Scheduling: Round Robin, Deadlines, Priorities, Multi-level Feedback Queues

CSCI 3753 Operating Systems

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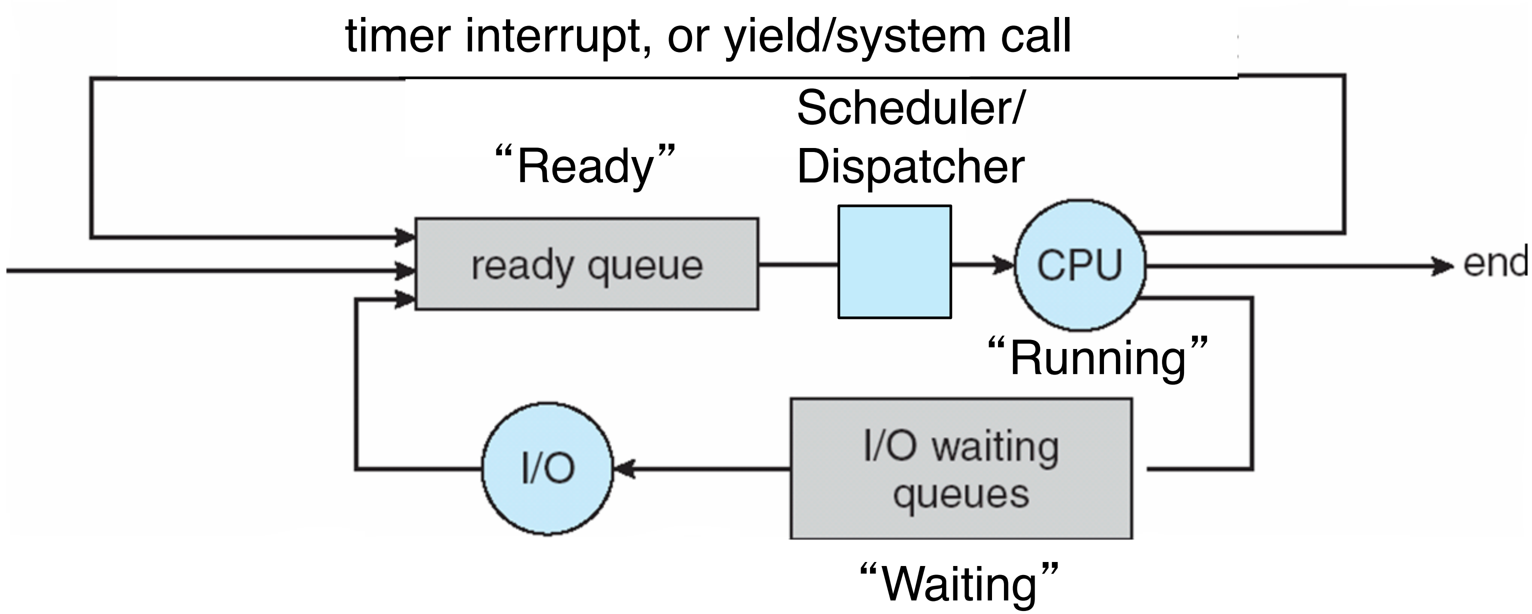
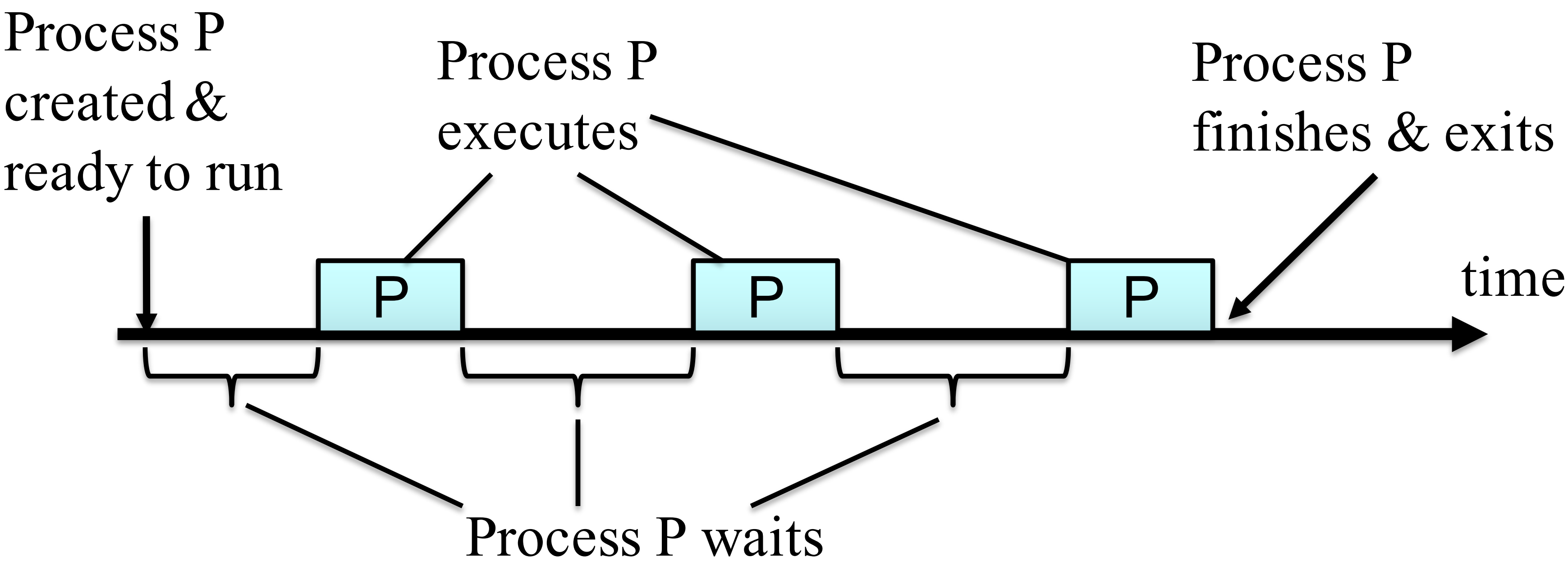
Process Scheduling



If threads are implemented as kernel threads, then OS can schedule threads as well as processes

Modified version of Silberschatz et al slides

Recap

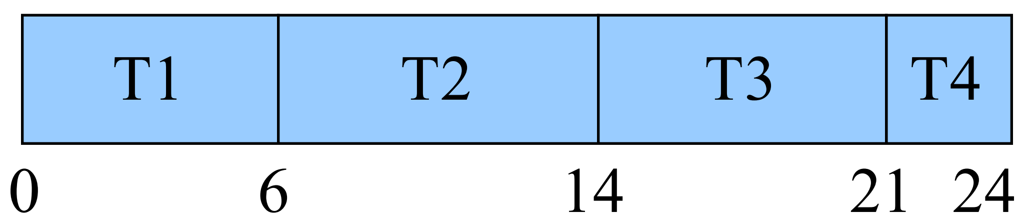


- CPU Scheduler implements a scheduling policy
  – Minimize ave/peak wait time, response time, turnaround time, etc.

First Come First Serve (FCFS) Scheduling

- Tasks are scheduled according to the order they arrive
  - Simple to implement
  - Can result in high variance

Task	CPU Execution Time
T1	6
T2	8
T3	7
T4	3

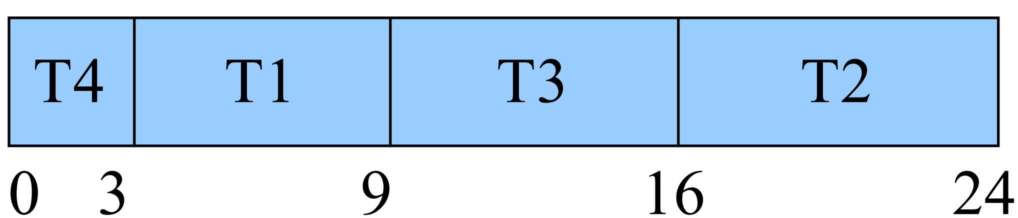


average wait time
= (0+6+14+21)/4
= 10.25 seconds

Shortest Job First Scheduling

- Schedule tasks with the shortest execution times first
  - Can prove this results in the lowest average wait time

Task	CPU Execution Time
T1	6
T2	8
T3	7
T4	3



average wait time
= (0+3+9+16)/4
= 7 seconds

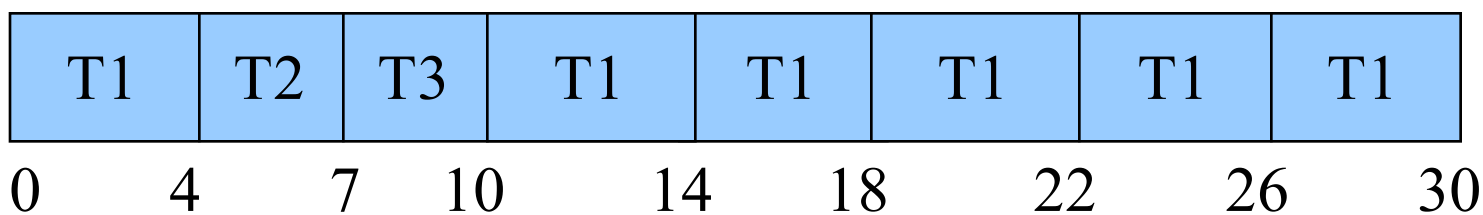
Round Robin Scheduling

- Assume preemptive time slicing
  - A task is forced to relinquish the CPU before it's necessarily done
  - Periodic timer interrupt transfers control to the CPU scheduler, which *rotates* among the processes in the ready queue, giving each a time slice,
  - e.g. if there are 3 tasks T1, T2, & T3, then the scheduler will keep rotating among the three: T1, T2, T3, T1, T2, T3, T1, …
  - treats the ready queue as a circular queue

Round Robin Scheduling

- Example: let time slice = 4 ms
- Now T1 is time sliced out, and T2 and T3 are allowed to run sooner than FCFS
- average response time is fast at 3.66 ms
  - Compare to FCFS w/ long 1st task

Task	CPU Execution Time (ms)
T1	24
T2	3
T3	3



Round Robin Scheduling

- useful to support interactive applications in multitasking systems
  - hence is a popular scheduling algorithm
- Properties:
  - Simple to implement: just rotate, and don't need to know execution times a priori
  - Fair: If there are n tasks, each task gets 1/n of CPU
- A task can finish before its time slice is up
  - Scheduler just selects the next task in the queue

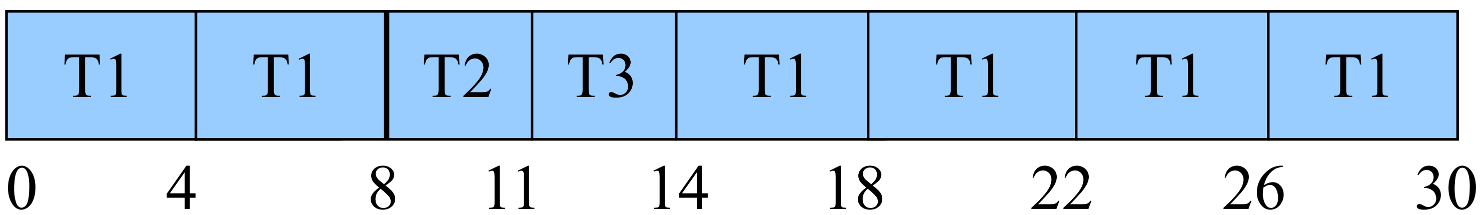
Weighted Round Robin

- Give some some tasks more time slices than others
  - This is a way of implementing priorities – higher priority tasks get more time slices per round
  - If task T_i gets N_i slots per round, then the fraction α_i of the CPU bandwidth that task i gets is:

$$\alpha_\iota = \frac{N_i}{\sum_i N_i}$$

Weighted Round Robin

- In previous example, could give T1 2 time slices, and T2 and T3 only 1 each round



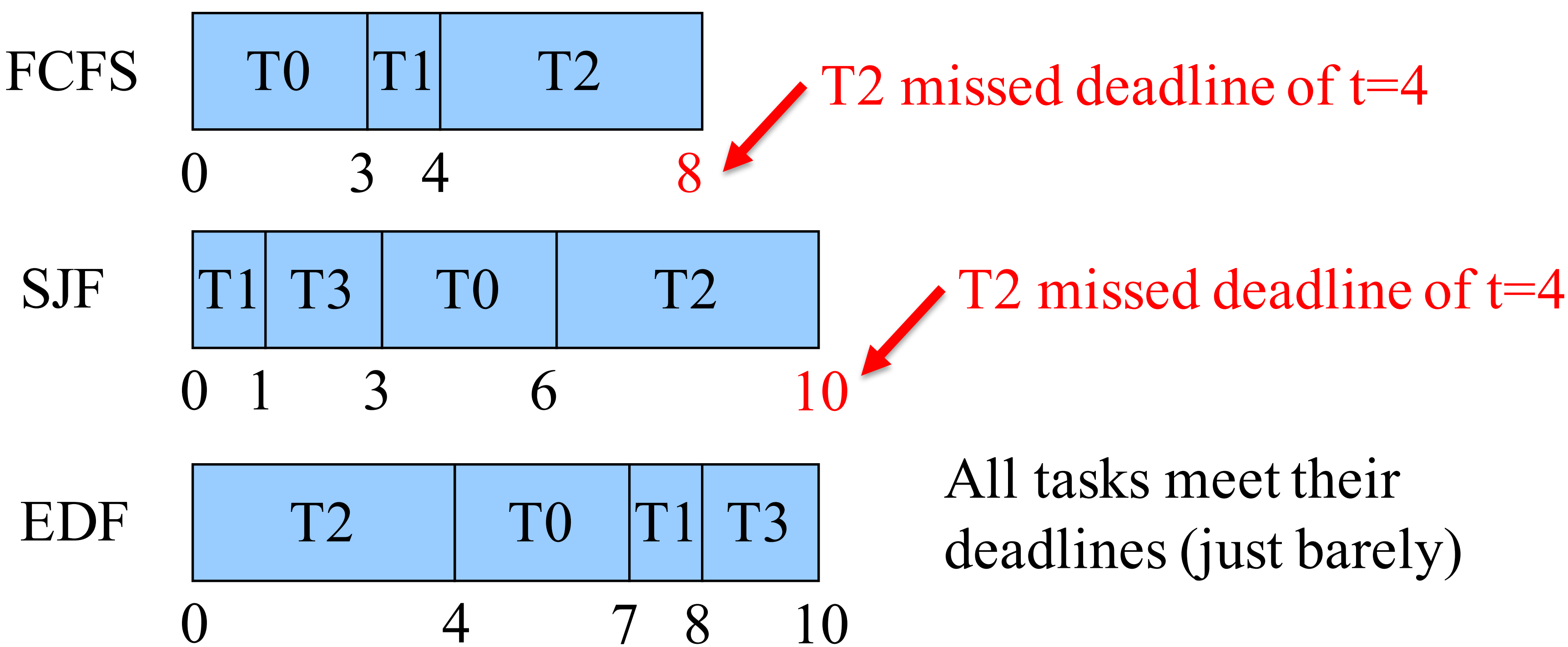
Deadline Scheduling

- Hard real time systems require that certain tasks *must* finish executing by a certain time, or the system fails
  - e.g. robots and self-driving cars need a real time OS (RTOS) whose tasks (actuating an arm/leg or steering wheel) must be scheduled by a certain deadline

Task	CPU Execution Time	Deadline from now
T0	3	7
T1	1	9
T2	4	4
T3	2	10

Earliest Deadline First (EDF) Scheduling

- Choose the task with the earliest deadline
  - This task most urgently needs to be completed



Deadline Scheduling

- Even EDF may not be able to meet all deadlines:
  - In previous example, if T3's deadline was t=9, then EDF cannot meet T3's deadline
- When EDF fails, the results of further failures, i.e. missed deadlines, are unpredictable
  - Which tasks miss their deadlines depends on when the failure occurred and the system state at that time
    - Could be a cascade of failures
  - This is one disadvantage of EDF

Deadline Scheduling

- Admission control policy
  - Check on entry to system whether a task's deadline can be met,
    - Examine the current set of tasks already in the ready queue and their deadlines
    - If all deadlines can be met with the new task, then admit it. The *schedulability* of the set of real-time tasks has been verified.
    - Else, deny admission to this task if its deadline can't be met.
  - Note FCFS, SJF and priority had no notion of refusing admission

EDF and Preemption

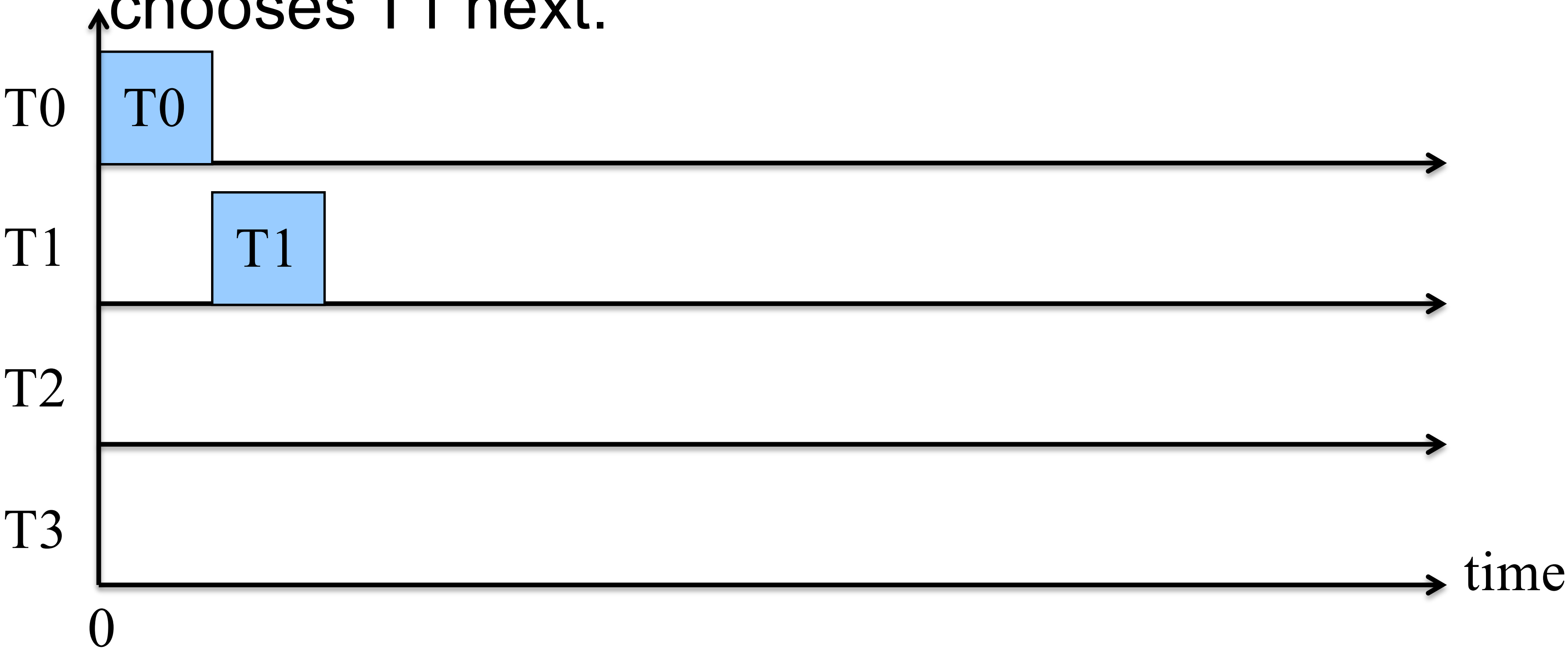
- Assume a preemptively time sliced system
  - A task arriving with an earlier deadline can preempt one currently executing with a later deadline.

Task	CPU Execution Time	Absolute Deadline	Arrival time
T0	1	2	0
T1	2	5	0
T2	2	4	2
T3	2	10	3

Assume in this example time slice = 1, i.e. the executing task is interrupted every second and a new scheduling decision is made

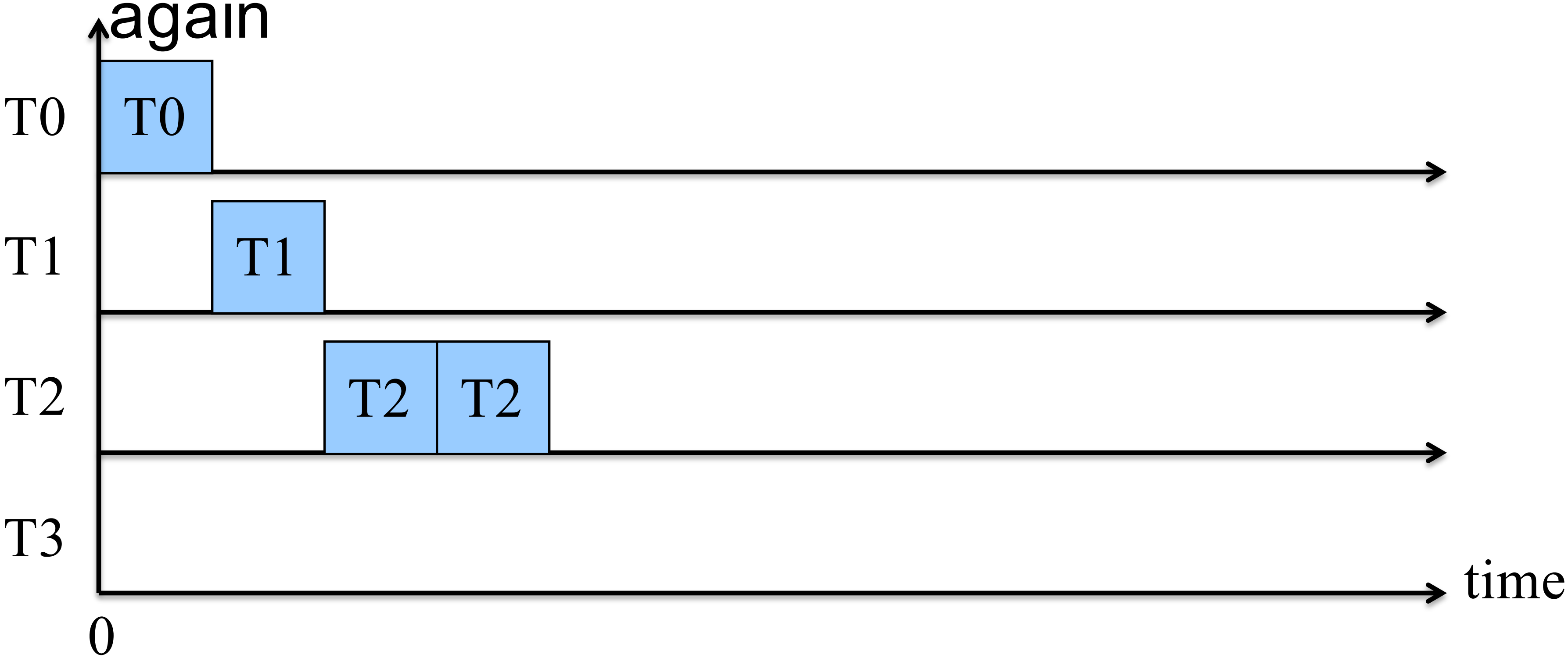
EDF and Preemption

- At time 0, tasks T0 and T1 have arrived. EDF chooses T0.
- At time 1, T0 finishes, makes deadline. EDF chooses T1 next.



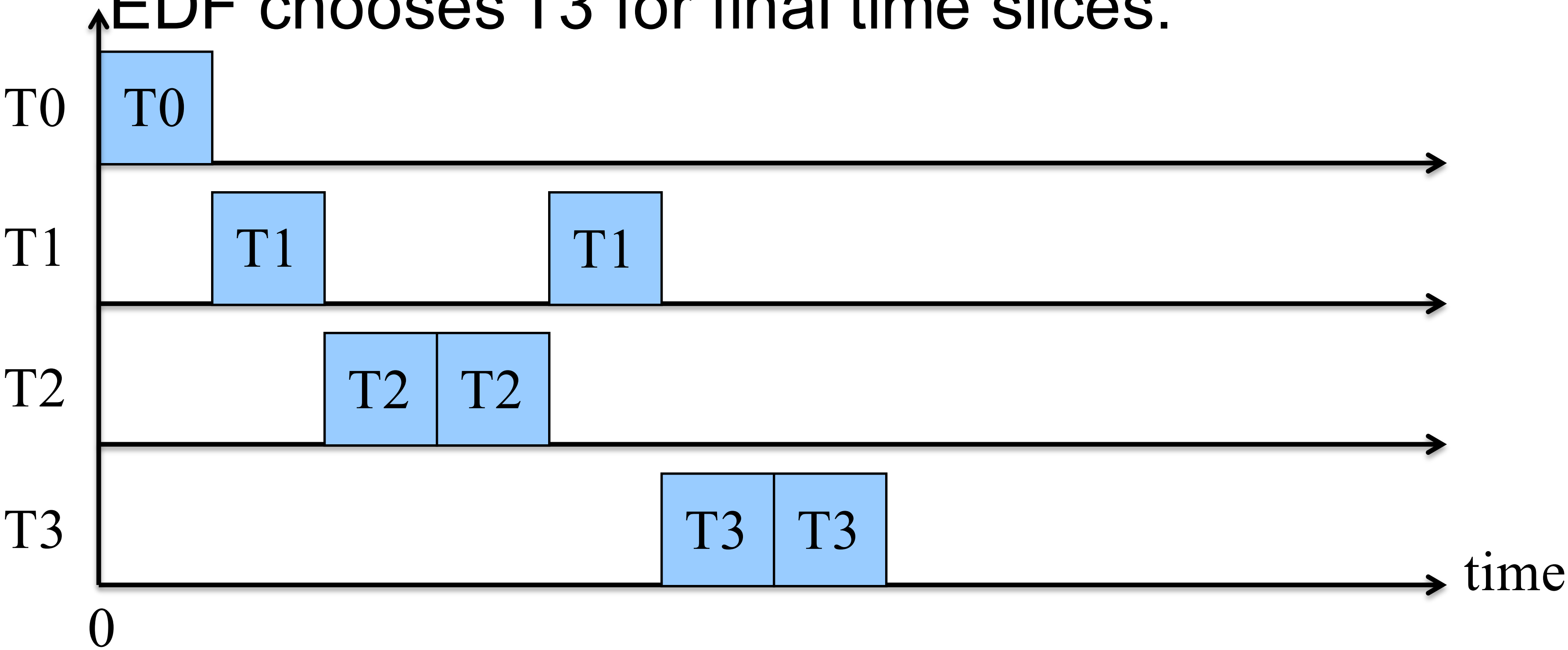
EDF and Preemption

- At time 2, preempt T1. EDF chooses newly arrived T2 with earlier deadline.
- At time 3, preempt T2. EDF chooses T2 again



EDF and Preemption

- At time 4, T2 finishes and makes deadline. EDF chooses T1.
- At time 5, T1 finishes and makes deadline. EDF chooses T3 for final time slices.



Deadline Scheduling

- There are other types of deadline schedulers
  - Example: a Least Slack algorithm chooses the task with the smallest slack = time until deadline – remaining execution time
  - i.e. slack is the maximum amount of time that a task can be delayed without missing its deadline
    - Tasks with the least slack are those that have the least flexibility to be delayed given the amount of remaining computation needed before their deadline expires
- Both EDF and Least Slack are optimal according to different criteria

Soft Real Time Systems

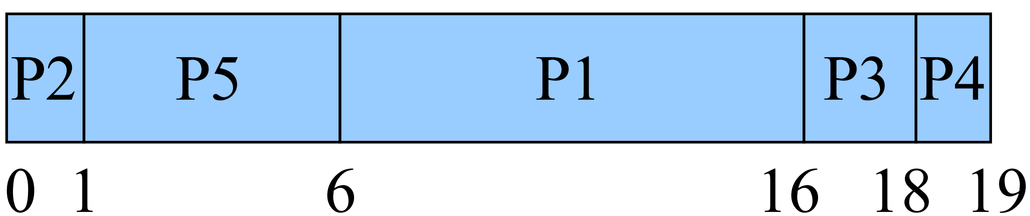
- *Soft* real time systems seek to meet most deadlines, but allow some to be missed
  - Unlike hard real time systems, where every deadline must be met or else the system fails
  - Soft real time scheduler may seek to provide probabilistic guarantees
    - e.g. if 60% of deadlines are met, that may be sufficient for some systems
  - Linux supports a soft real-time scheduler based on priorities – we'll see this next

Priority-based Scheduling

- Assign each task a priority, and schedule higher priority tasks first, before lower priority tasks
- Any criteria can be used to decide on a priority
  - measurable characteristics of the task
  - external criteria based on the “importance” of the task
  - Example: foreground processes may get high priority, while background processes get low priority

Priority-based Scheduling

Process	CPU Execution Time	Priority
P1	10	3
P2	1	1
P3	2	4
P4	1	5
P5	5	2



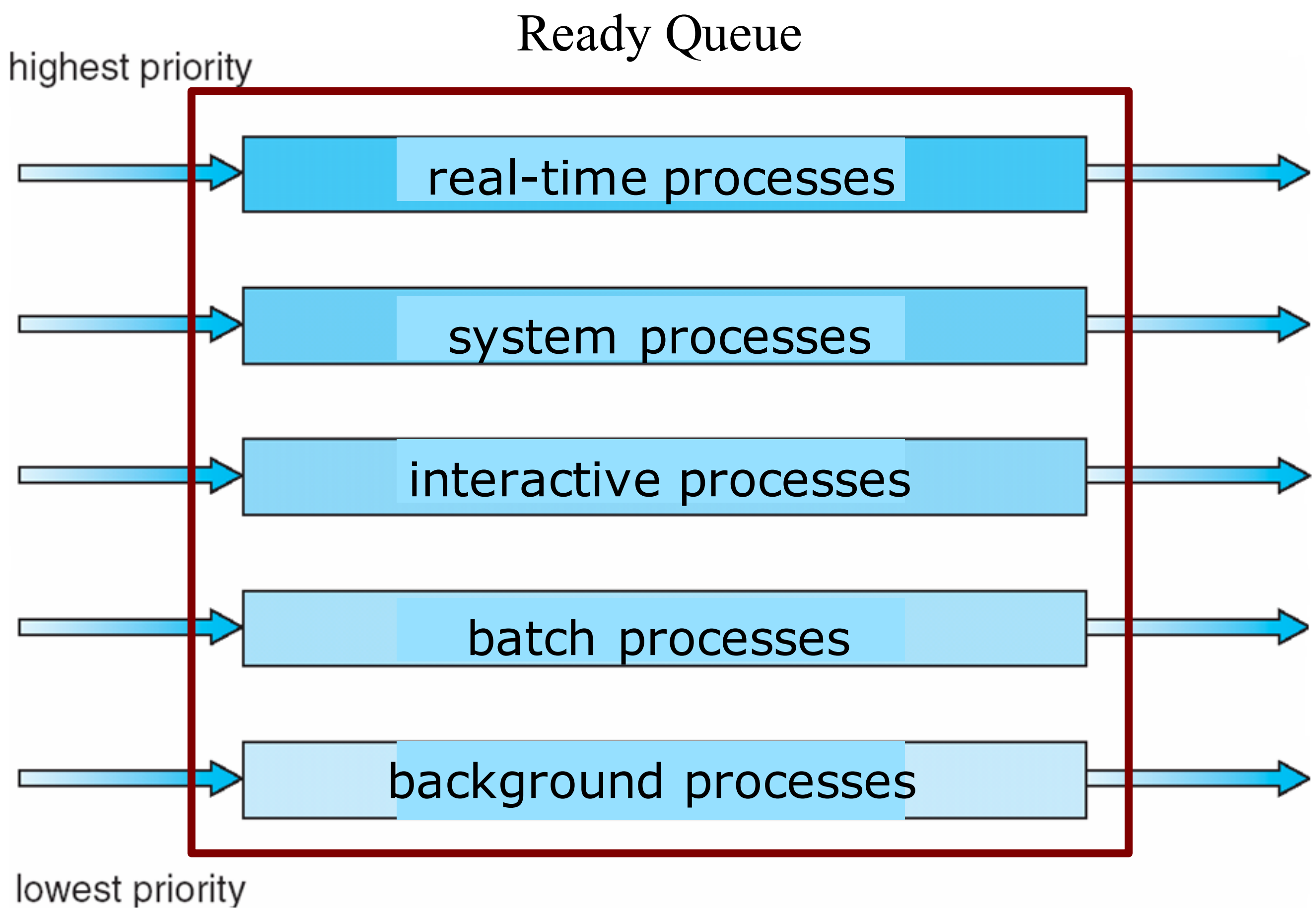
Priority-based Scheduling

- Can be preemptive:
  - A higher priority process arriving in the ready queue can preempt a lower priority running process
  - Can occur if the lower priority process …:
    - Yields CPU with a system call
    - Is interrupted by a timer interrupt
    - Is interrupted by a hardware interrupt
  - Each of these cases gives control back to the OS, which can then schedule the higher priority process

Priority-based Scheduling

- Multiple tasks with the same priority are scheduled according to some policy
  - FCFS, round robin, etc.
- Each priority level has a set of tasks, forming a *multi-level queue*
  - Each level's queue can have its own scheduling policy
- We use priority-based scheduling and multi-level queue scheduling interchangeably

Multilevel Queue Scheduling



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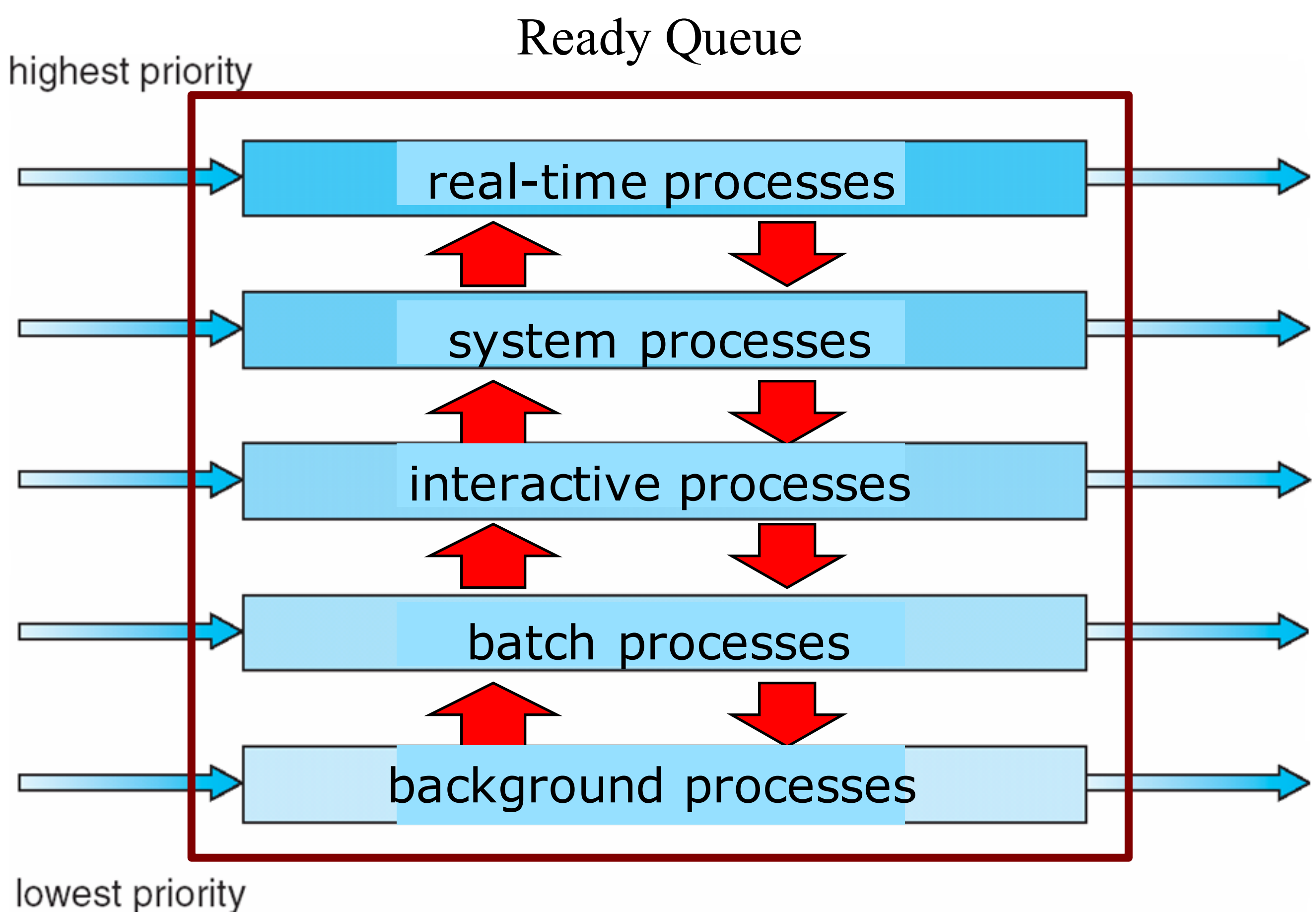
Priority-based Scheduling

- Preemptive priorities can starve low priority processes
  - A higher priority task always gets served ahead of a lower priority task, which never sees the CPU
- Some starvation-free solutions:
  - Assign each priority level a proportion of time, with higher proportions for higher priorities, and rotate among the levels
    - Similar to weighted round robin, except across levels
  - Create a *multi-level feedback queue* that allows a task to move up/down in priority
    - Avoids starvation of low priority tasks

Multilevel Feedback Queue Scheduling



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Multilevel Feedback Queue

- 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

Multi-level Feedback Queues

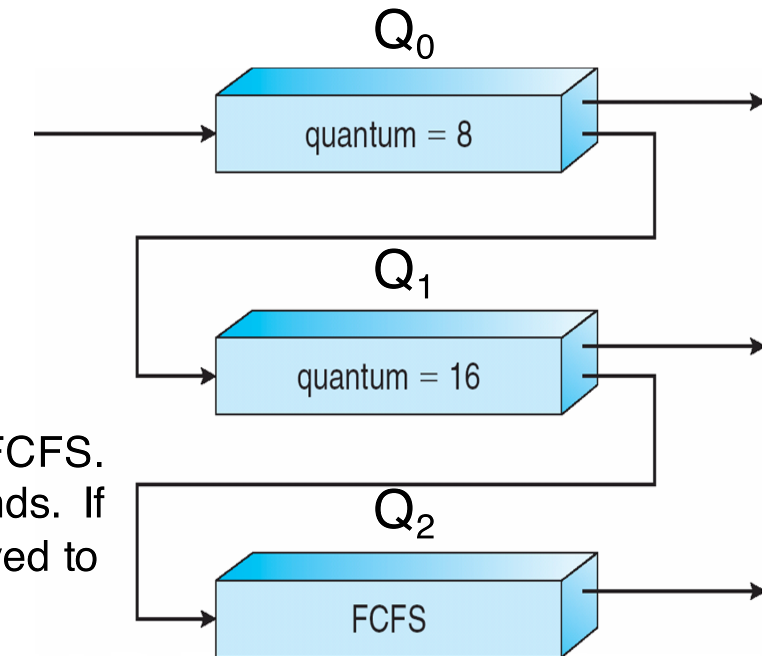
- Criteria for process movement among priority queues could depend upon age of a process:
  - old processes move to higher priority queues, or conversely, high priority processes are eventually demoted
  - sample aging policy: if priorities range from 1-128, can decrease (increment) the priority by 1 every T seconds
  - eventually, the low priority process will get scheduled on the CPU

Multi-level Feedback Queues

- Criteria for process movement among priority queues could depend upon behavior of a process:
  - could be CPU-bound processes move down the hierarchy of queues, allowing interactive and I/O-bound processes to move up
  - give a time slice to each queue, with smaller time slices higher up
  - if a process doesn’t finish by its time slice, it is moved down to the next lowest queue
  - over time, a process gravitates towards the time slice that typically describes its average local CPU burst

Example of 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 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.
  - Interactive processes are more likely to finish early, processing a small amount of data, while compute-bound processes will exhaust their time slice. So interactive processes will gravitate towards higher priority queues.



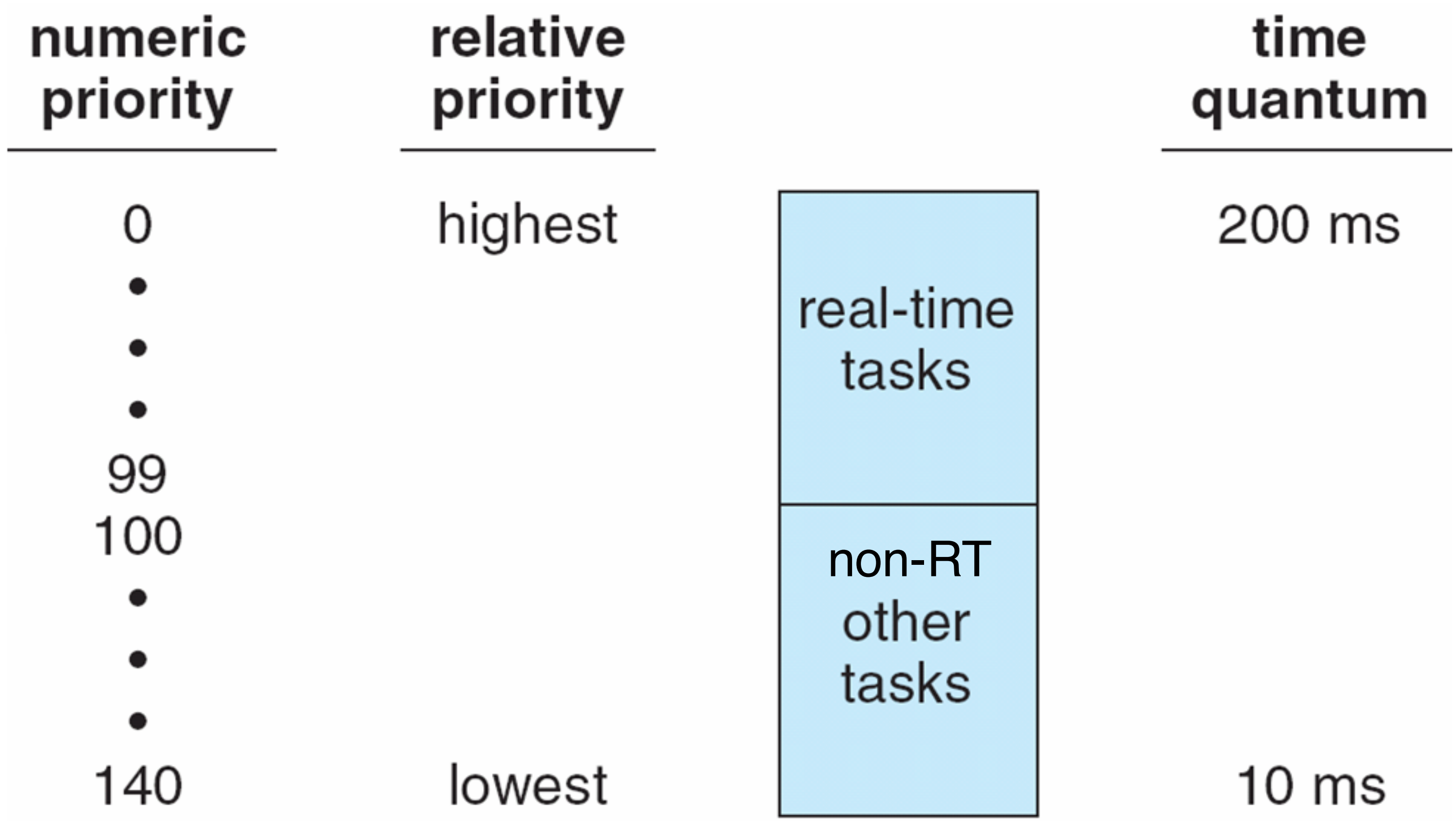
Priority-based Scheduling

- In Unix/Linux, you can *nice* a process to set its priority, within limits
  - e.g. priorities can range from -20 to +20, with lower values giving higher priority, a process with 'nice +15' is "nicer" to other processes by incrementing its value (which lowers its priority)
    - E.g. if you want to run a compute-intensive process compute.exe with low priority, you might type at the command line "nice –n 19 compute.exe"
  - To lower the niceness, hence increase priority, you typically have to be root
  - Different schedulers will interpret/use the nice value in their own ways

Multi-level Feedback Queues

- In Windows XP and Linux, system & real-time tasks are grouped in a priority range that is higher in priority than the priority range of non-real-time tasks
  - XP has 32 priorities. 1-15 are for normal processes, 16-31 are for real-time processes. One queue for each priority.
    - XP scheduler traverses queues from high priority to low priority until it finds a process to run
  - In Linux, priorities 0-99 are for important/real-time processes while 100-139 are for 'nice' user processes. Lower values mean higher priorities.
    - Also, longer time quanta for higher priority tasks (200 ms for highest) and shorter time quanta for lower priority tasks (10 ms for lowest).

Linux Priorities and Time-slice length



Multi-level Feedback Queues

- Most modern OSs use or have used multi-level feedback queues for priority-based preemptive scheduling
  - e.g. Windows NT/XP, Mac OS X, FreeBSD/NetBSD and Linux pre-2.6
  - Linux 1.2 used a simple round robin scheduler
  - Linux 2.2 introduced scheduling classes (priorities) for real-time and non-real-time processes and SMP (symmetric multi-processing) support
  - Linux 2.4 and above next lecture…