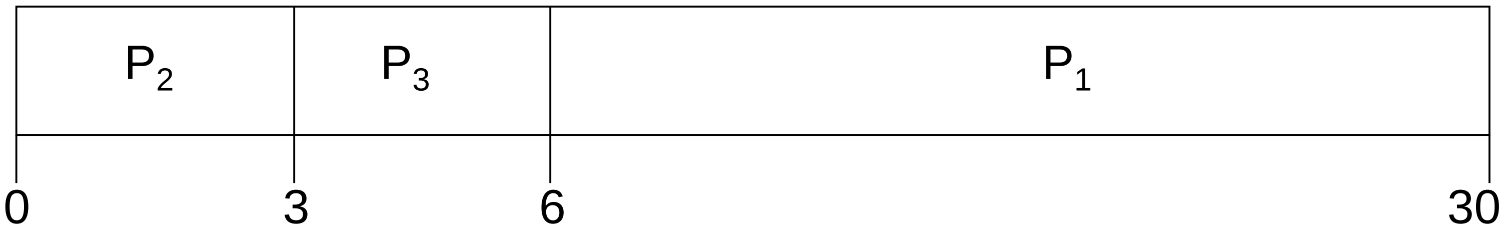
The Gantt Chart for the schedule is:

Waiting time for *P1* = 0; *P2* = 24; *P3* = 27
Average waiting time: (0 + 24 + 27)/3 = 17

Turnaround time for *P1* = 24; *P2* = 27; *P3* = 30
Average turnaround time : (24 + 27 + 30)/3 = 27

FCFS Scheduling (Cont.)

- Suppose that the processes arrive in the order : *P2* , *P3* , *P1*



FCFS Scheduling (Cont.)

- Suppose that the processes arrive in the order : *P2* , *P3* , *P1*

Waiting time for *P1* = 6; *P2* = 0; *P3* = 3
Average waiting time: (6 + 0 + 3)/3 = 3

Turnaround time for *P1* = 30; *P2* = 3; *P3* = 6
Average turnaround time : (30 + 3 + 6)/3 = 13

Example-2 of FCFS

Process	Arrival Time	Burst Time
P1	0.0	3
P2	2.0	6
P3	4.0	4
P4	6.0	5
P5	8.0	2

Example-2 of FCFS

Process	Arrival Time	Burst Time
P1	0.0	7
P2	2.0	4
P3	4.0	1
P4	5.0	4

P1	P2	P3	P4

0 7 11 12 16

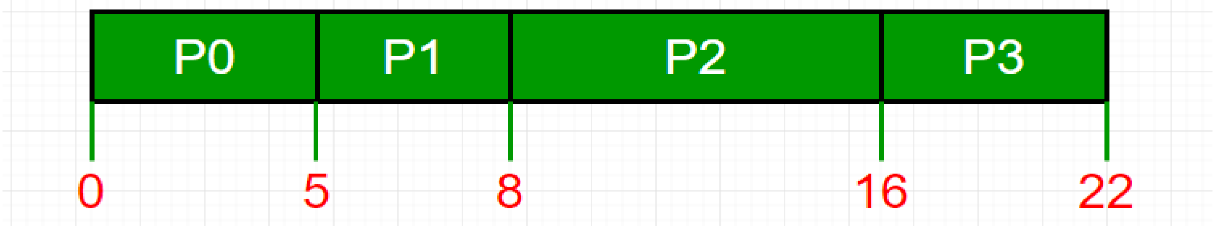
Average waiting time = (0 + 5 + 7 + 7)/4 = 4.75
Average Turnaround Time = (7+9+8+11)/4=8.75

First Come First Serve (FCFS) (Non Pre-emptive)

Processes	Burst time	Arrival Time	Service Time
P0	5	0	0
P1	3	1	5
P2	8	2	8
P3	6	3	16

- **Service Time :** Service time means amount of time after which a process can start execution.

It is summation of burst time of previous processes (Processes that came before)



First Come First Serve (FCFS) (Non Pre-emptive)

Processes	Burst time	Arrival Time	Service Time
P0	5	0	0
P1	3	1	5
P2	8	2	8
P3	6	3	16

- **To find waiting time:**

  Time taken by all processes before the current process to be started

  (i.e. burst time of all previous processes) – arrival time of current process

  wait_time[i] = (bt[0] + bt[1] +…… bt[i-1]) – arrival_time[i]

Process	Wait Time : Service Time - Arrival Time
P0	0 - 0 = 0
P1	5 - 1 = 4
P2	8 - 2 = 6
P3	16 - 3 = 13

Average Wait Time: (0 + 4 + 6 + 13) / 4 = 5.75

First Come First Serve (FCFS) (Non Pre-emptive)

Implementation

1) Input the processes along with their burst time (bt) and arrival time (at).

2) Find **waiting time (wt)** for all processes. i.e. for a given process i:

   wt[i] = (bt[0] + bt[1] + ... + bt[i-1]) - at[i] .

3) Now find **turnaround time** = waiting_time + burst_time for all processes.

4) Find **average waiting time** = total_waiting_time / no_of_processes.

5) Similarly, find **average turnaround time** = total_turn_around_time / no_of_processes.

Shortest-Job-First (SJF) Scheduling

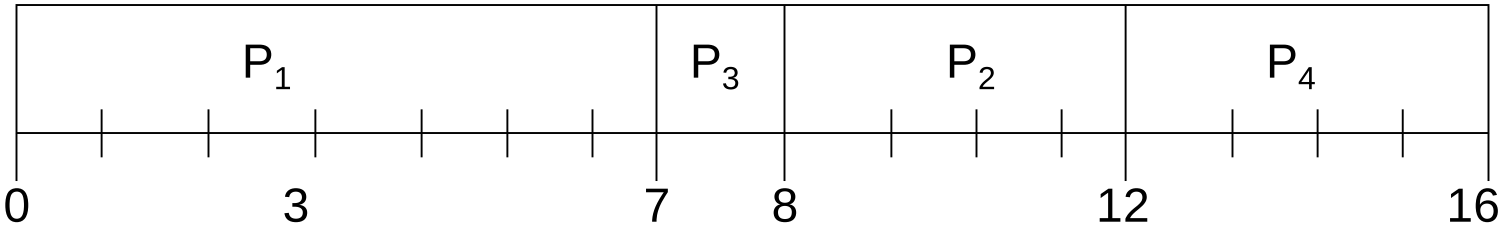
- Associate with each process the length of its next CPU burst. Use these lengths to schedule the process with the shortest time
- Two schemes:
  - **Nonpreemptive** – once CPU given to the process it cannot be preempted until completes its CPU burst
  - **Preemptive** – If a new process arrives with CPU burst length less than remaining time of current executing process, preempt. This scheme is know as the **Shortest-Remaining-Time-First (SRTF)**
- **SJF is optimal** – gives minimum average waiting time for a given set of processes

Example of Non-Preemptive SJF

Process	Arrival Time	Burst Time
P1	0.0	7
P2	2.0	4
P3	4.0	1
P4	5.0	4

Example of Non-Preemptive SJF

Process	Arrival Time	Burst Time
P1	0.0	7
P2	2.0	4
P3	4.0	1
P4	5.0	4



- **Average waiting time = (0 + 6 + 3 + 7)/4 = 4**
- **Average Turnaround Time = (7+10+4+11)/4=8**

Shortest Job First Preemptive or Shortest Remaining Time

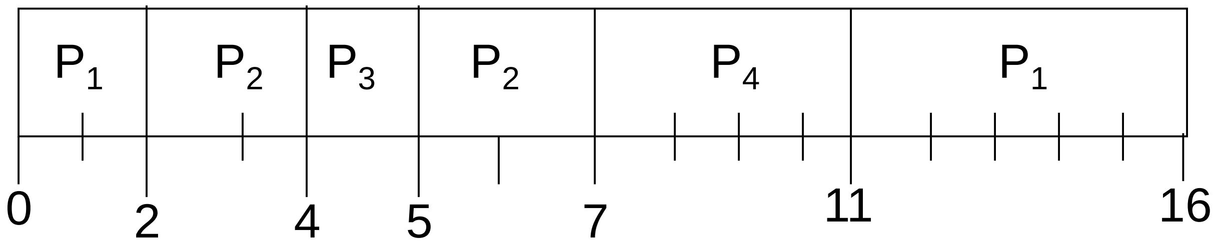
- It is a preemptive version of SJF. In this policy, scheduler always chooses the process that has the **shortest expected remaining processing time.**
- When a new process arrives in the ready queue, it may in fact have a shorter remaining time than the currently running process.
- Accordingly, the scheduler may preempt whenever a new process becomes ready.
- Scheduler must have an estimate of processing time to perform the selection function.

Shortest Job First Preemptive or Shortest Remaining Time: characteristics

- **Selection Function**: minimum total service time required by the process, minus time spent in execution so far.
- **Decision Mode :** Preemptive (At arrival time)
- **Throughput:** High
- **Response Time:** Provides good response time
- **Overhead:** Can be high
- **Effect on Processes:** Penalizes long processes.
- **Starvation:** Possible

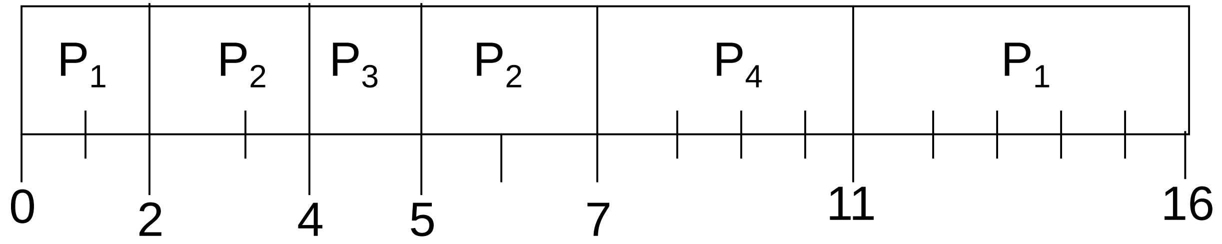
Example of Preemptive SJF

Process	Arrival Time	Burst Time
P_1	0.0	7
P_2	2.0	4
P_3	4.0	1
P_4	5.0	4



Example of Preemptive SJF

Process	Arrival Time	Burst Time
P_1	0.0	7
P_2	2.0	4
P_3	4.0	1
P_4	5.0	4



- Average waiting time = (9 + 1 + 0 +2)/4 = 3
- Average turnaround time= (16+5+1+6)/4=7

Shortest Remaining Time Next (SRTN) (Pre-emptive)_Example

Process	Arrival Time (T0)	CPU Burst Time (in milliseconds) (Time required for completion ΔT)
P0	0	10
P1	1	6
P2	3	2
P3	5	4

Gantt Chart

P0	P1	P2	P1	P3	P0

0 1 3 5 9 13 22

- Initially only process P0 is present and it is allowed to run
- But when process P1 comes, it has shortest remaining run time.
- So, P0 is pre-empted and P1 is allowed to run.
- Whenever new process comes or current process blocks, such type of decision is taken.
- This procedure is repeated till all processes complete their execution.

Shortest Remaining Time Next (SRTN) (Pre-emptive)_Example

Output

Process	Arrival Time (T0)	Burst Time (ΔT)	Finish Time (T1)
P0	0	10	22
P1	1	6	9
P2	3	2	5
P3	5	4	13

Gantt Chart

P0	P1	P2	P1	P3	P0

0 1 3 5 9 13 22

Shortest Remaining Time Next (SRTN) (Pre-emptive)_Example

Output

Process	Arrival Time (T0)	Burst Time (ΔT)	Finish Time (T1)	Turnaround Time (TAT = T1 - T0)
P0	0	10	22	22
P1	1	6	9	8
P2	3	2	5	2
P3	5	4	13	8

Gantt Chart

P0	P1	P2	P1	P3	P0

0 1 3 5 9 13 22

- Average Turnaround Time= (22+8+2+8) / 4 = 10 milliseconds

Shortest Remaining Time Next (SRTN) (Pre-emptive)_Example

Output

Process	Arrival Time (T0)	Burst Time (ΔT)	Finish Time (T1)	Turnaround Time (TAT = T1 - T0)	Waiting Time (WT = TAT - ΔT)
P0	0	10	22	22	12
P1	1	6	9	8	2
P2	3	2	5	2	0
P3	5	4	13	8	4

Gantt Chart

P0	P1	P2	P1	P3	P0

0 1 3 5 9 13 22

- Average Turnaround Time= (22+8+2+8) / 4 = 10 milliseconds
- Average Waiting Time = (12+2+0+4) / 4= 4.5 milliseconds

Priority scheduling

- A priority number (integer) is associated with each process
- The CPU is allocated to the process with the highest priority (smallest integer ≡ highest priority)
  - Preemptive
  - Nonpreemptive
- SJF is a priority scheduling where priority is the predicted next CPU burst time
- Problem ≡ **Starvation** – low priority processes may never execute
- Solution ≡ **Aging** – as time progresses increase the priority of the process

Example

Consider the set of processes with arrival time (in milliseconds), CPU burst time (in milliseconds) , and priority (0 is the highest priority) shown below. None of the processes have I/O burst time.

Process	Arrival time	Burst Time	Priority
P1	0	11	2
P2	5	28	0
P3	12	2	3
P4	2	10	1
P5	9	16	4

The average waiting time (in milliseconds) of all the processes using preemptive priority scheduling algorithm is __________.

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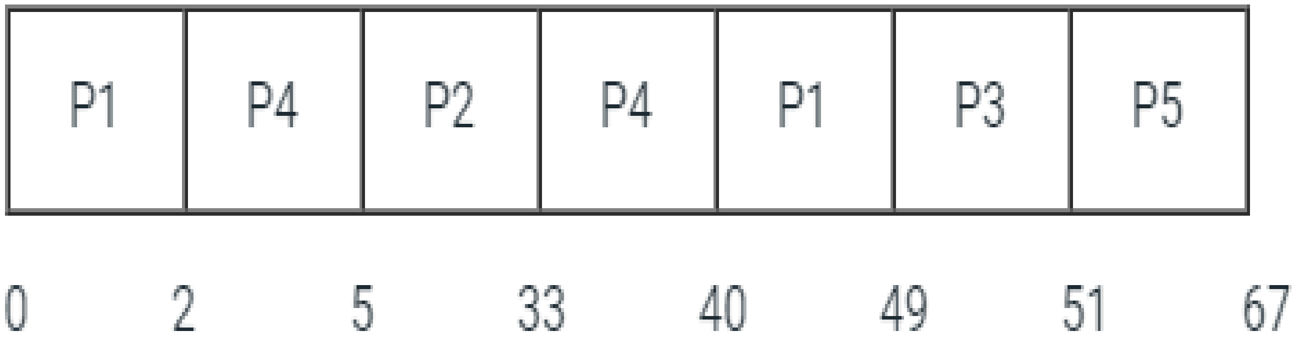
Process	Arrival Time	Burst Time	Priority
P_1	0	11	2
P_2	5	28	0
P_3	12	2	3
P_4	2	10	1
P_5	9	16	4

Gantt chart:



Process Table:

Process	Arrival Time	Burst Time	Priority	Completion time (CT)	Turnaround time (TAT) TAT= CT – AT	Waiting time (WT) WT = TAT-BT
P_1	0	11	2	49	49	38
P_2	5	28	0	33	28	0
P_3	12	2	3	51	39	37
P_4	2	10	1	40	38	28
P_5	9	16	4	67	58	42

Example

Consider the set of processes with arrival time (in milliseconds), CPU burst time (in milliseconds) , and priority (0 is the highest priority) shown below. None of the processes have I/O burst time.

Process	Arrival time	Burst Time	Priority
P1	0	11	2
P2	5	28	0
P3	12	2	3
P4	2	10	1
P5	9	16	4

The average waiting time (in milliseconds) of all the processes using preemptive priority scheduling algorithm is __________.

$$\text{Average waiting time} = \frac{\sum \textit{waiting time of all the processes}}{\textit{number of processes}}$$

$$= \frac{38+0+37+28+42}{5} = 29 \text{ milliseconds}$$

Answer
=29

Round Robin (RR)

- Each process gets a small unit of CPU time (*time quantum*)
- After time has elapsed, the process is preempted and added to the end of the ready queue.
- If there are *n* processes in the ready queue and the time quantum is *q*, then each process gets 1/*n* of the CPU time in chunks of at most *q* time units at once.
- No process waits more than (n-1)q time units.

RR: characteristics

- **Selection Function**: constant
- **Decision Mode :** Preemptive (At time quantum)
- **Throughput:** May be low if time quantum is too small
- **Response Time:** Provides good response time for short processes
- **Overhead:** Minimum
- **Effect on Processes:** Fair treatment
- **Starvation:** No

Example of RR with Time Quantum = 20

Process	Burst Time
P1	53
P2	17
P3	68
P4	24

Example of RR with Time Quantum = 20

Process	Burst Time
P1	53
P2	17
P3	68
P4	24

P_1	P_2	P_3	P_4	P_1	P_3	P_4	P_1	P_3	P_3

0 20 37 57 77 97 117 121 134 154 162

- Average waiting time = (81+ 20 + 94+ 97)/4 = 73
- Average turnaround time= (134+37+162+121)/4=113.5

- Typically, higher average turnaround than SJF, but better *response*

Example: Round Robin (By Default preemptive: Time Quantum 2)

Process	Arrival Time	Burst Time
P_1	0.0	7
P_2	2.0	4
P_3	4.0	1
P_4	5.0	4

Example: Round Robin (By Default preemptive: Time Quantum 2)

Process	Arrival Time	Burst Time
P_1	0.0	7
P_2	2.0	4
P_3	4.0	1
P_4	5.0	4

P1	P2	P1	P3	P2	P4	P1	P4	P1

0 2 4 6 7 9 11 13 15 16

Example: Round Robin (By Default preemptive: Time Quantum 2)

Process	**Arrival Time**	**Burst Time**
P_1	**0.0**	**7**
P_2	**2.0**	**4**
P_3	**4.0**	**1**
P_4	**5.0**	**4**

P1	P2	P1	P3	P2	P4	P1	P4	P1

0 2 4 6 7 9 11 13 15 16

Average waiting time = (9 + 3 + 2 +6)/4 =5
Average turnaround time =(16+7+3+10)/4=9

Consider the following four processes with arrival times (in milliseconds) and their length of CPU bursts (in milliseconds) as shown below:

Process	P1	P2	P3	P4
Arrival time	0	1	3	4
CPU burst time	3	1	3	Z

These processes are run on a single processor using preemptive Shortest Remaining Time First scheduling algorithm. If the average waiting time of the processes is 1 millisecond, then the value of Z is_____.

Assume that: P4 < P3

Gantt chart:

P1	P2	P1	P1	P4	P3

0 1 2 3 4 4+Z 7+Z

Process Table1:

Process	Arrival Time (AT)	Burst Time (BT)	Completion time (CT)	Turnaround time TAT = CT - AT	Waiting time WT = TAT - BT
P1	0	3	4	4	1
P2	1	1	2	1	0
P3	3	3	7 + Z	4 + Z	1 + Z
P4	4	z	4 + Z	Z	0

Average waiting time = 1

$$\frac{1+0+(1+z)+0}{4} = 1$$

The value of Z is 2.

Assume that: P4 ≥p3

Gantt chart:

P1	P2	P1	P1	P3	P4

0 1 2 3 4 7 7+Z

Process Table2:

Process	Arrival Time (AT)	Burst Time (BT)	Completion time (CT)	Turnaround time TAT = CT - AT	Waiting time WT = TAT - BT
P1	0	3	4	4	1
P2	1	1	2	1	0
P3	3	3	7	4	1
P4	4	Z	7 + Z	Z + 3	3

Given average waiting time = 1

$$But\ \frac{1+0+1+3}{4} \neq 1$$

$$\frac{5}{4} \neq 1$$

$$\therefore p4 > p3\ is\ not\ possible$$

$\therefore$ **Z = 2**

Exercise

Consider the following four processes with arrival times (in milliseconds) and their length of CPU bursts (in milliseconds) as shown below:

Process	P1	P2	P3	P4
Arrival time	0	1	3	4
CPU burst time	3	1	3	Z

These processes are run on a single processor using preemptive Shortest Remaining Time First scheduling algorithm. If the average waiting time of the processes is 1 millisecond, then the value of Z is______.

Answer
Z=2

Exercise

Considrer the following CPU processes with arrival times (in miliseconds) and length of CPU bursts (in miliseconds) as given below:

Process	Arrival time	Burst time
P1	0	7
P2	3	3
P3	5	5
P4	6	2

If the pre-emptive shortest remaining time first scheduling algorithm is used to schedule the processes, then the average waiting time across all processes is ______ milliseconds.

Considrer the following CPU processes with arrival times (in miliseconds) and length of CPU bursts (in miliseconds) as given below:

Process	Arrival time	Burst time
P1	0	7
P2	3	3
P3	5	5
P4	6	2

If the pre-emptive shortest remaining time first scheduling algorithm is used to schedule the processes, then the average waiting time across all processes is ______ milliseconds.

Answer
=3

Exercise

Consider the following processes, with the arrival time and the length of the CPU burst given in milliseconds. The scheduling algorithm used is preemptive shortest remaining-time first.

Process	Arrival Time	Burst Time
P_1	0	10
P_2	3	6
P_3	7	1
P_4	8	3

The average turn around time of these processes is milliseconds _______.

Exercise

Consider the following processes, with the arrival time and the length of the CPU burst given in milliseconds. The scheduling algorithm used is preemptive shortest remaining-time first.

Process	Arrival Time	Burst Time
P_1	0	10
P_2	3	6
P_3	7	1
P_4	8	3

The average turn around time of these processes is milliseconds ______.

Answer
=8.25

Exercise

For the processes listed in the following table, which of the following scheduling schemes will give the lowest average turnaround time?

Process	Arrival Time	Processing Time
A	0	3
B	1	6
C	4	4
D	6	2

- (A) First Come First Serve
- (B) Non – preemptive Shortest Job First
- (C) Shortest Remaining Time
- (D) Round Robin with Quantum value two

Exercise

For the processes listed in the following table, which of the following scheduling schemes will give the lowest average turnaround time?

Process	Arrival Time	Processing Time
A	0	3
B	1	6
C	4	4
D	6	2

(A) First Come First Serve
(B) Non – preemptive Shortest Job First
(C) Shortest Remaining Time
(D) Round Robin with Quantum value two

Answer (C) Shortest Remaining Time

Exercise

Consider the 3 processes, P1, P2 and P3 shown in the table.

Process	Arrival time	Time Units Required
P1	0	5
P2	1	7
P3	3	4

The completion order of the 3 processes under the policies FCFS and RR2 (round robin scheduling with CPU quantum of 2 time units) are

- (A) **FCFS:** P1, P2, P3 **RR2:** P1, P2, P3
- (B) **FCFS:** P1, P3, P2 **RR2:** P1, P3, P2
- (C) **FCFS:** P1, P2, P3 **RR2:** P1, P3, P2
- (D) **FCFS:** P1, P3, P2 **RR2:** P1, P2, P3

Exercise

Consider the 3 processes, P1, P2 and P3 shown in the table.

Process	Arrival time	Time Units Required
P1	0	5
P2	1	7
P3	3	4

The completion order of the 3 processes under the policies FCFS and RR2 (round robin scheduling with CPU quantum of 2 time units) are

- (A) **FCFS:** P1, P2, P3 **RR2:** P1, P2, P3
- (B) **FCFS:** P1, P3, P2 **RR2:** P1, P3, P2
- (C) **FCFS:** P1, P2, P3 **RR2:** P1, P3, P2
- (D) **FCFS:** P1, P3, P2 **RR2:** P1, P2, P3

Answer (C) **FCFS:** P1, P2, P3 **RR2:** P1, P3, P2

In RR, time slot is of 2 units. Processes are assigned in following order
p1, p2, p1, p3, p2, p1, p3, p2, p2

This question involves the concept of ready queue. At t=2, p2 starts and p1 is sent to the ready queue and at t=3 p3 arrives so then the job p3 is queued in ready queue after p1.
So at t=4, again p1 is executed then p3 is executed for first time at t=6

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1. William Stallings, Operating System: Internals and Design Principles, Prentice Hall, ISBN-10: 0-13-380591-3, ISBN-13: 978-0-13-380591-8, 8th Edition

2. Abraham Silberschatz, Peter Baer Galvin and Greg Gagne, Operating System Concepts, WILEY,ISBN 978-1-118-06333-0, 9th Edition