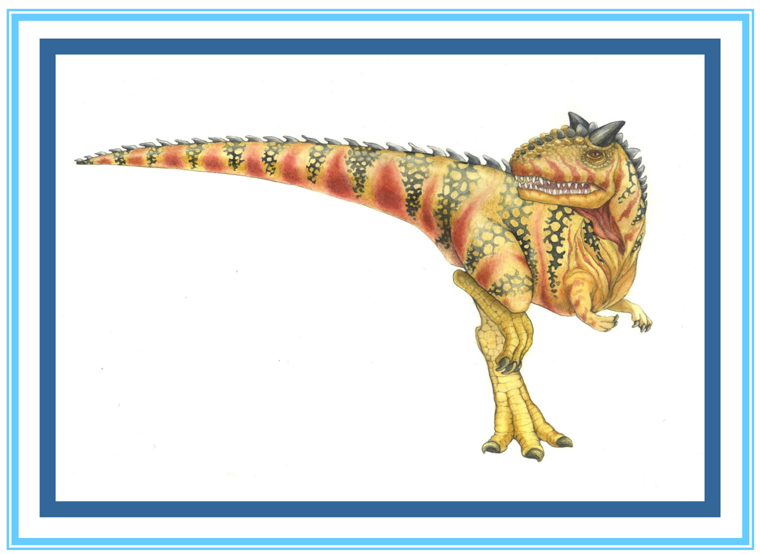
Chapter 5: CPU Scheduling



Chapter 5: CPU Scheduling

- Basic Concepts
- Scheduling Criteria
- Scheduling Algorithms
- Examples

Objectives

- To introduce CPU scheduling, which is the basis for multiprogrammed operating systems

- To describe various CPU-scheduling algorithms

- To discuss evaluation criteria for selecting a CPU-scheduling algorithm for a particular system

Basic Concepts

- Maximum CPU utilization obtained with multiprogramming

- Continuous Cycle :
  - one process has to wait (I/O)
  - Operating system takes the CPU away
  - Give CPU to another process
  - This pattern continues

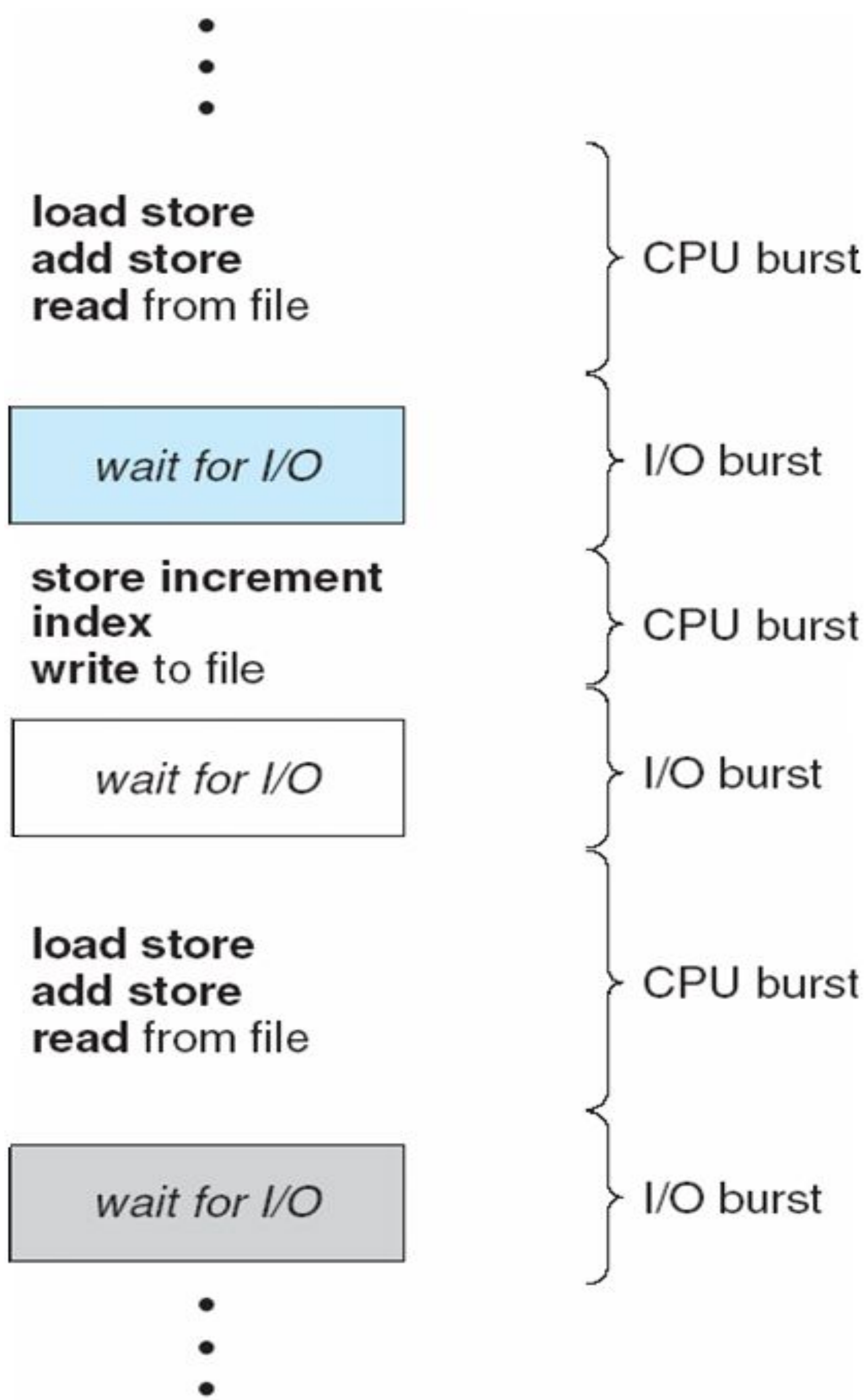
- CPU–I/O Burst Cycle – Process execution consists of a *cycle* of CPU execution and I/O wait

CPU and I/O Burst Cycle

- Almost all processes alternate between two states in a continuing ***cycle***, as shown in Figure below ***:***
  - A CPU burst of performing calculations, and
  - An I/O burst, waiting for data transfer in or out of the system.

- Processes alternate back and forth between this two states.

Alternating Sequence of CPU and I/O Bursts



CPU Scheduler

- Selects from the processes in ready queue, and allocates the CPU to one of them
  - FIFO queue
  - Priority queue
  - Tree
  - Unordered linked-list
- **CPU scheduling decisions** may take place when a process:
  1. Switches from running to waiting state (I/O request)
  2. Switches from running to ready state (e.g. when interrupt occurs)
  3. Switches from waiting to ready (e.g. at completion of I/O)
  4. Terminates
- Scheduling under 1 and 4 is **nonpreemptive**
- All other scheduling is **preemptive**
  - Consider access to shared data
  - Consider preemption while in kernel mode
  - Consider interrupts occurring during crucial OS activities

Scheduling Criteria

- **CPU utilization** – keep the CPU as busy as possible
- **Throughput** – # of processes that complete their execution per time unit
- **Turnaround time**
  – amount of time to execute a particular process
  -- the interval from the time of submission of a process to the time of the completion.
  -- sum of the periods spent waiting to get into memory, waiting in the ready queue, executing on the CPU, doing I/O
- **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, not output (for time-sharing environment)

Scheduling Algorithm Optimization Criteria

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

First-Come, First-Served (FCFS) Scheduling

Process	Burst Time
P_1	24
P_2	3
P_3	3

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

- Waiting time for P_1 = 0; P_2 = 24; P_3 = 27
- Average waiting time: (0 + 24 + 27)/3 = 17
- Turnaround time P_1 = 24; P_2 = 27; P_3 = 30

FCFS Scheduling (Cont.)

Suppose that the processes arrive in the order:

P_2 , P_3 , P_1

- The Gantt chart for the schedule is:

Waiting time for $P_1 = 6$; $P_2 = 0$; $P_3 = 3$
Average waiting time: $(6 + 0 + 3)/3 = 3$
Much better than previous case
Convoy effect - short process behind long process
Consider one CPU-bound and many I/O-bound processes

FCFS Scheduling (Cont.)

Convoy Effect :

many I/O bound process and one CPU bound process

CPU bound process	I/O bound process	Effect
I/O device	I/O queue	CPU site idle
CPU processing	Ready queue	I/O site idle

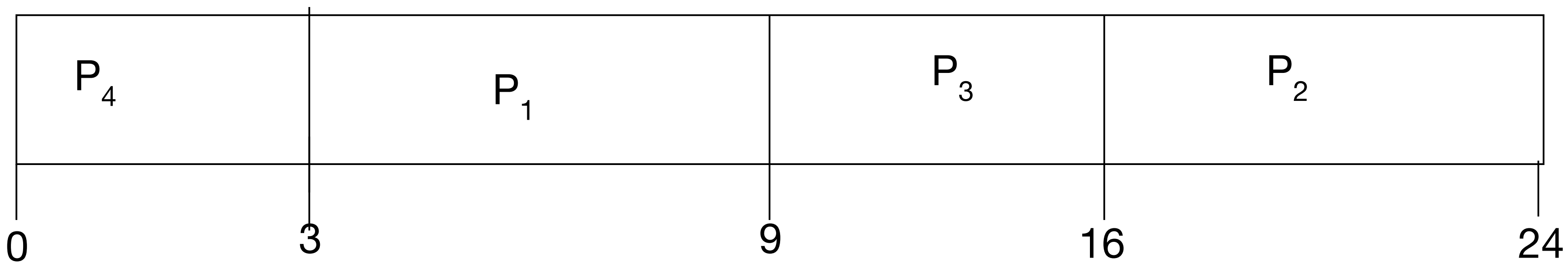
Shortest-Job-First (SJF) Scheduling

- Associate with each process the length of its next CPU burst. Use these lengths to schedule the process with the shortest time
- Two schemes:
  - **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)
- SJF is optimal – gives minimum average waiting time for a given set of processes

Example of SJF

Process	Burst Time
P_1	6
P_2	8
P_3	7
P_4	3

- SJF scheduling chart

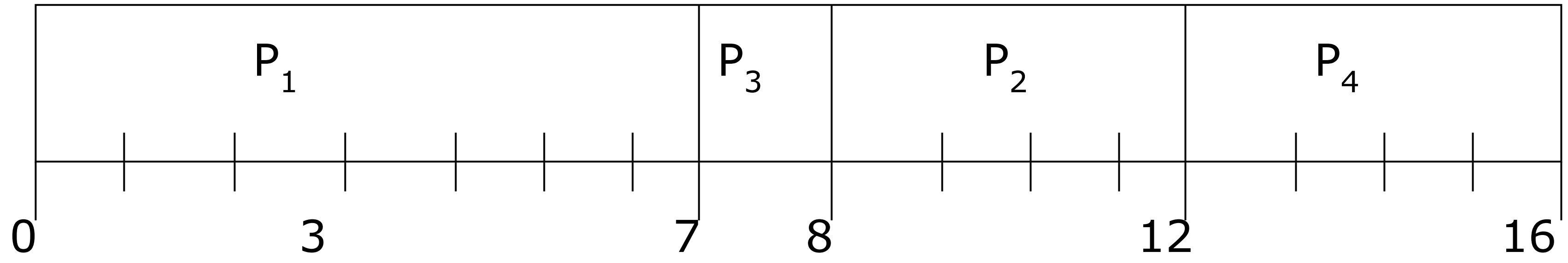


Average waiting time = (3 + 16 + 9 + 0) / 4 = 7

Example of Non-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

- SJF (non-preemptive)

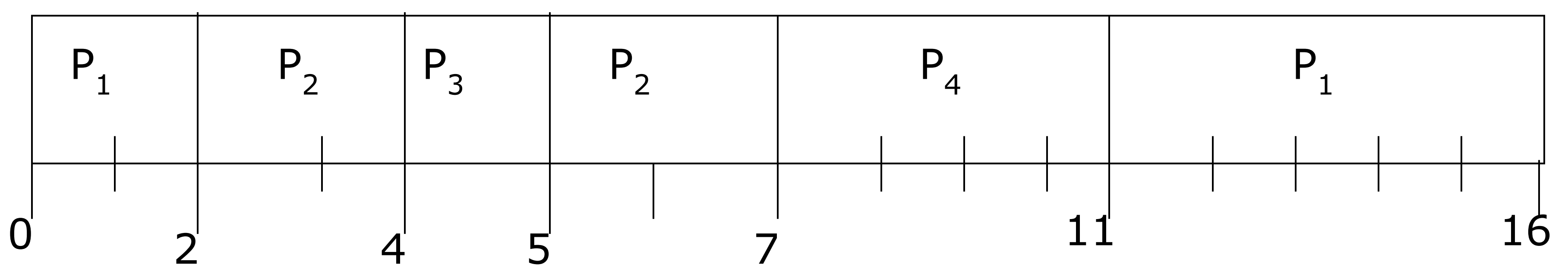


Average waiting time = (0 + 6 + 3 + 7)/4 = 4

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

- SJF (preemptive)



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

Example of Shortest-remaining-time-first

- Now we add the concepts of varying arrival times and preemption to the analysis

Process	*Arrival* Time	Burst Time
P_1	0	8
P_2	1	4
P_3	2	9
P_4	3	5

- *Preemptive* SJF Gantt Chart

P_1	P_2	P_4	P_1	P_3

0 1 5 10 17 26

- Average waiting time = [(10-1)+(1-1)+(17-2)+5-3)]/4 = 26/4 = 6.5 msec

- Exponential average

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can pick the process with the shortest predicted CPU burst.

The next CPU burst is generally predicted as an exponential average of the measured lengths of previous CPU bursts. Let t_n be the length of the nth CPU

burst, and let τ_{n+1} be our predicted value for the next CPU burst. Then, for α, $0 \le \alpha \le 1$, define

$$\tau_{n+1} = \alpha\, t_n + (1 - \alpha)\tau_n.$$

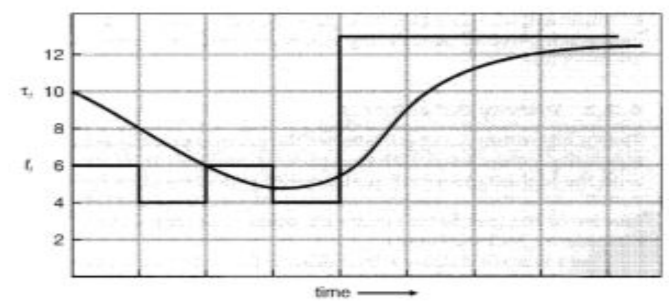
This formula defines an **exponential average**. The value of t_n contains our most recent information; τ_n stores the past history. The parameter α controls the relative weight of recent and past history in our prediction. If $\alpha = 0$, then $\tau_{n+1} = \tau_n$, and recent history has no effect (current conditions are assumed to be transient); if $\alpha = 1$, then $\tau_{n+1} = t_n$, and only the most recent CPU burst matters (history is assumed to be old and irrelevant). More commonly, $\alpha = 1/2$, so recent history and past history are equally weighted. The initial τ_0 can be defined as a constant or as an overall system average. Figure 5.3 shows an exponential average with $\alpha = 1/2$ and $\tau_0 = 10$.

To understand the behavior of the exponential average, we can expand the formula for τ_{n+1} by substituting for τ_n, to find

$$\tau_{n+1} = \alpha t_n + (1 - \alpha)\alpha t_{n-1} + \cdots + (1-\alpha)^j \alpha t_{n-j} + \cdots + (1-\alpha)^{n+1}\tau_0.$$

Since both α and $(1 - \alpha)$ are less than or equal to 1, each successive term has less weight than its predecessor.

The SJF algorithm can be either preemptive or nonpreemptive. The choice arises when a new process arrives at the ready queue while a previous process is still executing. The next CPU burst of the newly arrived process may be shorter than what is left of the currently executing process. A preemptive SJF algorithm



CPU burst (t_i)		6	4	6	4	13	13	13	...
"guess" (τ_i)	10	8	6	6	5	9	11	12	...

Figure 5.3 Prediction of the length of the next CPU burst.

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 priority scheduling where priority is the inverse of predicted next CPU burst time
- Priority can be defined either internally or externally.
  - Factors for internal priority assignment:
    - Time limit, memory requirements, the number or open files etc.
  - Factors for external priority assignment:
    - Importance of the process, the type and amount of funds of funds being paid for computer use, department sponsoring works etc.

Example of Priority Scheduling

Process	Burst Time	Priority
P_1	10	3
P_2	1	1
P_3	2	4
P_4	1	5
P_5	5	2

- Priority scheduling Gantt Chart

P_2	P_5	P_1	P_3	P_4
0–1	1–6	6–16	16–18	18–19

0 1 6 16 18 19

Average waiting time = 8.2 msec

Priority Scheduling

- Problem ≡ **Starvation** – low priority processes may never execute
- Solution ≡ **Aging** – as time progresses increase the priority of the process

Round Robin (RR)

- Each process gets a small unit of CPU time (**time quantum** q), usually 10-100 milliseconds. After this 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.
- Timer interrupts every quantum to schedule next process
- Performance
  - q large $\Rightarrow$ FCFS
  - q small $\Rightarrow$ q must be large with respect to context switch, otherwise overhead is too high

Example of RR with Time Quantum = 4

Process	Burst Time
P_1	24
P_2	3
P_3	3

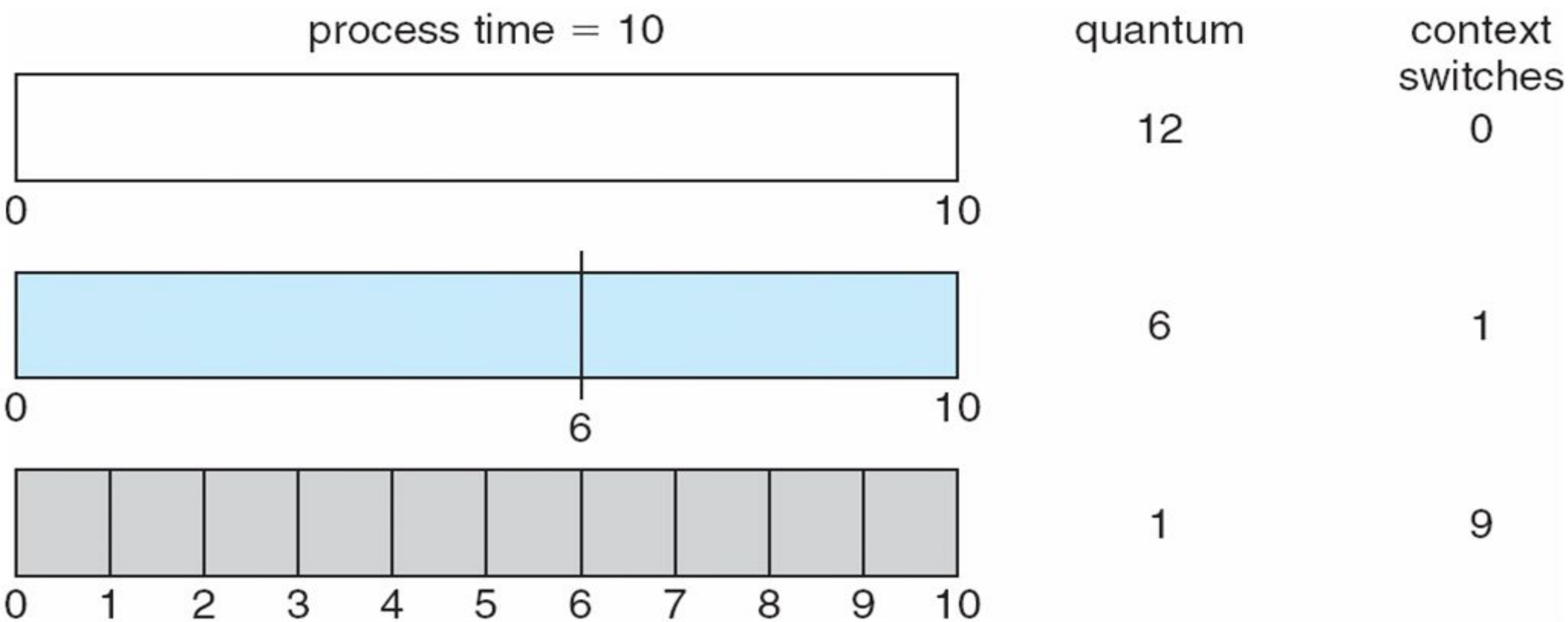
- The Gantt chart is:

P_1	P_2	P_3	P_1	P_1	P_1	P_1	P_1

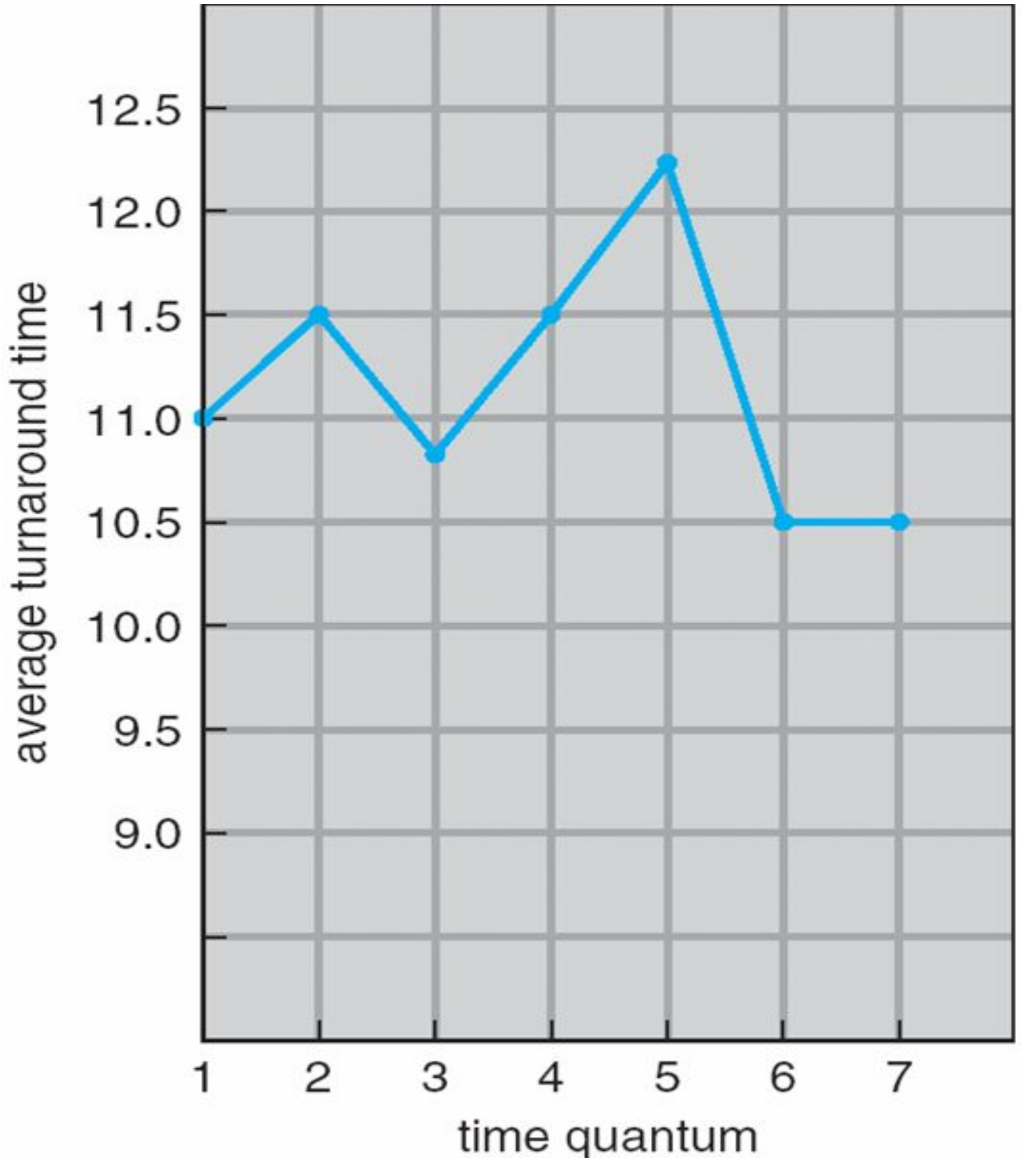
0 4 7 10 14 18 22 26 30

- Average waiting time is 17 / 3 = 5.66 milisecond
- Typically, higher average turnaround than SJF, but better *response*
- quantum should be large compared to context switch time
- Quantum usually 10ms to 100ms, context switch < 10 usec

Time Quantum and Context Switch Time



Turnaround Time Varies With The Time Quantum



process	time
P_1	6
P_2	3
P_3	1
P_4	7

80% of CPU bursts should be shorter than quantum

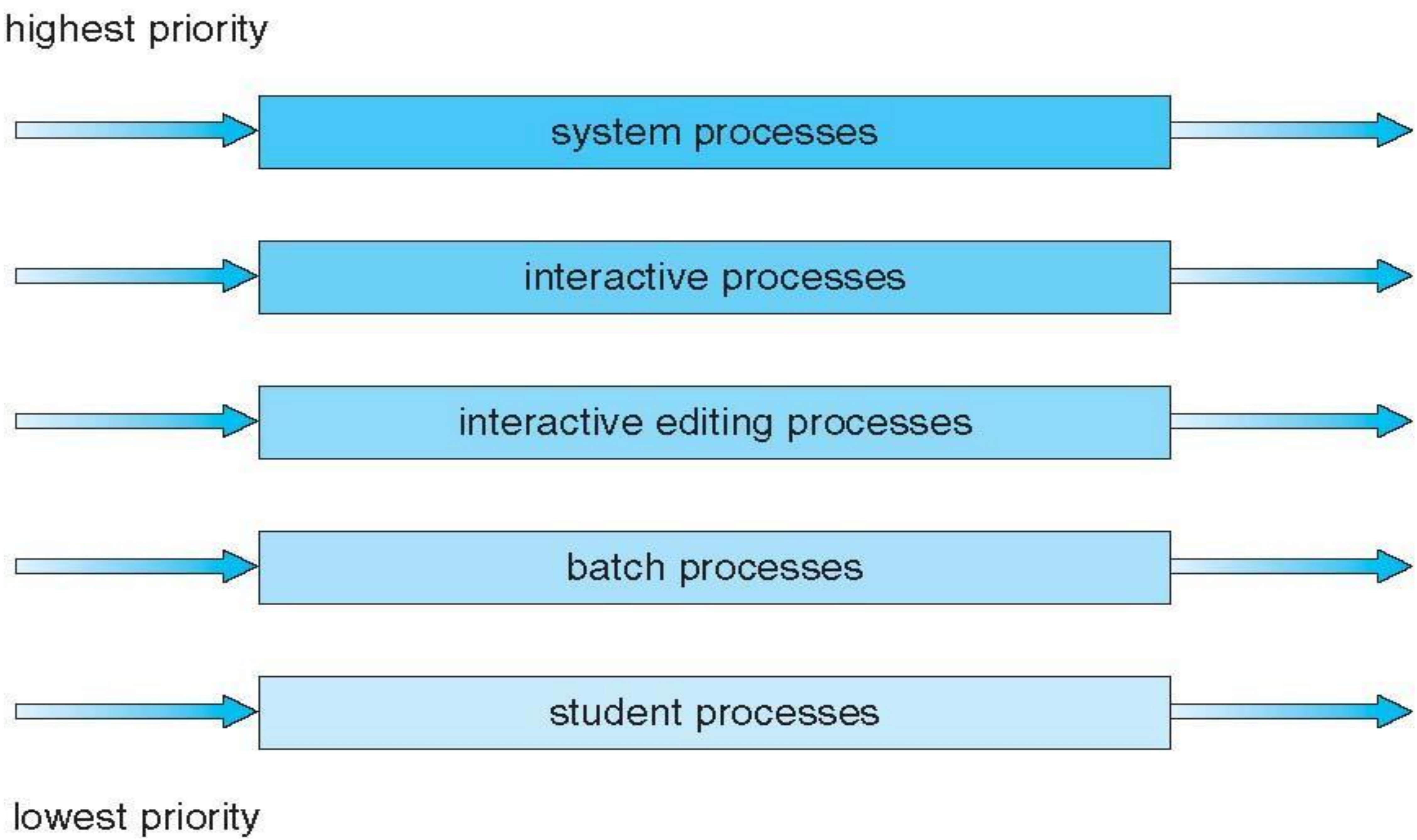
Multilevel Queue

- Another class of scheduling algorithm needs- in which processes are classified into different groups, e.g.:
  - foreground (interactive) processes
  - background (batch) processes
- They have different response time requirements-so different scheduling needs.
- Foreground processes may have priority over background processes.
- A multilevel queue-scheduling algorithm partitions the ready queue into several separate queues-we can see it in the figure of next slide:-

- Each queue has its own scheduling algorithm:
  - Foreground queue scheduled by – RR algorithm
  - Background queue scheduled by – FCFS algorithm

- Scheduling must be done between the queues:
  - Fixed priority preemptive 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., foreground queue can be given 80% of the CPU time for RR-scheduling among its processes, while 20% to background in FCFS manner.

Multilevel Queue Scheduling



Multilevel Feedback Queue scheduling

- Processes do not move from one queue to the other----But
- Multilevel Feedback Queue scheduling, allows a process to move between queues.
- If a process uses too much CPU time, it will be moved to a lower priority queue.
- Similarly, a process that waits too long in a lower-priority queue may me moved to a higher-priority queue.

Multilevel Feedback Queue scheduling

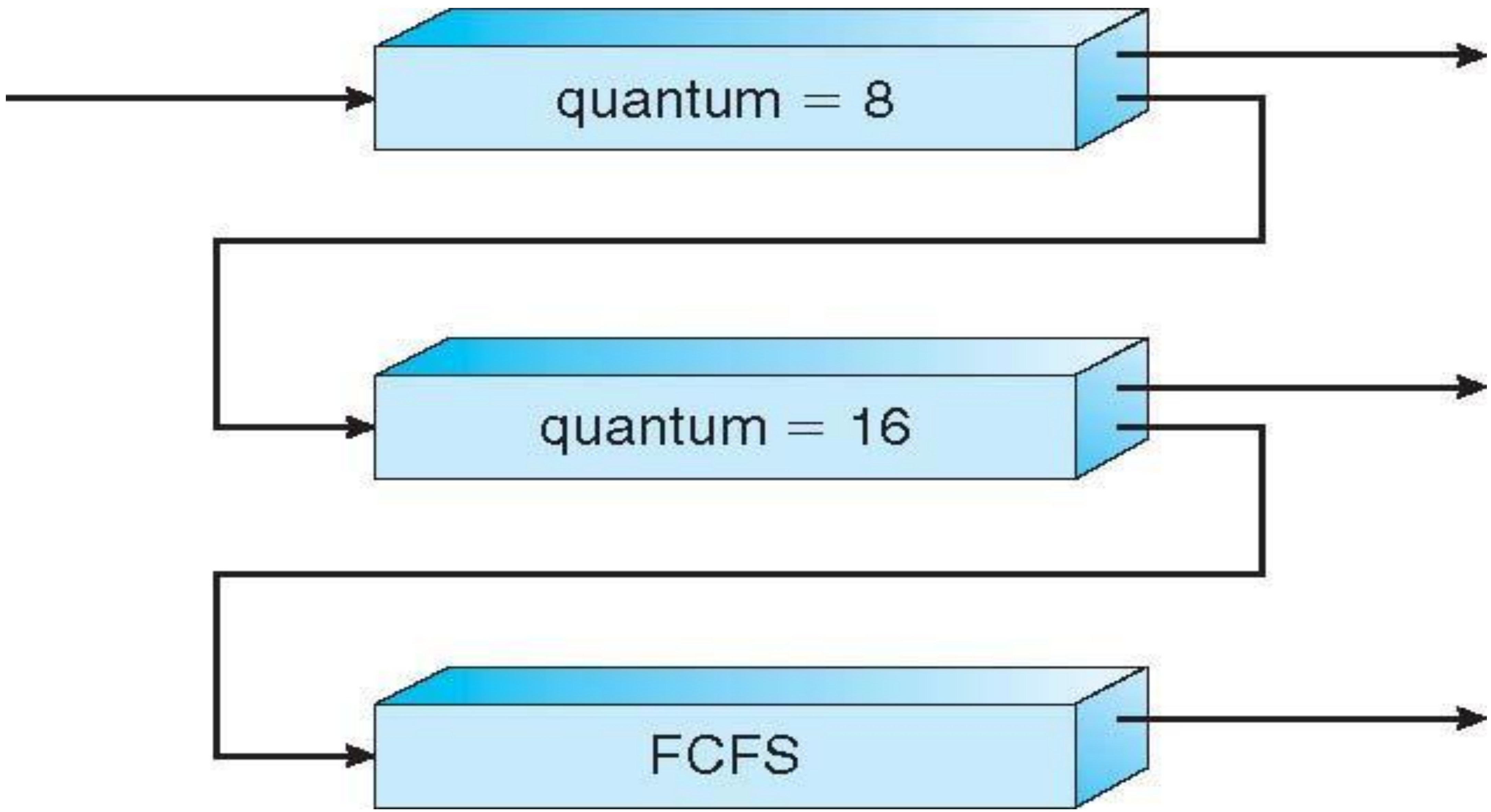
- Multilevel-feedback-queue scheduler defined by the following parameters:
  - number of queues
  - scheduling algorithms for each queue
  - method used to determine when to upgrade a process
  - method used to determine when to demote a process
  - method used to determine which queue a process will enter when that process needs service

Example of Multilevel Feedback Queue

- Three queues: (can see the figure in next slide)
  - Q_0 – RR with time quantum 8 milliseconds
  - Q_1 – RR time quantum 16 milliseconds
  - Q_2 – FCFS

- Scheduling
  - A new job enters queue Q_0 which is served for RR
    - 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 RR and receives 16 additional milliseconds
    - If it still does not complete, it is preempted and moved to queue Q_2

Multilevel Feedback Queues



End of Chapter 5