CISC 3320

CPU Scheduling Criteria and Algorithms

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Acknowledgement

- These slides are a revision of the slides by the authors of the textbook

Outline

- Scheduling Criteria
- Scheduling Algorithms

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, i.e., the interval from the time of submission of a process to the time of completion is the turnaround time.
- **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

- Maximize CPU utilization
- Maximize throughput
- Minimize turnaround time
- Minimize waiting time
- Minimize response time

- Q: Can we optimize for more than one criteria?

Questions?

- CPU scheduling criteria?
- Can we optimize all of them? How about different systems, such as, batch system, interactive system, and real time system?

Scheduling Algorithms

- First-Come, First-Served (FCFS) Scheduling
- Shortest-Job-First (SJF) Scheduling
  - Preemptive shortest-remaining-time-first
- Round Robin (RR)
- Priority Scheduling
  - Priority Scheduling with Round-Robin

First- Come, First-Served (FCFS) Scheduling: Example

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

First- Come, First-Served (FCFS) Scheduling: Example

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

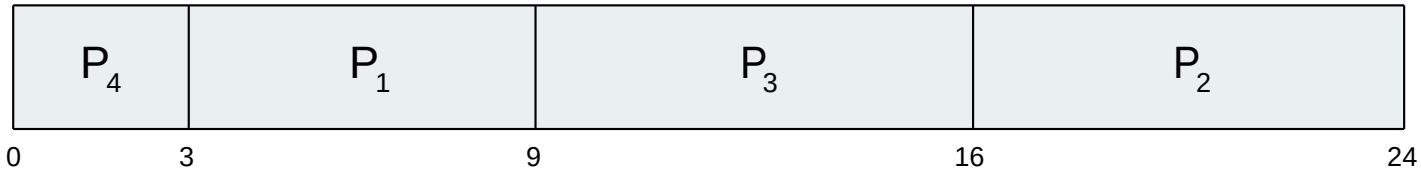
Shortest-Job-First (SJF) Scheduling

- Associate with each process the length of its next CPU burst
  - Use these lengths to schedule the process with the shortest time
- SJF is optimal – gives minimum average waiting time for a given set of processes
  - The difficulty is knowing the length of the next CPU request
  - Could ask the user

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

SJF: Assumptions

- The length of the next CPU burst is known.
- But, how do we determine length of next CPU burst?

Determining Length of Next CPU Burst

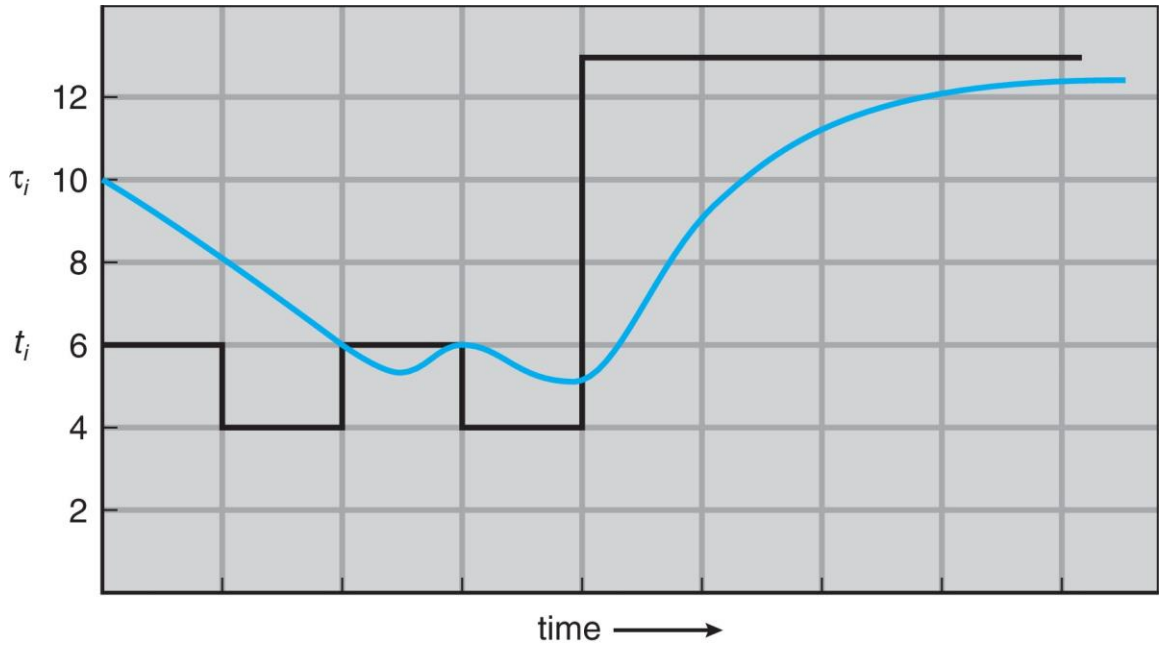
- Can only estimate the length – should be similar to the previous one
  - Then pick process with shortest predicted next CPU burst

- Can be done by using the length of previous CPU bursts, using exponential averaging

1. t_n = actual length of n^{th} CPU burst
2. τ_{n+1} = predicted value for the next CPU burst
3. $\alpha, 0 \leq \alpha \leq 1$
4. Define : $\tau_{n+1} = \alpha\, t_n + (1 - \alpha)\tau_n.$

- Commonly, α set to $\frac{1}{2}$
- Preemptive version called **shortest-remaining-time-first**

Prediction of the Length of the Next CPU Burst



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

Examples of Exponential Averaging

- α =0
  - $\tau_{n+1} = \tau_n$
  - Recent history does not count
- α =1
  - $\tau_{n+1} = \alpha\, t_n$
  - Only the actual last CPU burst counts
- If we expand the formula, we get:

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

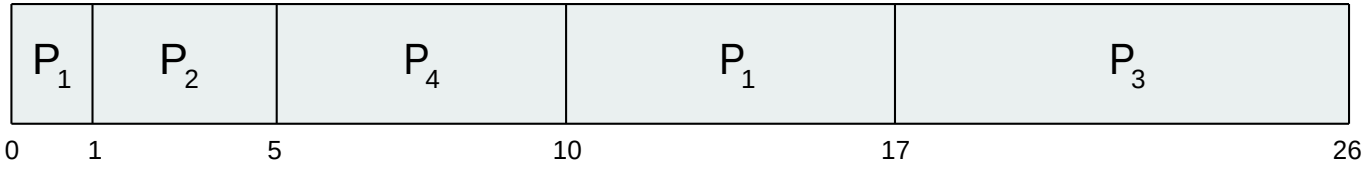
- Since both α and (1 - α) are less than or equal to 1, each successive term has less weight than its predecessor

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



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

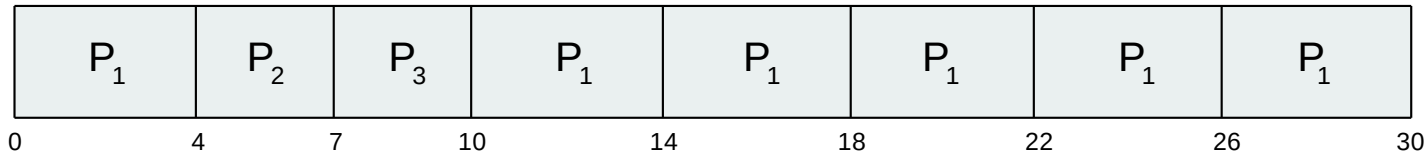
Round Robin (RR)

- 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 $(n\text{-}1)q$ time units.
- Timer interrupts every quantum to schedule next process
- Performance
  - q large $\Rightarrow$ FIFO
  - q small $\Rightarrow$ q must be large with respect to context switch, otherwise overhead is too high

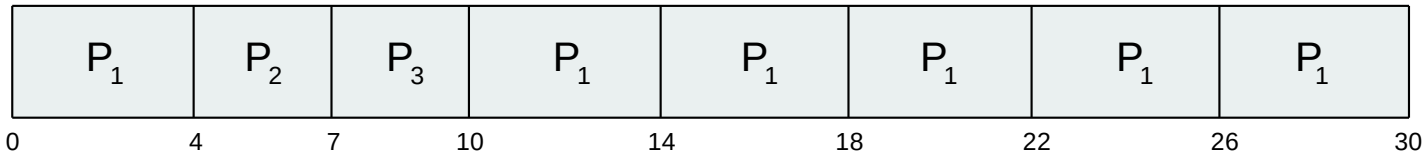
Example of RR with Time Quantum = 4

Process	Burst Time
P_1	24
P_2	3
P_3	3

- The Gantt chart is:



Estimating Metrics



- Assuming all 3 processes are in ready queue at time 0
  - Average waiting time
    - P_1 waits (0 – 0) + (10 – 4) = 6; P_2 waits (4 – 0) = 4; P_3 waits (7 – 0) = 7; and (6 + 4 + 7)/3 = 17/3
  - Average response time
    - P_1 responses after (0 – 0) = 0; P_2 responses after (4 – 0) = 4; P_3 responses after (7 – 0) = 7; and (0 + 4 + 7)/3 = 11/3
  - Average turnaround time
    - P_1 completes after submission (4 – 0) = 4; P_2 responses after (7 – 0) = 7; P_3 responses after (30 – 0) = 30; and (4 + 7 + 30)/3 = 41/3

Comparing with SJF

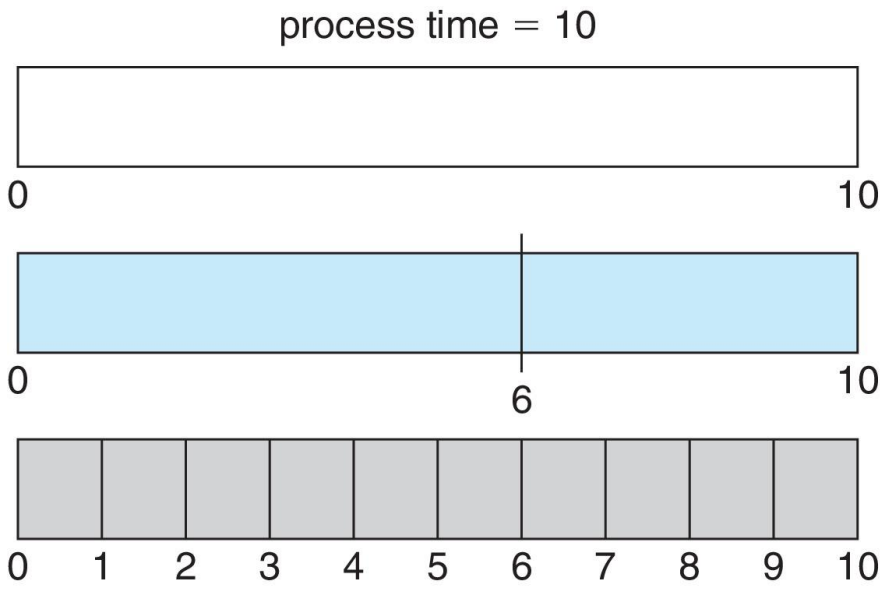
- Exercises for you
  - If we use SJF instead, what are the metrics (average waiting time, average response time, average turnaround time)?
  - What if we choose different time quantum (shorter or longer) for RR?

- Typically, RR has higher average turnaround and higher waiting time than SJF, but better **response**

Time Quantum (q) and Context Switch Time

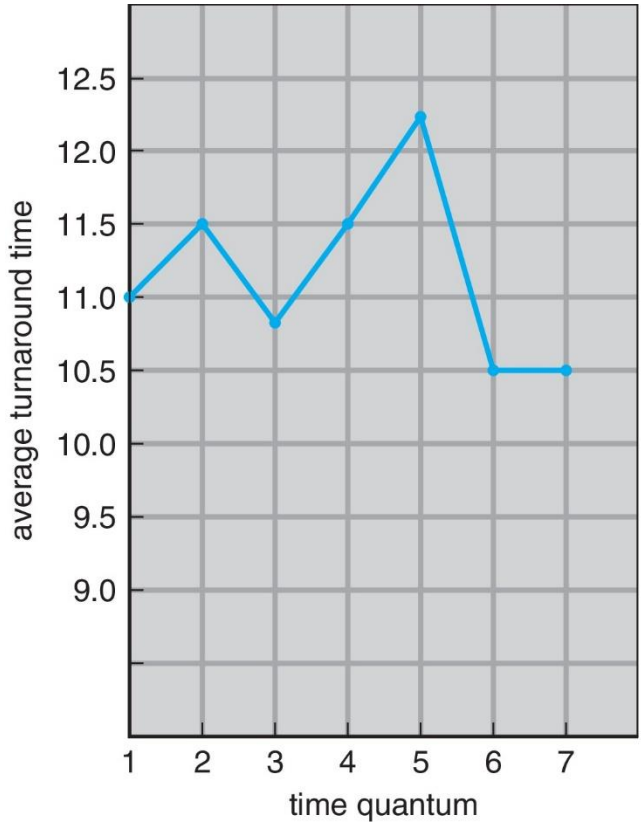
- q should be large compared to context switch time
- q usually 10ms to 100ms, context switch < 10 μsec

Time Quantum and Context Switch Time



quantum	context switches
12	0
6	1
1	9

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 q

Questions?

- System design objectives and CPU scheduling criteria
- Comparing RR and SJF
  - Q: can we always optimize for multiple scheduling criteria?

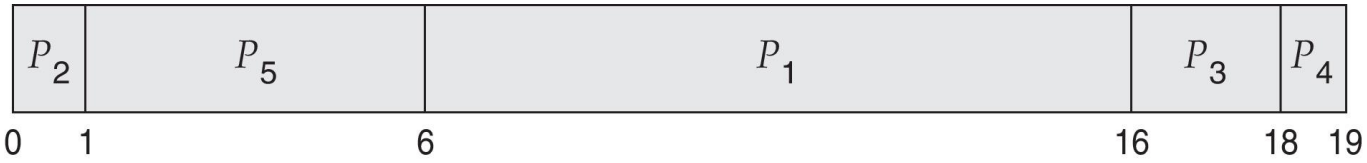
Priority Scheduling

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

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

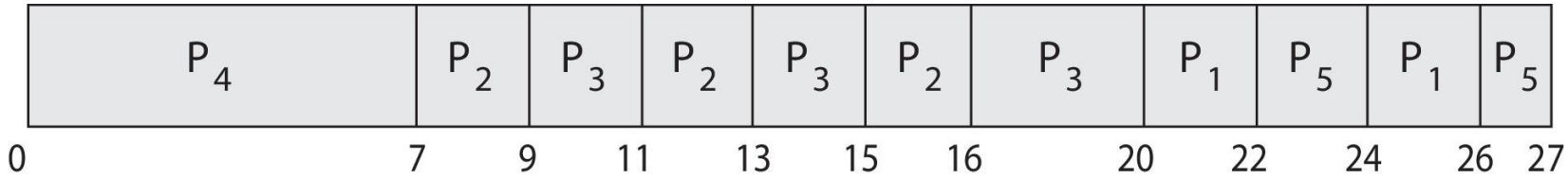


- Average waiting time = 8.2 msec

Priority Scheduling with Round-Robin

Process	Burst Time	Priority
P_1	4	3
P_2	5	2
P_3	8	2
P_4	7	1
P_5	3	3

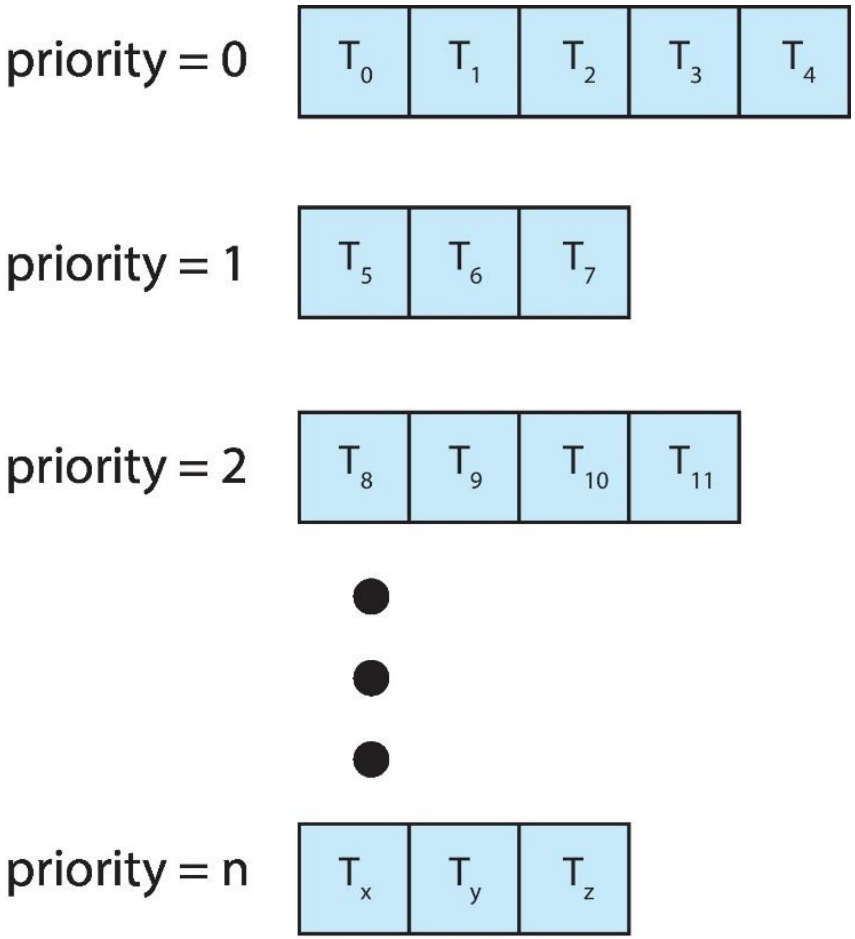
- Run the process with the highest priority. Processes with the same priority run round-robin
- Gantt Chart wit 2 ms time quantum



Priority Scheduling: Multilevel Queue

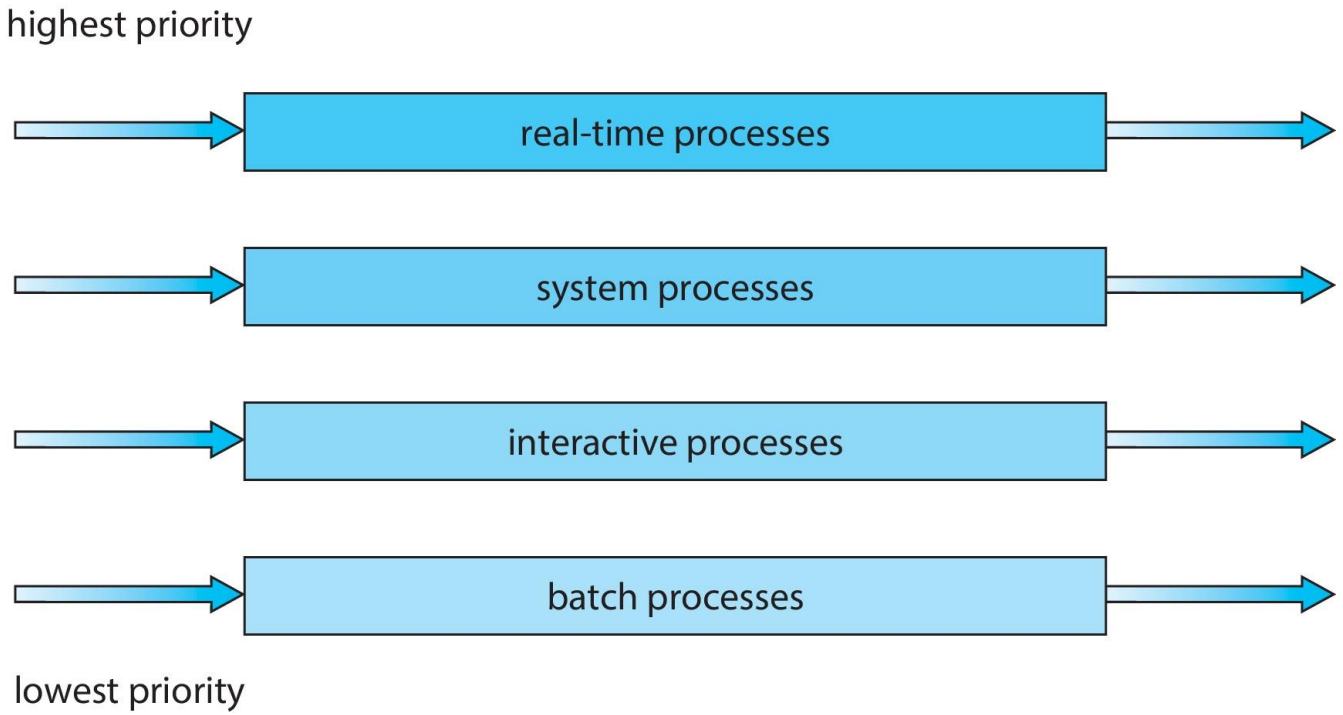
- With priority scheduling, have separate queues for each priority.
- Schedule the process in the highest-priority queue!

Multilevel Queue



Process Type and Multilevel Queue

- Example: Prioritization based upon process type

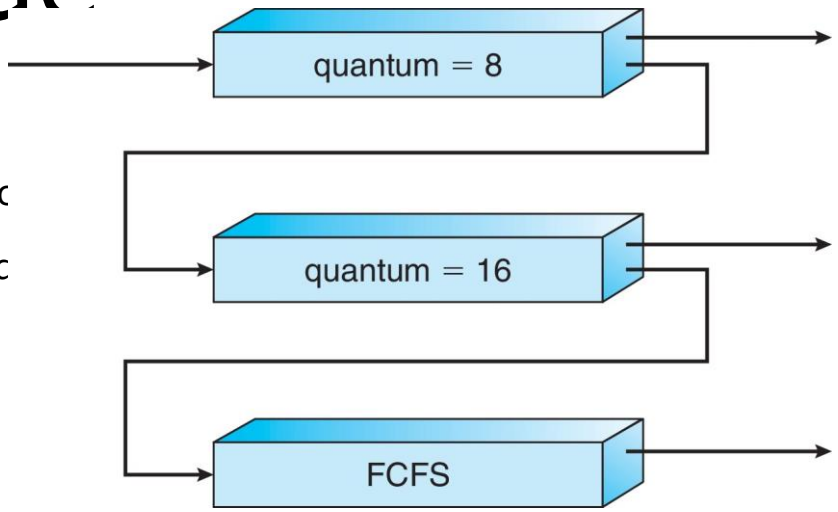


Multilevel Feedback Queue

- A process can move between the various queues; aging can be implemented this way
- 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:
  - Q_0 – RR with time quantum 8 millisec
  - Q_1 – RR time quantum 16 milliseconc
  - Q_2 – FCFS



- Scheduling
  - A new job enters queue Q_0 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

Questions?

- Various CPU scheduling algorithms
  - Computing scheduling criteria
- Determine CPU burst time
- Different types of queues