Scheduling Criteria

CPU utilization – keep the CPU as busy as possible (from 0% to 100%)

Throughput – # of processes that complete their execution per time unit

Turnaround time – amount of time to execute a particular Process

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

Scheduling Algorithems

- First Come First Serve Scheduling
- Shortest Job First Scheduling
- Priority Scheduling
- Round-Robin Scheduling
- **Multilevel Queue Scheduling**
- **Multilevel Feedback-Queue Scheduling**

First Come First Serve Scheduling (FCFS)

Process	Burst time
P1	24
P2	3
P2	3

Suppose that the processes arrive in the order: P_1 , P_2 , P_3
The Gantt Chart for the schedule is:

First Come First Serve Scheduling

- The average of waiting time in this policy is usually quite long

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

First Come First Serve Scheduling

- Suppose we change the order of arriving job P2, P3, P1

The Gantt chart for the schedule is:

Waiting time for $P_1 = 6$; $P_2 = 0$, $P_3 = 3$

Average waiting time: $(6 + 0 + 3)/3 = 3$

First Come First Serve Scheduling

- Consider if we have a CPU-bound process and many I/O-bound processes
- There is a **convoy effect** as all the other processes waiting for one of the big process to get off the CPU
- FCFS scheduling algorithm is non-preemptive

Short job first scheduling (SJF)

- This algorithm associates with each process the length of the processes' next CPU burst

- If there is a tie, FCFS is used
- In other words, this algorithm can be also regard as shortest-next-cpu-burst algorithm

Short job first scheduling

- SJF is optimal – gives minimum average waiting time for a given set of processes

Example

Processes	Burst time
P1	6
P2	8
P3	7
P4	3

FCFS average waiting time: (0+6+14+21)/4=10.25

SJF average waiting time: (3+16+9+0)/4=7

Short job first scheduling

Two schemes:

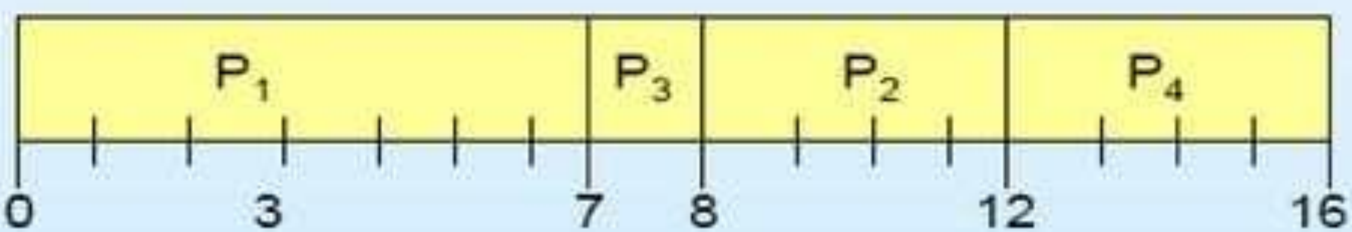
Non-preemptive – once CPU given to the process it cannot be preempted until completes its CPU burst

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)

Short job first scheduling-Non-preemptive

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

SJF (non-preemptive)

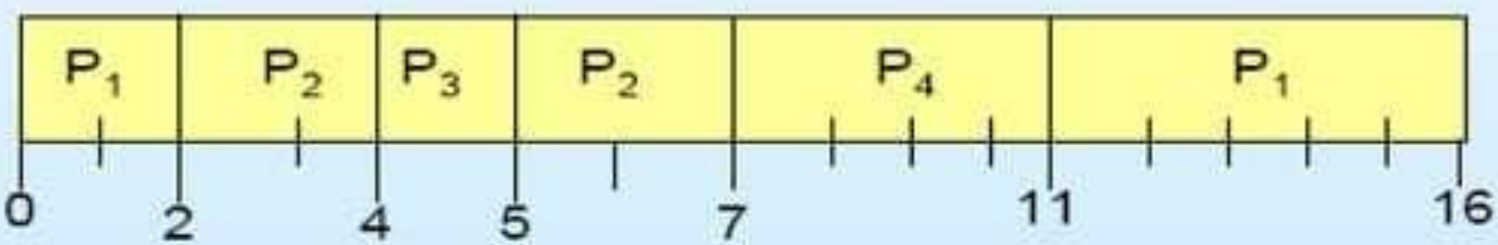


Average waiting time = (0 + 6 + 3 + 7)/4 = 4

Short job first scheduling-Preemptive

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

SJF (preemptive)



Average waiting time = (9 + 1 + 0 +2)/4 = 3

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
- Non-preemptive

SJF is a special priority scheduling where priority is the predicted next CPU burst time, so that it can decide the priority

Priority Scheduling

Processes	Burst time	Priority	Arrival time
P1	10	3	
P2	1	1	
P3	2	4	
P4	1	5	
P5	5	2	

The average waiting time=(6+0+16+18+1)/5=8.2

Priority Scheduling

Processes	Burst time	Priority	Arrival time
P1	10	3	0.0
P2	1	1	1.0
P3	2	4	2.0
P4	1	5	3.0
P5	5	2	4.0

Gantt chart for both preemptive and non-preemptive, also waiting time

Priority Scheduling

Problem : Starvation – low priority processes may never execute

Solution : Aging – as time progresses increase the priority of the process

Round-Robin Scheduling

- The Round-Robin is designed especially for time sharing systems.
- It is similar FCFS but add preemption concept
- A small unit of time, called **time quantum**, is defined

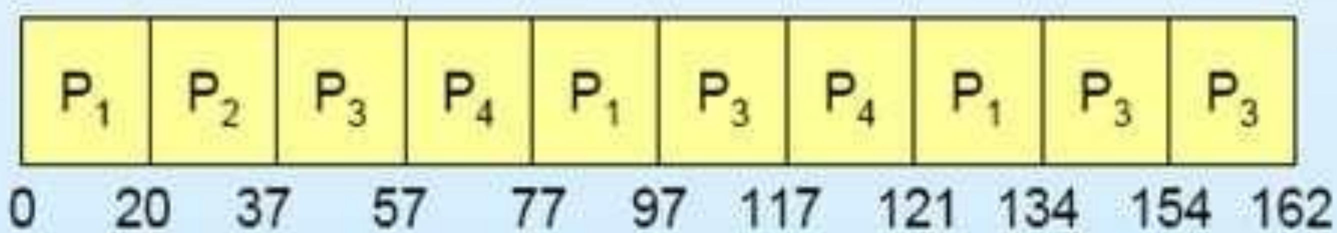
Round-Robin Scheduling

- Each process gets a small unit of CPU time (*time quantum*), usually 10-100 milliseconds. After this time has elapsed, the process is preempted and added to the end of the ready queue.

Round-Robin Scheduling

Process	Burst Time
P_1	53
P_2	17
P_3	68
P_4	24

The Gantt chart is:



Round-Robin Scheduling

- 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.

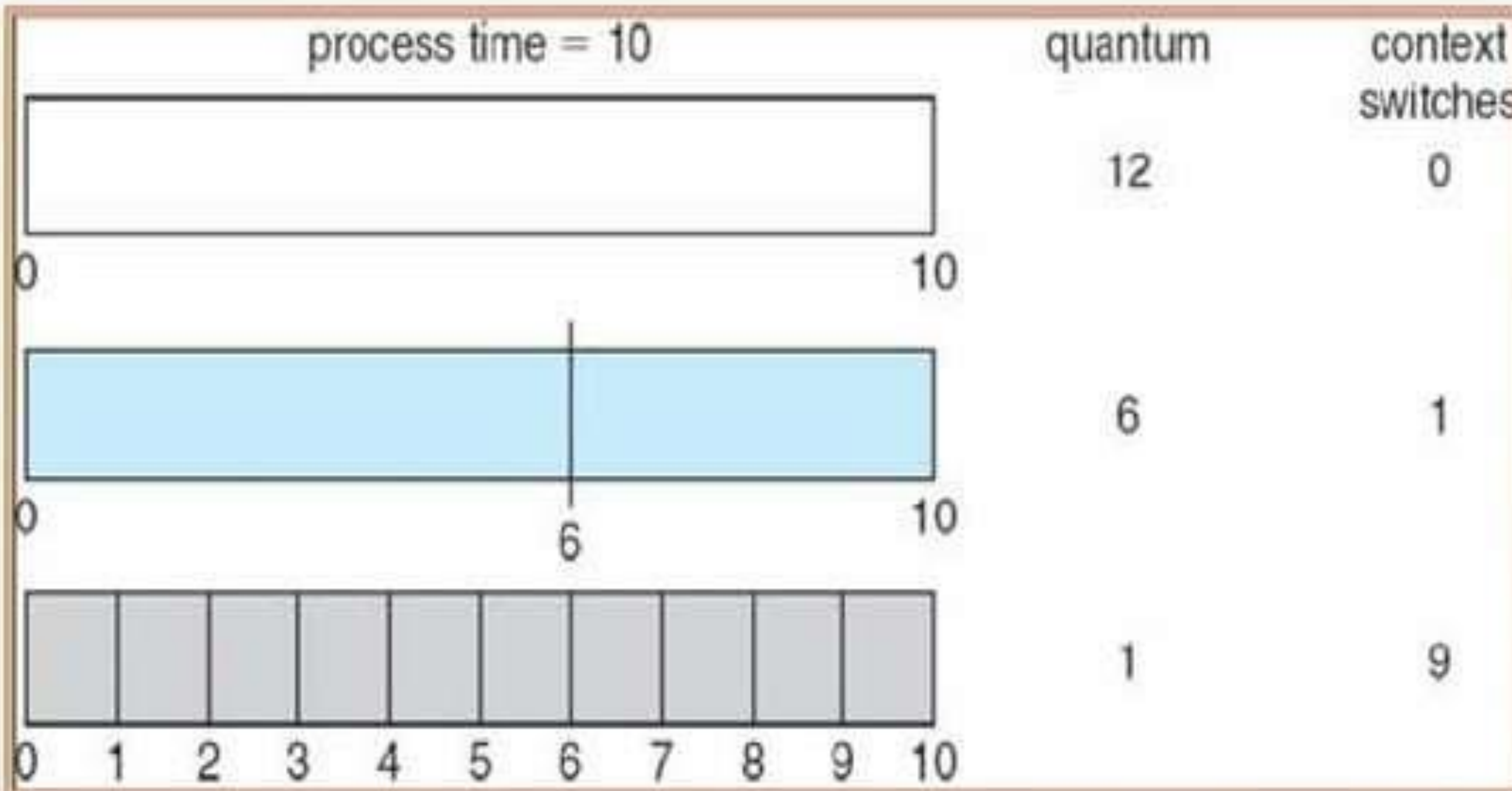
Round-Robin Scheduling

Performance

- *q* large => FIFO
- *q* small => *q* must be large with respect to context switch, otherwise overhead is too high

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

Round-Robin Scheduling



Multilevel Queue

Ready queue is partitioned into separate queues:

- foreground (interactive)
- background (batch)

Each queue has its own scheduling algorithm

foreground – RR
background – FCFS

Multilevel Queue example

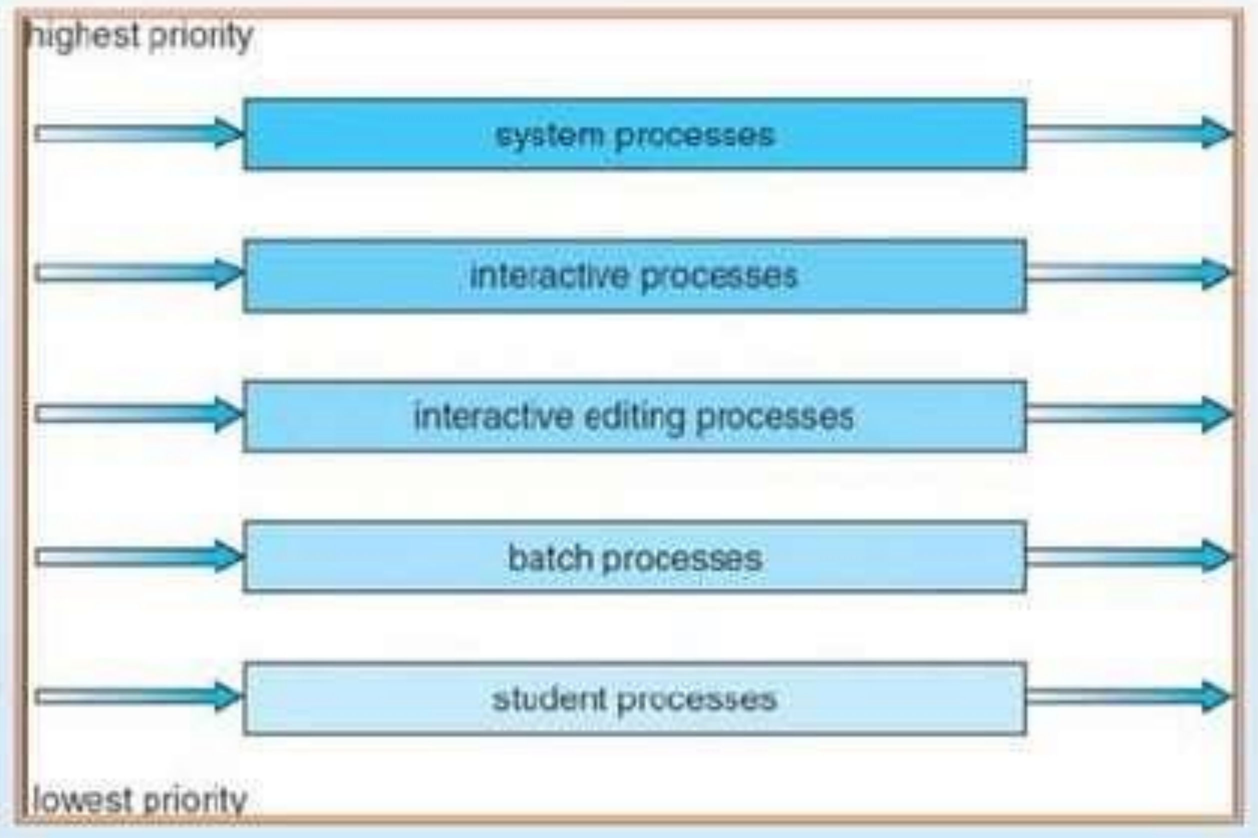
Foreground	P1	53	(RR interval:20)
	P2	17	
	P3	42	
Background	P4	30	(FCFS)
	P5	20	

Multilevel Queue

Scheduling must be done between the queues

- Fixed priority scheduling; (i.e., serve all from foreground then from background). Possibility of starvation.
- Time slice – each queue gets a certain amount of CPU time which it can schedule amongst its processes; i.e., 80% to foreground in RR

Multilevel Queue



Multilevel Feedback Queue

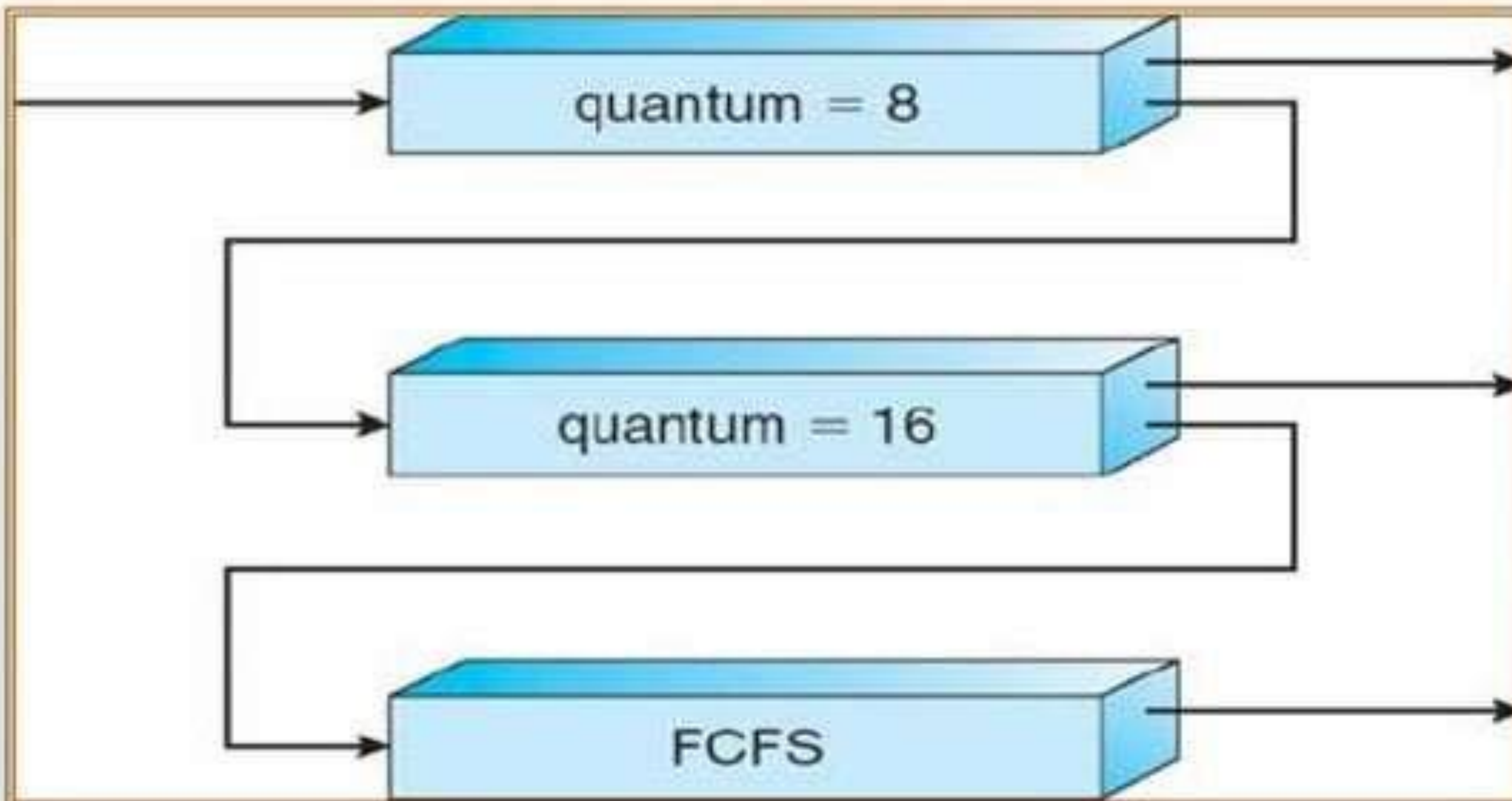
Three queues:

- *Q*0 – RR with time quantum 8 milliseconds
- *Q*1 – RR time quantum 16 milliseconds
- *Q*2 – FCFS

Scheduling
A new job enters queue *Q0* which is served FCFS. When it gains CPU, job receives 8 milliseconds. If it does not finish in 8 milliseconds, job is moved to queue *Q*1.

At *Q*1 job is again served FCFS and receives 16 additional milliseconds. If it still does not complete, it is preempted and moved to queue *Q*2.

Multilevel Feedback Queue



Multilevel Feedback Queue

- P1 40
- P2 35
- P3 15

5.4 Multiple-Processor Scheduling

- We concentrate on systems in which the processors are identical (homogeneous)
- **Asymmetric multiprocessing** (by one master) is simple because only one processor access the system data structures.
- **Symmetric multiprocessing**, each processor is self-scheduling. Each processor may have their own ready queue.

Load balancing

- On symmetric multiprocessing systems, it is important to keep the workload balanced among all processors to fully utilized the benefits of having more than one CPU
- There are two general approached to load balancing: **Push Migration** and **Pull Migration**

Symmetric Multithreading

- An alternative strategy for symmetric multithreading is to provide multiple logical processors (rather than physical)
- It’s called **hyperthreading technology** on Intel processors

Symmetric Multithreading

- The idea behind it is to create multiple logical processors on the same physical processor (sounds like two threads)
- But it is not software provide the feature, but hardware
- Each logical processor has its own architecture state, each logical processor is responsible for its own interrupt handling.

Symmetric Multithreading