csci 3411: Operating Systems

CPU Scheduling

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Slides evolved from Silberschatz and West

Today: Scheduling

- Basis for multiprogrammed/multithreaded OSes

- Scheduling:
  - Given a runqueue of threads that are runnable/ready
  - Select one of those threads to execute next
  - *N*-processor systems require the scheduler to choose up to *N* threads to execute
  - Aside: processes vs. threads – use interchangeably

- Main question: *how do we choose the next thd to run?*

When is CPU Scheduling done?

- CPU scheduling occurs when
  1) A process is created and is put in a ready state
  2) A process voluntarily *yields* the CPU
  3) A process switches from running to waiting state
     - e.g. blocking on I/O
  4) A process switches from running to ready state
     - e.g. because it is interrupted and its timeslice expires
  5) A process switches from waiting to ready state
     - e.g. an interrupt signifies that I/O is complete
  6) A process terminates
- *Non-preemptive scheduling* includes all but 4) and 5)
- *Preemptive scheduling* includes all of the above
  - Characterized by interrupts that result in some process being moved from *running* to *ready* state – being *preempted*

Dispatching

- Scheduler decides *which* thread to run next
- Dispatcher switches to that thread
  - Switch register contents
  - Change virtual address spaces if next process is different than last
  - Resume execution in user-space
- These overheads define the *dispatch latency*
  - overhead!

Scheduling Goals/Criteria

- What should a scheduler try to
  - Maximize?
  - Minimize?

Scheduling Goals/Criteria

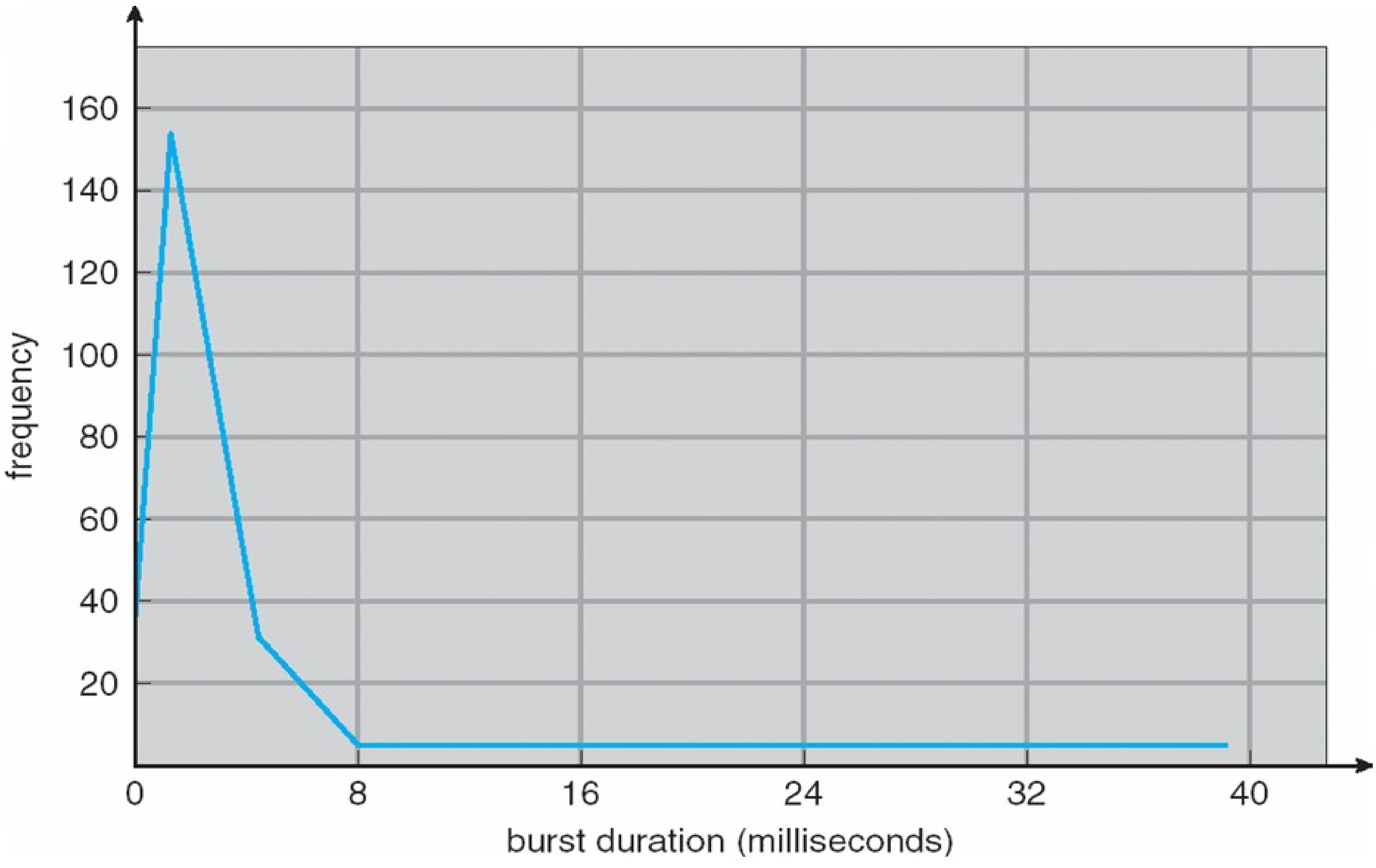
- *CPU Utilization*: % of time CPU is running thd
- *Turnaround Time:* life-time of a thread
- *Waiting Time*: time thd. spends in runqueue
- *Response Time/Interactivity*: time from beginning of execution, to when process can output or input
- *Fairness*: Are threads treated comparably?
  - *Starvation:* bounded turnaround time for all thds?

- *Tradeoffs:* Maximize which? Minimize which?

Scheduling Policies

- Goals of scheduler dictate
  - Algorithm/policy used to select next thread
  - Data structures used by algorithm
    - e.g. ready-queue data structure

CPU Burst Histogram



First-Come, First-Serve Scheduling

- One of the simplest scheduling policies
  - *non-preemptive*

Process	Burst Time
P_1	24
P_2	3
P_3	3

- Suppose process arrive in order: P1, P2, P3
- The schedule is:

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

FCFS II

Suppose the processes arrive in order: P_2 , P_3 , P_1

- 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

- Fairness/Starvation?
- Interactivity/Responsiveness?

Round Robin Scheduling

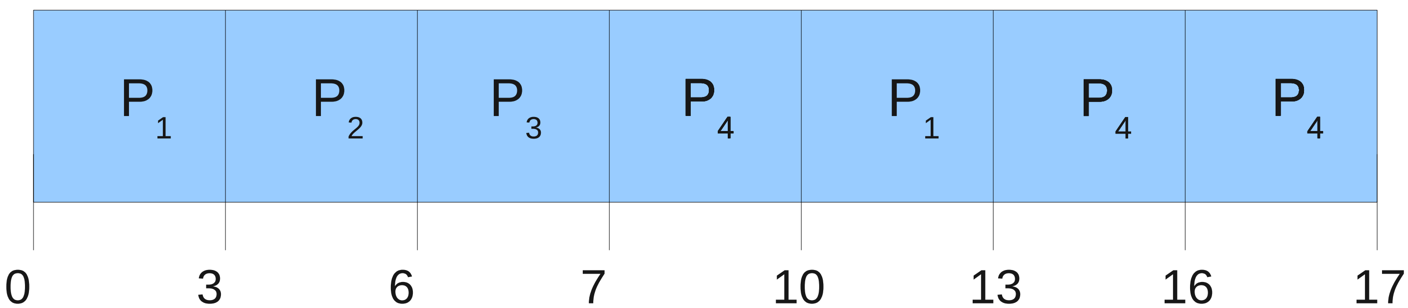
- Timesharing systems that wish to provide “fair” distribution of CPU resources
  - One thread cannot monopolize CPU
- FCFS with preemption
- Each thread executes a single timeslice (or quantum) before it is preempted
  - Preempted threads placed at end of runqueue
  - Requires timer interrupt to measure timeslices and preempt

Round Robin Scheduling II

- *N* threads in runqueue
- Time quantum of *Q*
- *Fairness*: each thread gets 1/n of the CPU, in chunks of size *Q*
- No thread waits for more than (*N*-1)*Q* time units before next quantum
- Size of *Q*?
  - *Q* == infinity is FCFS
  - *Q* == 0; is this possible?
  - Best fairness?
  - Best throughput? (what overheads are there?)

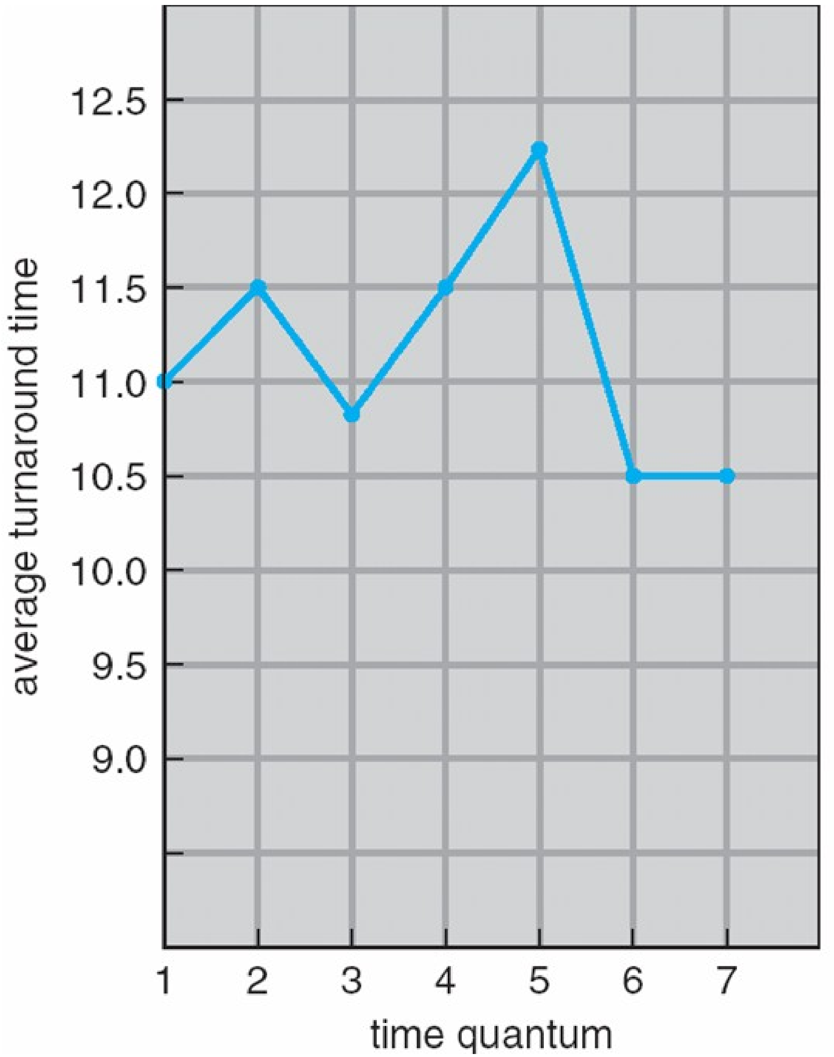
RR Example, $Q = 3$

Process	Burst Time
P_1	6
P_2	3
P_3	1
P_4	7



- Compared to FIFO
  - Turnaround time?
  - responsiveness?

Quantum Effects Turnaround Time



process	time
P_1	6
P_2	3
P_3	1
P_4	7

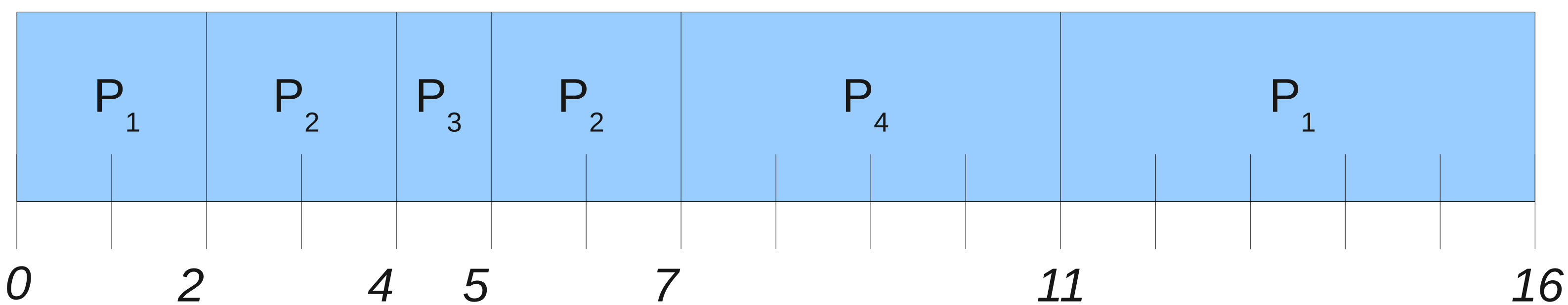
Shortest Job First (SJF) Scheduling

- Consider each process' next CPU burst (job) length
  - use these to schedule the process with the shortest next burst
- Preemptive SJF is optimal in that it minimizes average waiting time for a set of processes

Shortest Job First II

Process	Arrival Time	Burst Time
P_1	0	7
P_2	2	4
P_3	4	1
P_4	5	4

- SJF (preemptive)



- Average waiting time = (9+1+0+2)/4 = 3
  - Non-preemptive optimal?

Job Burst Length

- How do we know a job's burst time?
  - Before it actually executes!
- Become fortune tellers?
- General strategy in systems: Predict the future from past behavior
  - Is this a good idea? Does it really work?

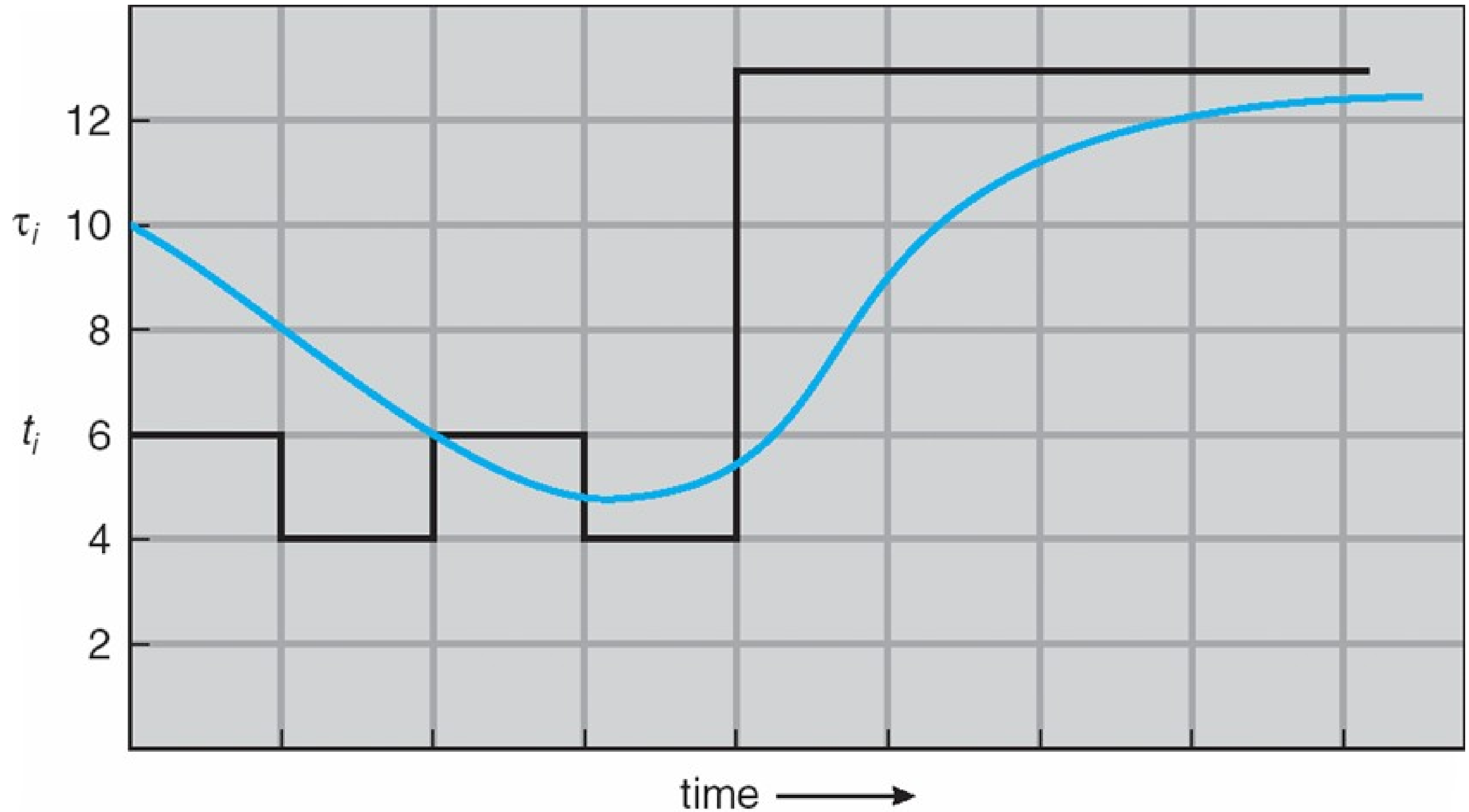
Determine Job Burst Length

- Take average of process' past burst lengths
  - Do we want to keep an exact average?

- Weighted Moving Average:
  - Measured length of nth burst = t_n
  - Predicted value for burst n = τ_n
  - Then for a weight, α, where $0 \leq \alpha \leq 1$:

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

Job Length Prediction Using WMA



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

Weighted Moving Average III

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

- If $\alpha = 0$, then $\tau_{n+1} = \tau_0$
  - Recent job burst lengths aren't counted
- If $\alpha = 1$, then $\tau_{n+1} = t_n$
  - Only the most recent job length counts
- Expand the formula: $\tau_{n+1} = \alpha\, t_n + (1-\alpha)\, \alpha\, t_{n-1} + \ldots$
  $+ (1-\alpha)^j \alpha\, t_{n-j} + \ldots$
  $+ (1-\alpha)^{n+1} \tau_0$
- Exponentially decrease the influence of older measurements

Priority Scheduling

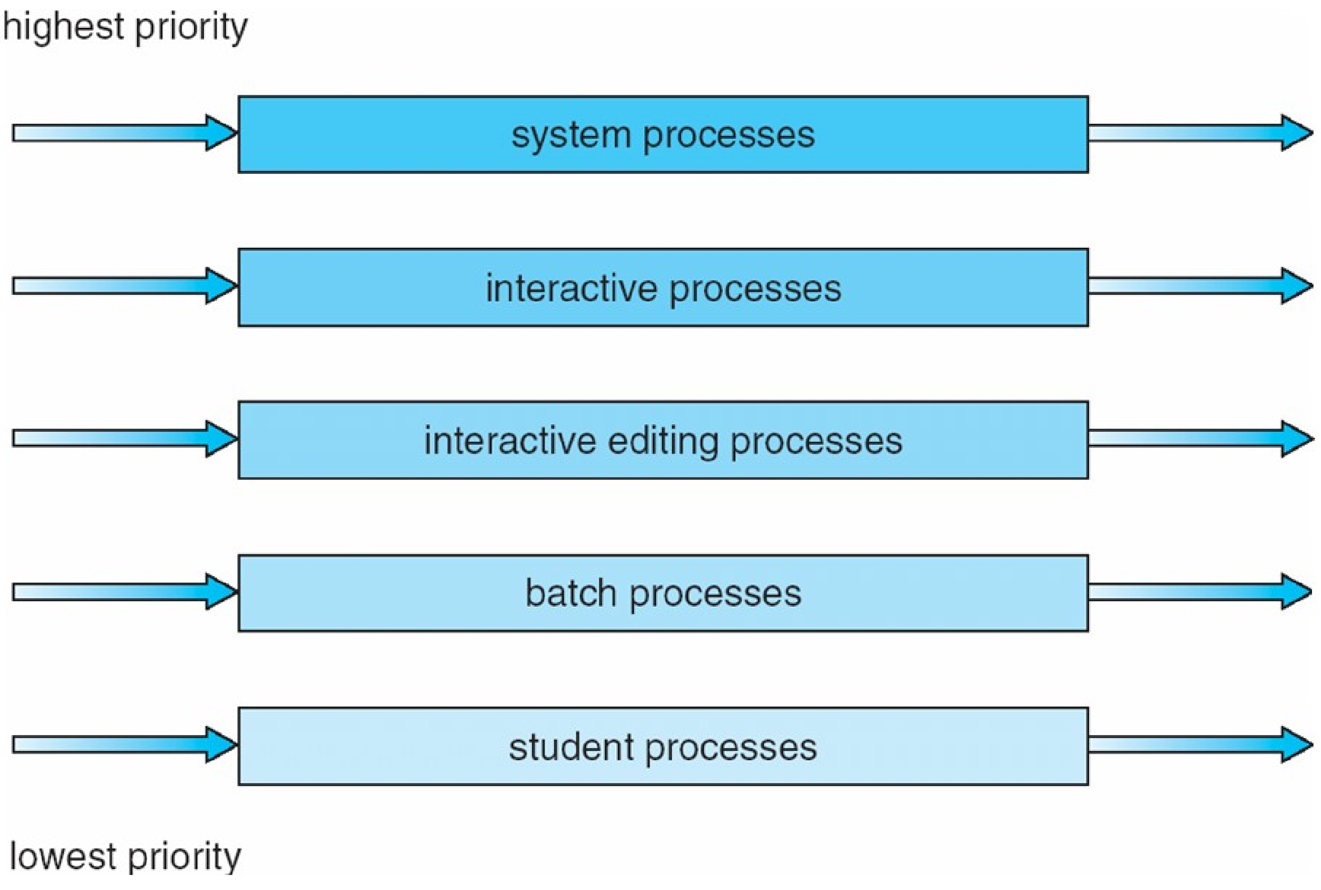
- *priority* associated with each thread
  - Scheduler selects thread with highest priority
  - Both preemptive and non-preemptive variants

- Problem → starvation
  - Low priority processes may never execute
- One solution → aging
  - As a thread uses more execution time, dynamically decrease its priority

Multilevel Queue Scheduling

- Ready-queue partitioned into separate queues
- Each queue has its own scheduling policy
  - I/O-bound/interactive task queue – RR
  - CPU-bound/background/batch queue – FCFS
- Scheduling done between queues
  - Fixed priority – some queues have higher priority
    - Possible starvation
  - Proportional allocation – background gets 20% CPU

Multilevel Queue Scheduling II



Multilevel Feedback Queuing

- How make thread ↔ queue mapping?
- Want interactive/I/O bound threads in higher priority queues

- Threads can move between different queues
  - Aging to avoid starvation
- Multilevel feedback queuing parameters:
  - # of queues
  - Scheduling algorithm for each queue
  - Policy to *promote* a thread to higher queues
  - Policy to *demote* a thread to lower queues
  - Entry queue for new threads

Multilevel Feedback Example

- Three queues – in order of decreasing priority
  - Q_0: RR with a timeslice of 8 time units
  - Q_1: RR with a timeslice of 16 time units
  - Q_2: FCFS
- New Jobs arrive in Q_0, until they expend 8 time units, demote to Q_1...
- Thread *promoted* when placed in “runqueue” after waiting on I/O
- Starvation???

Multilevel Feedback Example II