Scheduling Algorithms

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Calculations of different scheduling criteria

- If you want to evaluate an algorithm practically, you need a proper workload !
  - Processes with CPU and I/O bursts
  - Different durations of CPU bursts
  - Different durations of I/O bursts
    - How to do this programmatically?
    - How to ensure that after 2 seconds an I/O takes place?
  - Need periods when system will be “idle” – no process schedulable !

Calculations of different criteria

- CPU Utilization
  - % time spent in doing ‘useful’ work
  - What is useful work?
    - On linux
      - there is an “idle” thread, scheduled when no other task is RUNNABLE
      - Not running idle thread is productive work
      - Includes process + scheduling time + interrupts
    - On other systems?
      - Need to define
    - On xv6
      - We can say that time spent in the loop selecting a process is idle work

Calculations of different criteria

- Throughput
  - # processes that complete execution per unit time
  - Formula: total # processes completed / total time
  - Simply divide by your total workload that completed by the time taken
  - Depends on the workload as well. ‘long’ or ‘short’ processes.
  - If too many short processes , then throughput may appear to be high, like 10s of processes per second

Calculations of different criteria

- Turnaround time
  - Amount of time required for one process to complete
  - For every process, note down the starting and ending time, difference is TA-time
  - For process P1 : (Time when process ended – time when process started)

    = Sum of time spent in (ready queue + running + waiting for I/O)
  - One can find the average T.A. time

Calculations of different criteria

- Waiting time
  - amount of time a process has been waiting in the *ready* queue.
  - To be minimised.
  - Part of Turn Around time
  - CPU scheduling does not affect waiting time in I/O queues, it affects time in ready queue

Scheduling Criteria

- **Response time**
  - **amount of time it takes from when a request was submitted until the first response (not full output) is produced, (for time-sharing environment).**
  - **To be minimised.**
  - **E.g. time between your press of a key , and that key being shown in screen**

Challenges in implementing the scheduling algorithms

- Not possible to know number of CPU and I/O bursts and the duration of each before the process runs !
  - Although when we do numerical problems around each algorithm, we assume some values for CPU and I/O bursts, so the problems are solved in “hindsight” !
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GANTT chart

- A timeline chart showing the sequence in which processes get scheduled
- Used for analysing a scheduling algorithm

Scheduling Algorithms

First- Come, First-Served (FCFS) Scheduling

Process	Burst Time
P1	24
P2	3
P3	3

Suppose that the processes arrive in the order: P1 , P2 , P3

The Gantt Chart for the schedule is:

Waiting time for P1 = 0; P2 = 24; P3 = 27

Average waiting time: (0 + 24 + 27)/3 = 17

Non Pre-emptive algorithm

FCFS Scheduling (Cont.)

Suppose that the processes arrive in the order:

P2 , P3 , P1

The Gantt chart for the schedule is:

Waiting time for P1 = 6; P2 = 0; P3 = 3

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

Much better than previous case

FCFS: Convoy effect

- Consider one CPU-bound and many I/O-bound processes
- CPU bound process is scheduled, I/O bound processes are waiting in I/O queues
- I/O bound processes finish I/O and move to ready queue, and wait for CPU bound process to finish
  - I/O devices Idle
- CPU bound process over, goes for I/O. I/O bound processes run quickly, move to I/O queues again
  - CPU idle
- CPU bound process will run when it's ready to run
- Same process will repeat
- --> Lower CPU utilisation
  - Better if I/O bound processes run first

FCFS: further evaluation

- Troublesome for interactive processes
  - CPU bound process may hog CPU
  - Interactive process may not get a chance to run early and response time may be quite bad

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. Better name – Shortest Next CPU Burst Scheduler
- 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 – bad idea, unlikely to know!

Example of SJF

Process

Burst Time

P1

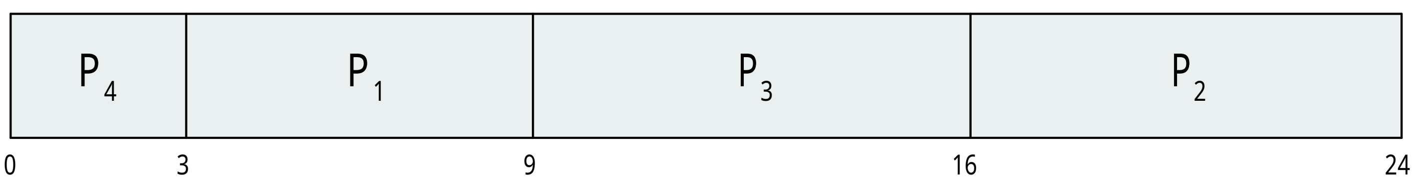
6

P2

8

P3

7



SJF scheduling chart

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

Determining Length of Next CPU Burst

- Not possible to implement SJF as can't know "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. $\tau_{n+1} =$ predicted value for the next CPU burst
3. $\alpha,\ 0 \le \alpha \le 1$
4. Define: $\tau_{n+1} = \alpha\, t_n + (1 - \alpha)\tau_n$.

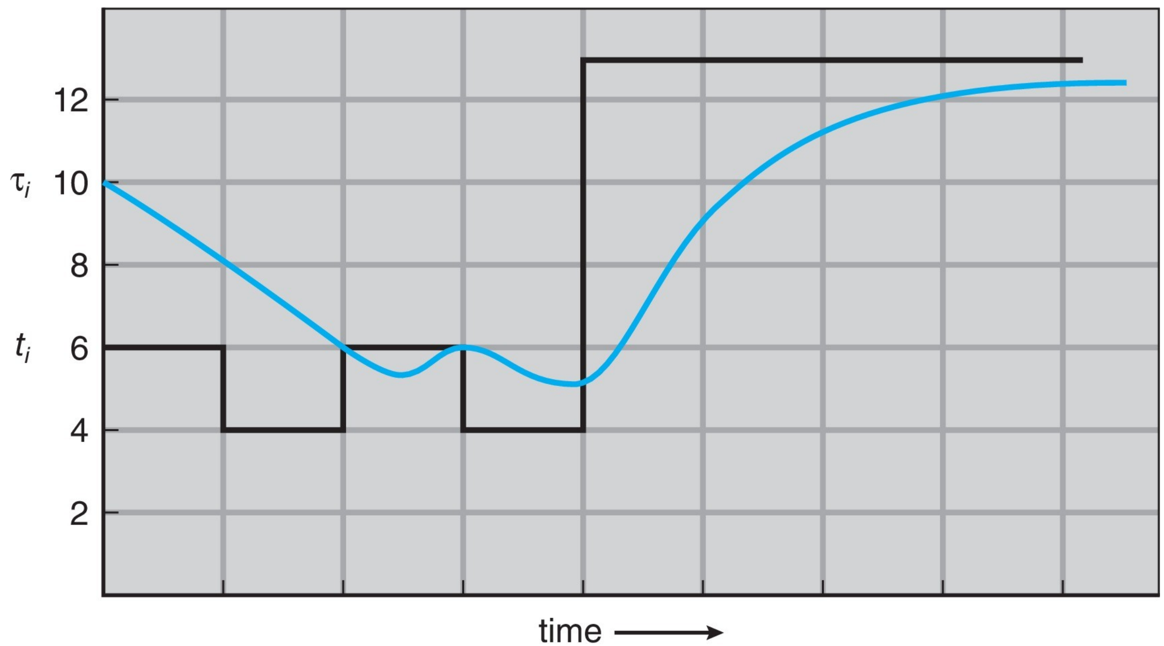
- Commonly, α set to ½
- Preemptive version called shortest-remaining-time-first

Examples of Exponential Averaging

- $\alpha = 0$
  - $\tau_{n+1} = \tau_n$
  - Recent history does not count
- $\alpha = 1$
  - $\tau_{n+1} = \alpha\, t_n$
  - 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 $(1 - \alpha)$ are less than or equal to 1, each successive term has less weight than its predecessor

Prediction of the Length of the Next CPU Burst

- $\alpha = 1/2$, $\tau_0 = 10$



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

Example of Shortest-remaining-time-first

Preemptive SJF = SRTF. Now we add the concepts of varying arrival times and preemption to the analysis

Process
Arrival Time
Burst Time

P1

0

8

P2

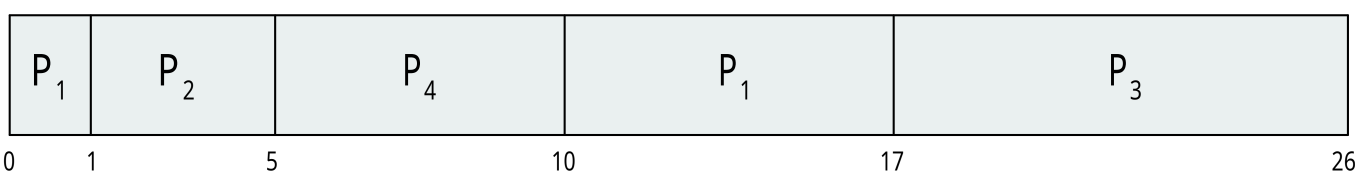
1

4

P3

2

9



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Preemptive SJF Gantt Chart

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

Round Robin (RR) Scheduling

- 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.

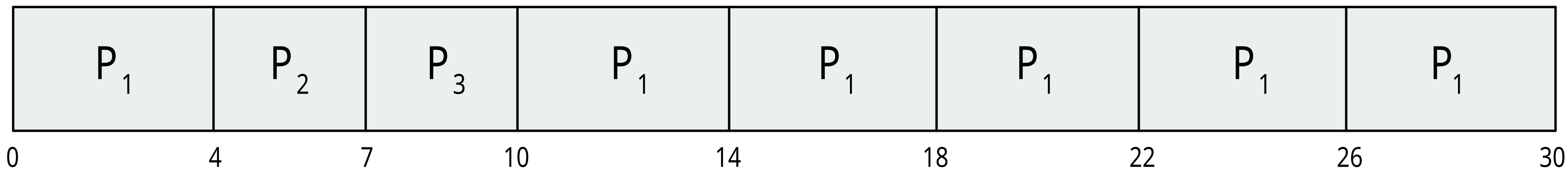
Round Robin (RR) Scheduling

- **Timer interrupts every quantum to schedule next process**
- **Performance**
  - ***q*** **large ⇒ FIFO**
  - ***q*** **small ⇒** ***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:

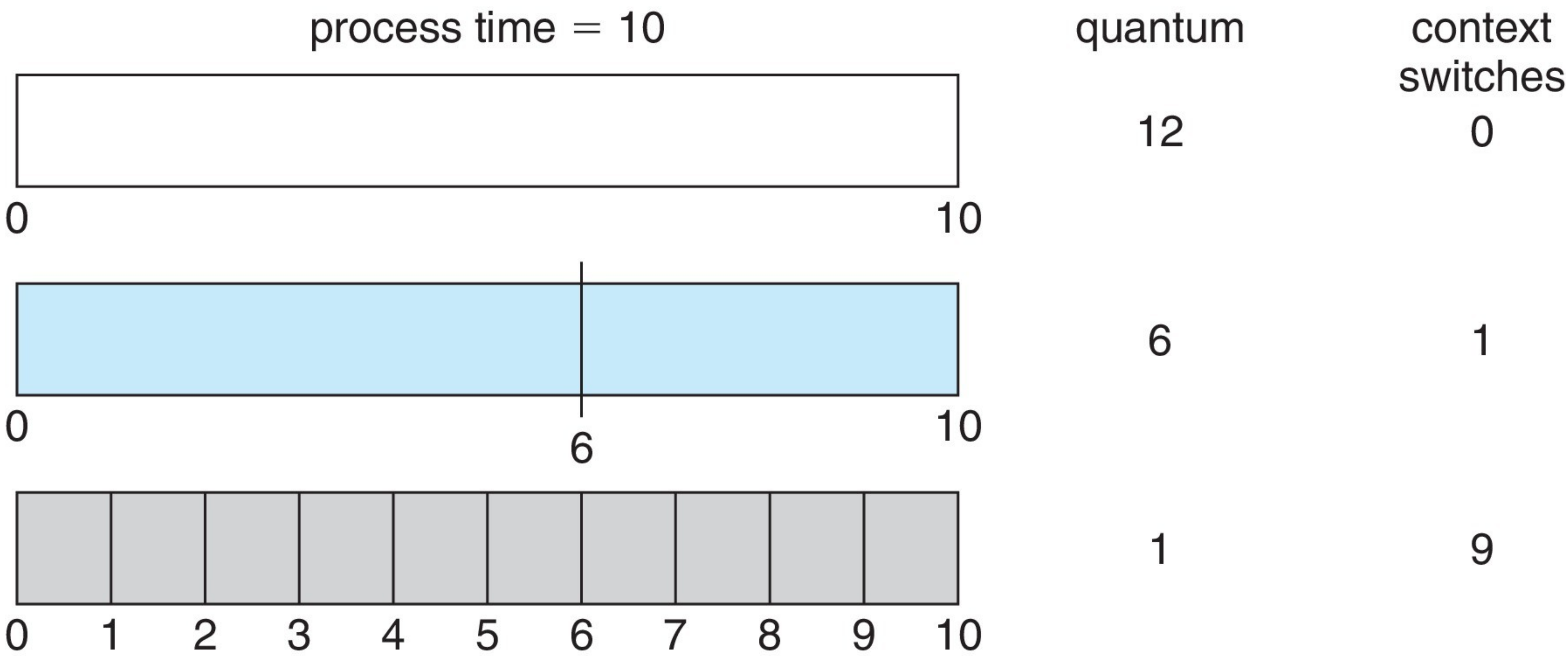


Typically, higher average turnaround than SJF, but better *response*

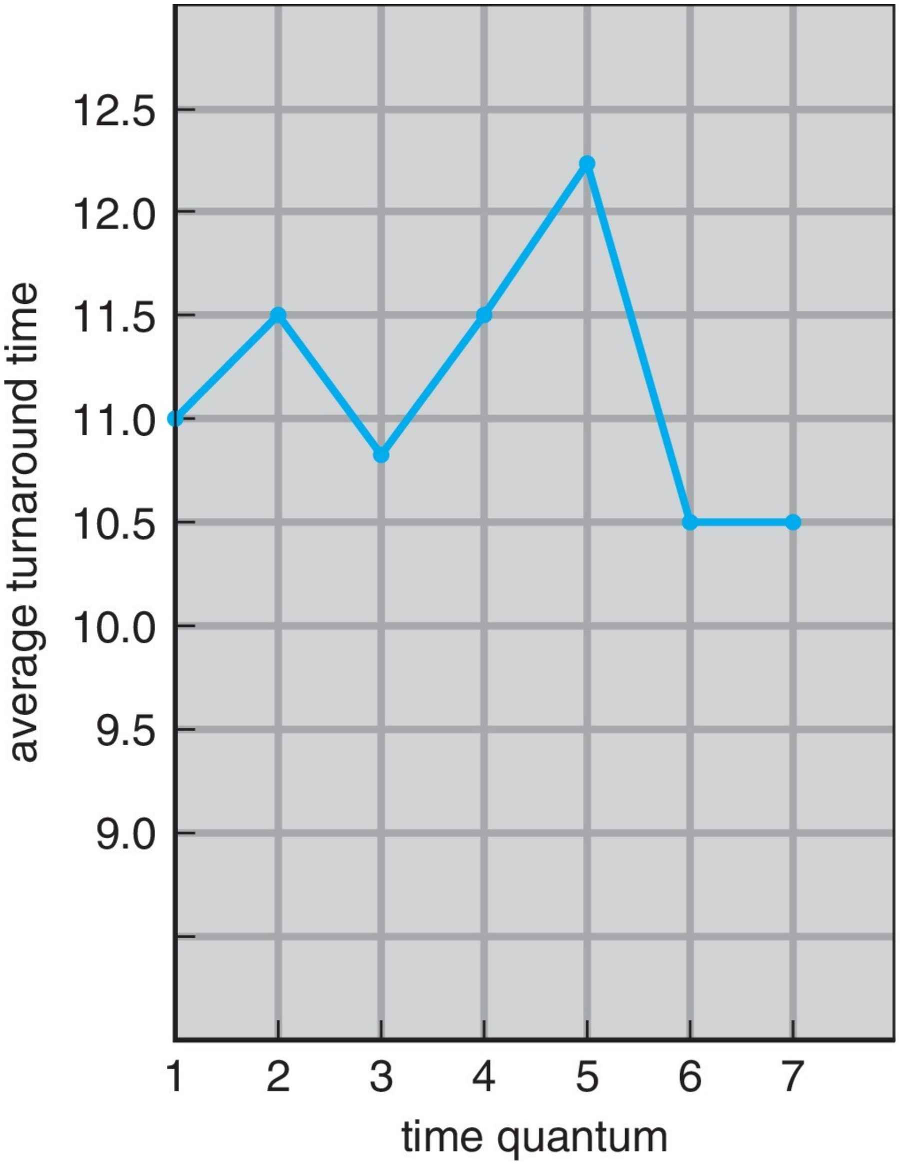
q should be large compared to context switch time

q 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

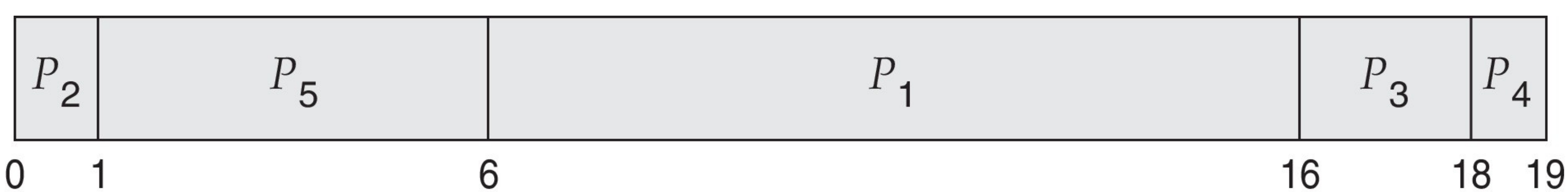
Priority Scheduling

- 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 (timer interrupt, more time for more priority)
  - Nonpreemptive (no timer interrupt, just schedule process with highest priority)
- 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



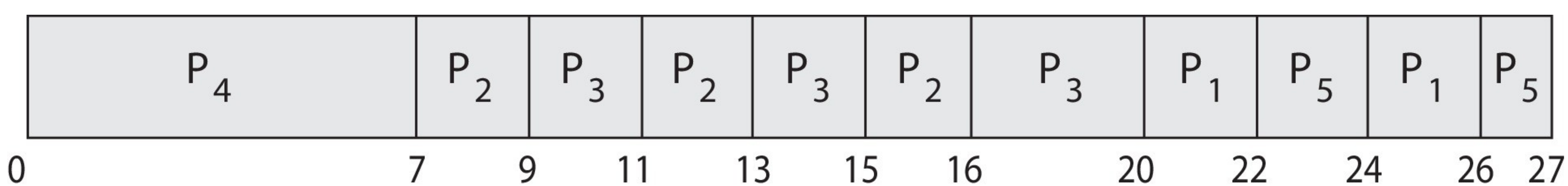
- Average waiting time = 8.2 msec

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

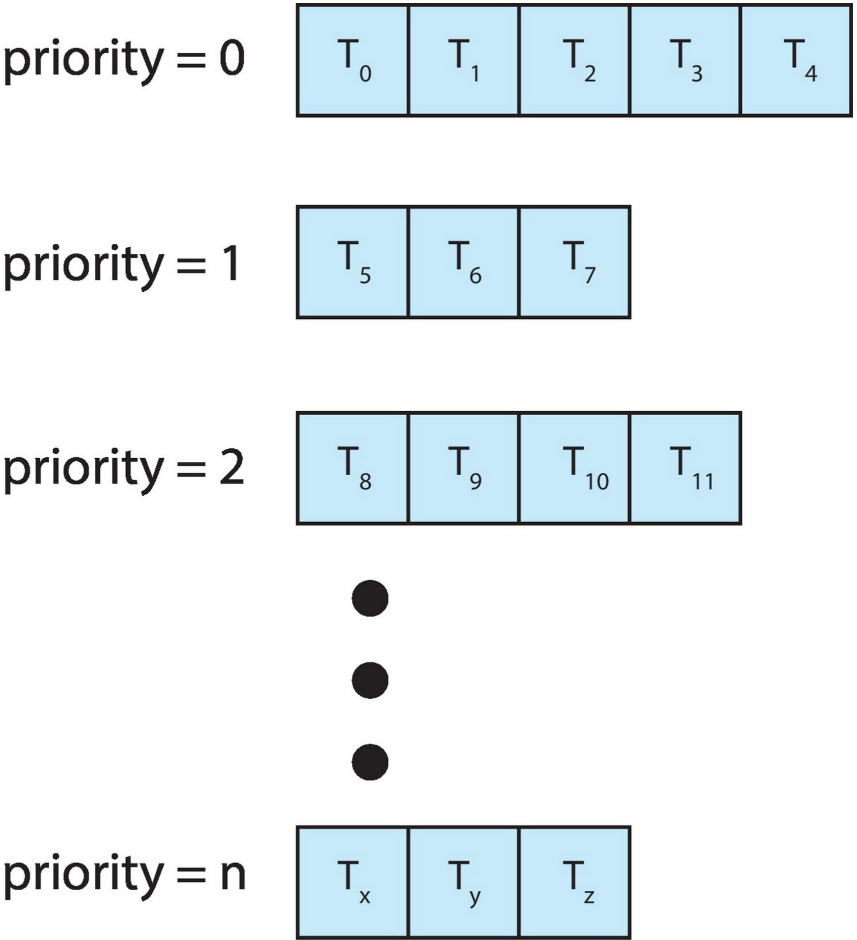
Run the process with the highest priority. Processes with the same priority run round-robin

Gantt Chart with 2 ms time quantum

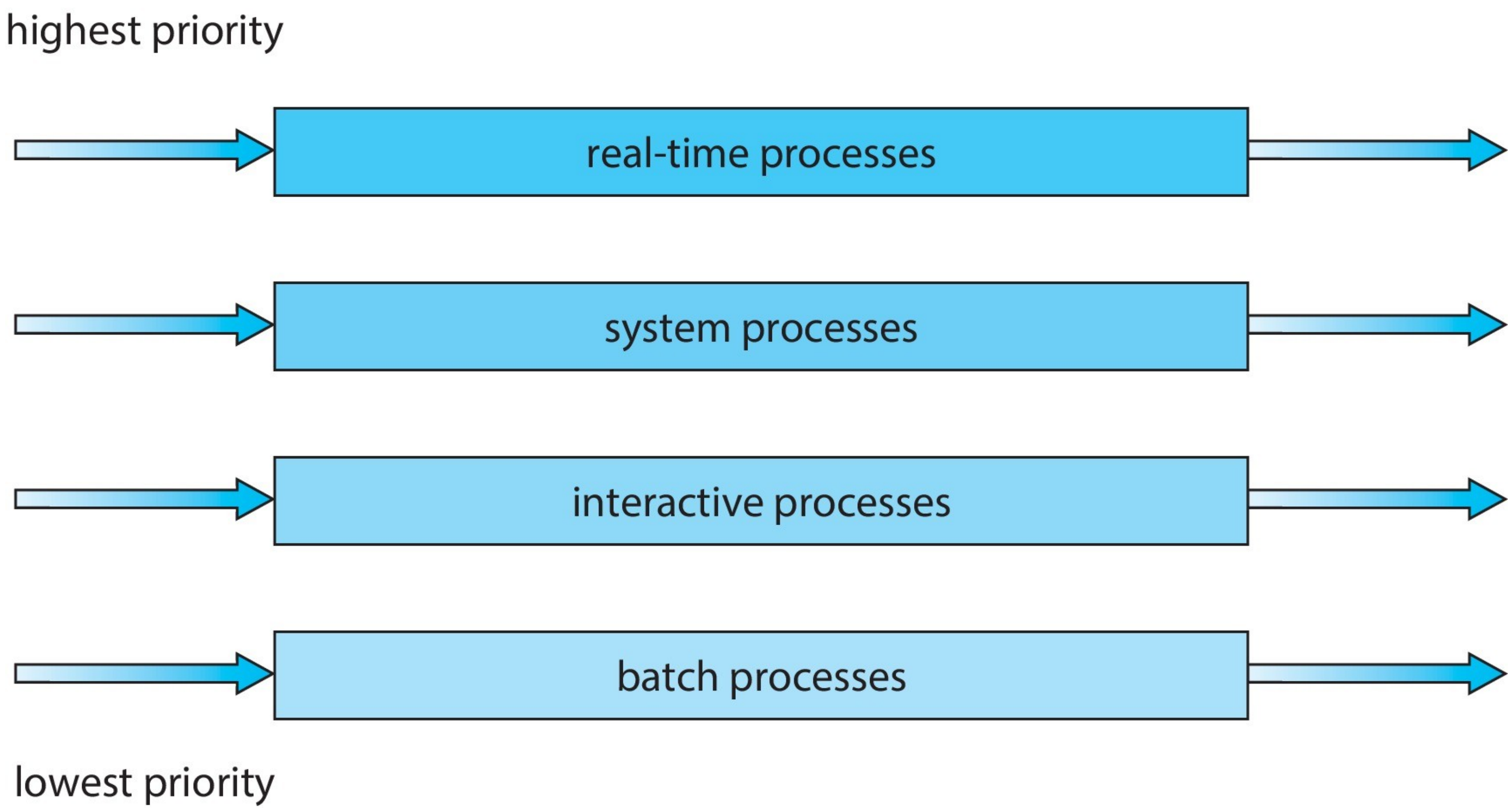


Multilevel Queue

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



Multilevel Queue



Implementing multilevel queue

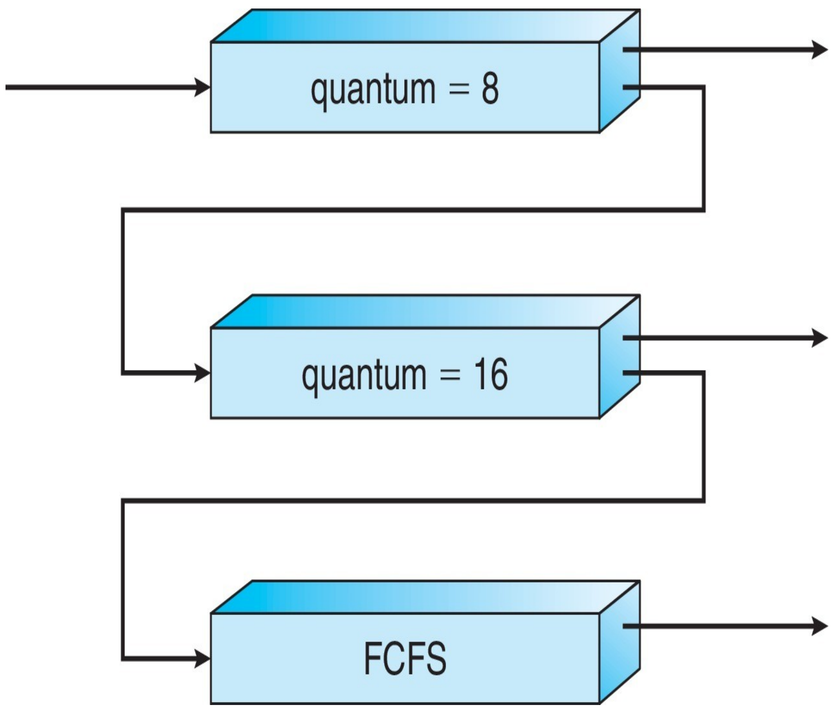
- Processes need to have a priority
  - Either modify fork()/exec() to have a priority
  - Or add a nice() system call to set priority
- How to know the priority?
  - The end user of the computer system needs to know this from needs of real life
  - E.g. on a database system, the database process will have a higher priority than other processes

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

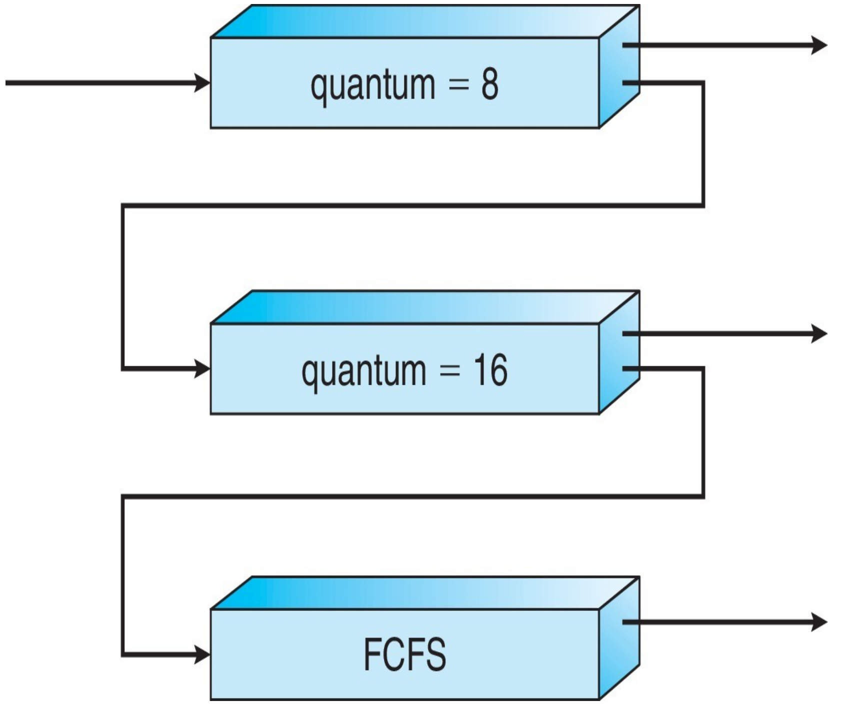
Example of Multilevel Feedback Queue

- **Three queues:**
  - Q_0 – RR with time quantum 8 milliseconds
  - Q_1 – RR time quantum 16 milliseconds
  - Q_2 – FCFS
- **Scheduling rules**
  - Serve all processes in Q0 first
  - Only when Q_0 is empty, serve processes in Q_1
  - Only when Q_0 and Q_1 are empty, serve processes in Q_2



Example of Multilevel Feedback Queue

- **Scheduling**
  - **A new job enters queue Q_0**
    - **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 receives 16 additional milliseconds**
    - **If it still does not complete, it is preempted and moved to queue Q_2**
  - **To prevent starvation, move a process from lower-priority queue to higher priority queue after it has waited for too long**



Thread Scheduling

- Distinction between user-level and kernel-level threads
- When threads supported, threads scheduled, not processes
- Many-to-one and many-to-many models, thread library schedules user-level threads to run on LWP
  - Known as process-contention scope (PCS) since scheduling competition is within the process
  - Typically done via priority set by programmer
- Kernel thread scheduled onto available CPU is system-contention scope (SCS) – competition among all threads in system

Pthread Scheduling

- PTHREAD_SCOPE_PROCESS schedules threads using PCS scheduling
- PTHREAD_SCOPE_SYSTEM schedules threads using SCS scheduling
- Linux and macOS only allow PTHREAD_SCOPE_SYSTEM
- Let’s see a Demo using a program

Multiple-Processor Scheduling – Load Balancing

- **Soft affinity** – the operating system attempts to keep a thread running on the same processor, but no guarantees.
- **Hard affinity** – allows a process to specify a set of processors it may run on.

End