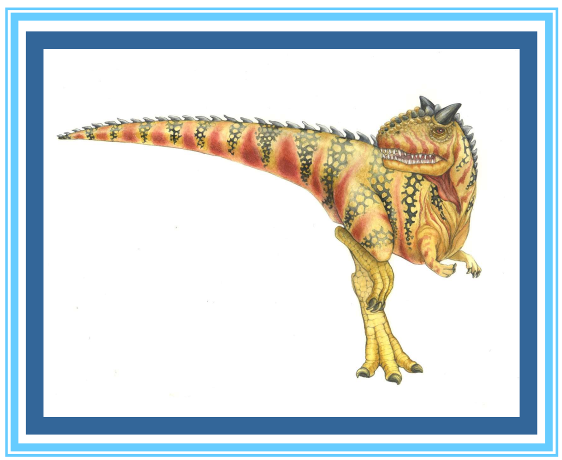
# Chapter 6:  CPU Scheduling



# Chapter 6:  CPU Scheduling

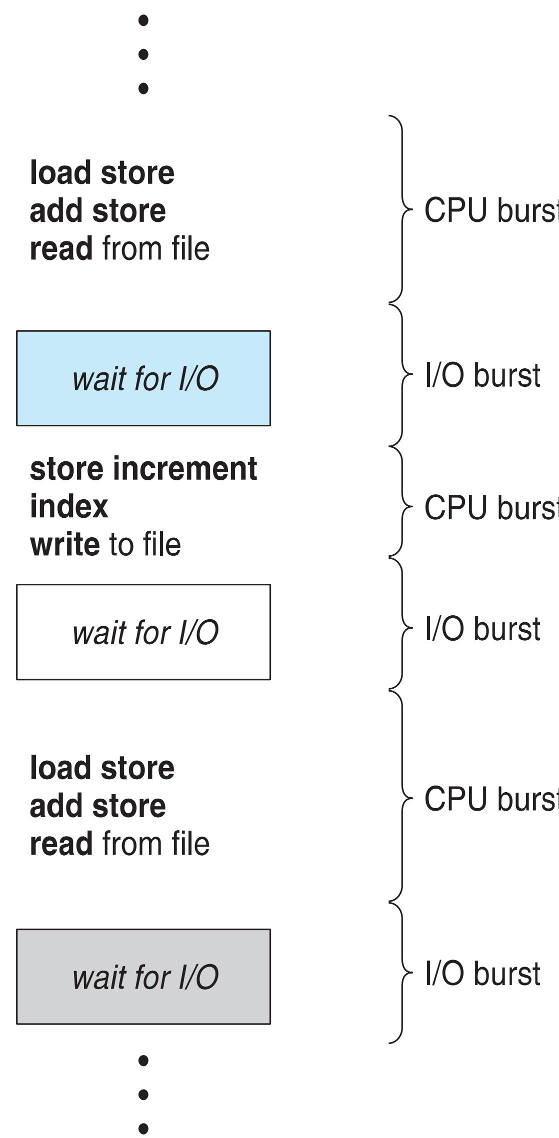
- Basic Concepts
- Scheduling Criteria
- Scheduling Algorithms
- Thread Scheduling

# Objectives

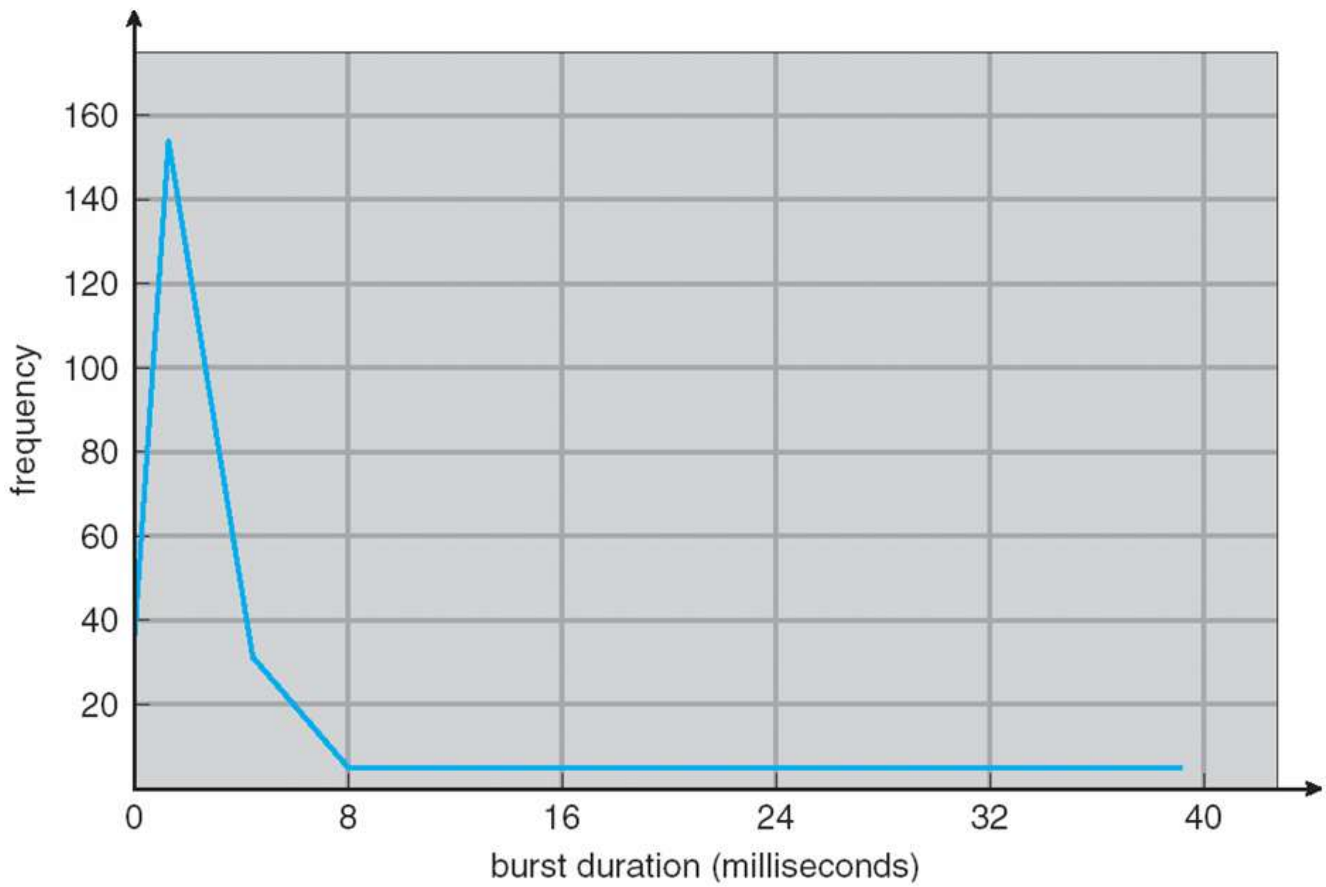
- To introduce CPU scheduling, which is the basis for multiprogrammed operating systems
- To describe various CPU-scheduling algorithms
- To discuss evaluation criteria for selecting a CPU-scheduling algorithm for a particular system

# Basic Concepts

- Maximum CPU utilization obtained with multiprogramming
- CPU–I/O Burst Cycle – Process execution consists of a **cycle** of CPU execution and I/O wait
- **CPU burst** followed by **I/O burst**
- CPU burst distribution is of main concern
- The following figure shows that we usually have a large number of short CPU bursts and a small number of long CPU bursts.



# Histogram of CPU-burst Times



# CPU Scheduler

- **Short-term scheduler** selects from among the processes in ready queue, and allocates the CPU to one of them
  - Queue may be ordered in various ways
  - A ready queue can be implemented as a FIFO queue, a priority queue, a tree, or simply an unordered linked list
  - The records in the queues are generally process control blocks (PCBs) of the processes
- CPU scheduling decisions may take place when a process:
  1. Switches from running to waiting state (no choice in terms of scheduling)
  2. Switches from running to ready state (there is a choice)
  3. Switches from waiting to ready (there is a choice)
  4. Terminates (no choice in terms of scheduling)

- Scheduling under 1 and 4 is **nonpreemptive (or cooperative)**
- All other scheduling is **preemptive**
- **Nonpreemptive scheduling: Once the CPU has been allocated to a process, the process keeps the CPU until it releases the CPU either by terminating or by switching to the waiting state.**
- **Unfortunately, preemptive scheduling can result in race conditions when data are shared among several processes.**
- **Preemptive Scheduling needs to**
  - Consider access to shared data (the race condition)
  - Consider preemption while in kernel mode (might also occur while accessing shared kernel data)
  - Consider interrupts occurring during crucial OS activities (the sections of code affected by interrupts must be guarded from simultaneous use; otherwise input might be lost or output overwritten; these sections of code are not accessed concurrently by several processes, they disable interrupts at entry and re-enable interrupts at exit. )

# Dispatcher

- Dispatcher module gives control of the CPU to the process selected by the short-term scheduler; this involves:
  - switching context
  - switching to user mode
  - jumping to the proper location in the user program to restart that program
- **Dispatch latency** – time it takes for the dispatcher to stop one process and start another running
- The dispatcher should be as fast as possible, since it is invoked during every process switch

# 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 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, This is the time it takes to start responding, not the time it takes to output the response  (for time-sharing environment). In an interactive system this is more important than the turn around time which is limited by the speed of the output device.

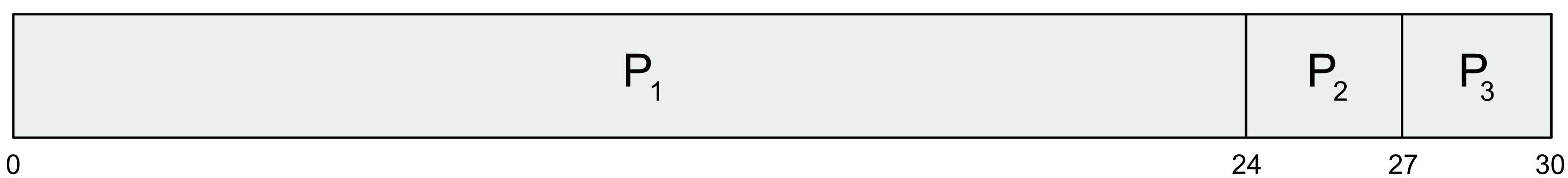
# Scheduling Algorithm Optimization Criteria

- 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

# FCFS Scheduling (Cont.)

Suppose that the processes arrive in the order:

$$P_2 , P_3 , P_1$$

- The Gantt chart for the schedule is:

| $P_2$ | $P_3$ | $P_1$ |
|---|---|---|
| 0–3 | 3–6 | 6–30 |

- Waiting time for $P_1 = 6$; $P_2 = 0$; $P_3 = 3$
- Average waiting time: $(6 + 0 + 3)/3 = 3$ (a substantial reduction)
- Much better than previous case
- Thus, the average waiting time under an FCFS policy is generally not minimal and may vary substantially if the processes' CPU burst times vary greatly
- **Convoy effect** - short process behind long process
  - Consider one CPU-bound and many I/O-bound processes
  - This effect results in lower CPU and device utilization than might be possible if the shorter processes were allowed to go first. (this is bad of course)

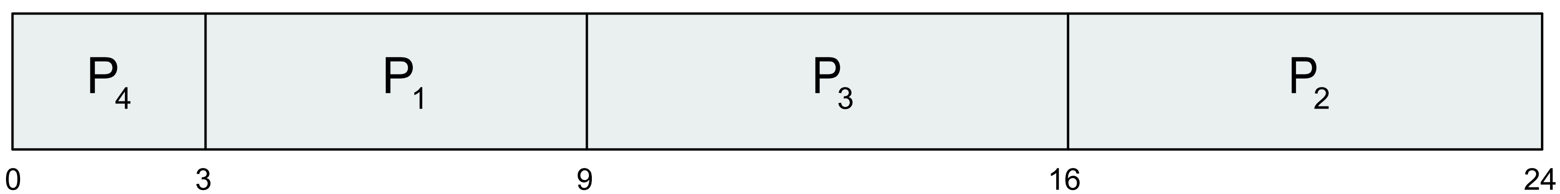
# Shortest-Job-First (SJF) Scheduling

- 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
- By comparison, if we were using the FCFS scheduling scheme, the average waiting time would be 10.25 milliseconds.
- Notice that the FCFS scheduling algorithm is non-pre-emptive

- The SJF scheduling algorithm **is provably optimal**, in that it gives the minimum average waiting time for a given set of processes.
- Moving a short process before along one decreases the waiting time of the short process more than it increases the waiting time of the long process.
- Consequently, the average waiting time decreases.

- Although the SJF algorithm is optimal, it cannot be implemented at the level of short-term CPU scheduling. With short-term scheduling, **there is no way to know the length of the next CPU burst.**

# Determining Length of Next CPU Burst

- With short-term scheduling, there is no way to know the length of the next CPU burst
- Can only estimate the length – should be similar to the previous ones
  - 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. $\alpha, 0 \leq \alpha \leq 1$
4. Define:

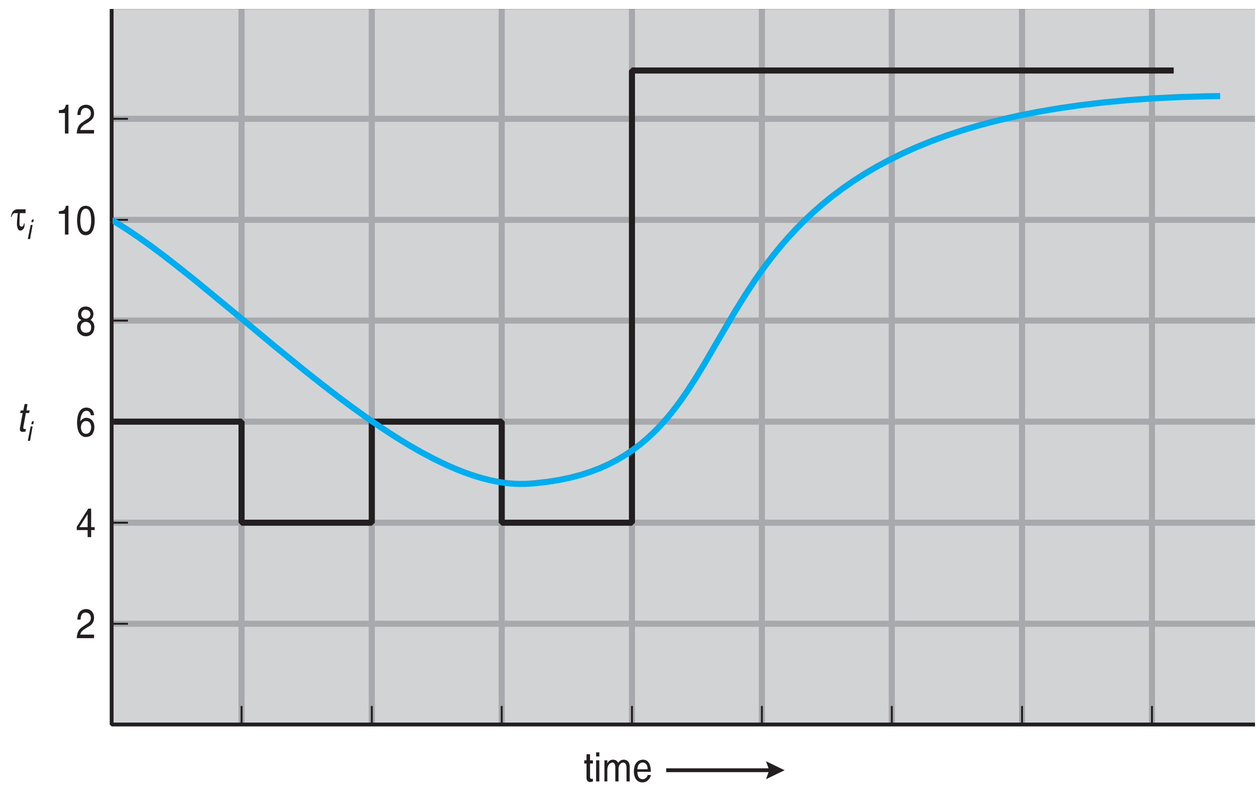
$$\tau_{n+1} = \alpha\, t_n + (1 - \alpha)\tau_n .$$

- Commonly, α set to ½ (to give recent and past history equal weights)
- Preemptive version called **shortest-remaining-time-first**

- Assuming alpha is ½ and $T_0$=10

# Prediction of the Length of the Next CPU Burst

- Assuming alpha is ½ and $T_0$=10




| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CPU burst ($t_i$) | | 6 | 4 | 6 | 4 | 13 | 13 | 13 | … |
| "guess" ($\tau_i$) | 10 | 8 | 6 | 6 | 5 | 9 | 11 | 12 | … |

# 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 by substituting for $T_n$, we get:

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

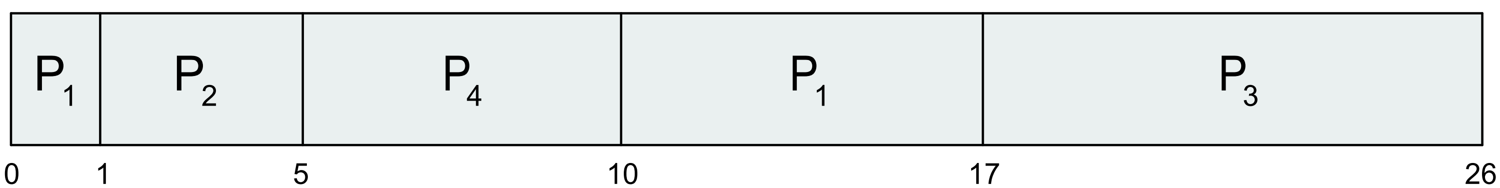
- Since both $\alpha$ and $(1 - \alpha)$ are less than or equal to 1, each successive term has less weight than its predecessor

# 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

- The next CPU burst of a newly arrived process may be shorter than what is left of the currently executing process.
- A preemptive SJF algorithm will preempt the currently executing process,
- whereas a nonpreemptive SJF algorithm will allow the currently running process to finish its CPU burst.
- Preemptive SJF scheduling is sometimes called shortest-remaining-time-first scheduling.

# 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

# Round Robin (RR)

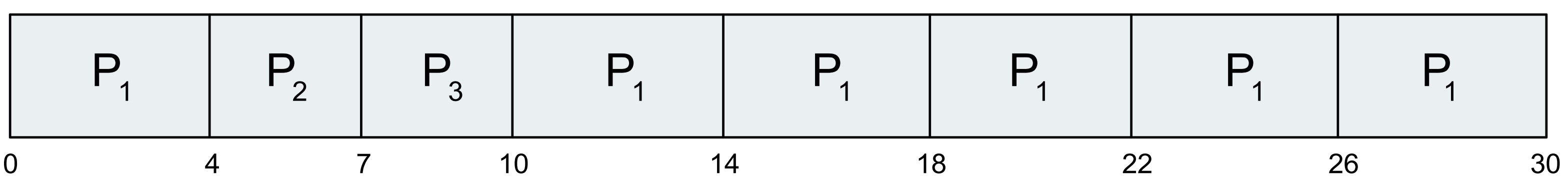
- Each process gets a small unit of CPU time (**time quantum** *q*), usually 10-100 milliseconds.
- After this time has elapsed, **the process is preempted** and **added to the end of the ready queue**.
- If there are *n* processes in the ready queue and the time quantum is *q*, then each process gets 1/*n* of the CPU time in chunks of at most *q* time units at once (because the process may release the CPU before its time slice is over).
- No process waits more than $(n-1)q$ time units until its next time quantum
- For example, with five processes and a time quantum of 20 milliseconds, each process will get up to 20 milliseconds every 100 milliseconds

- The performance of the RR algorithm depends heavily on the size of the time quantum.
  - At one extreme, if the time quantum is **extremely large**, **the RR policy s the same as the FCFS policy.**
  - In contrast, if the time quantum is **extremely small** (say, 1 millisecond), the RR approach can result in **a large number of context switches**.
- 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**
  - If the context-switch time is approximately 10 percent of the time quantum, then about 10 percent of the CPU time will be spent in context switching.

# Example of RR with Time Quantum = 4

| Process | Burst Time |
|---|---|
| $P_1$ | 24 |
| $P_2$ | 3 |
| $P_3$ | 3 |

- The Gantt chart is:

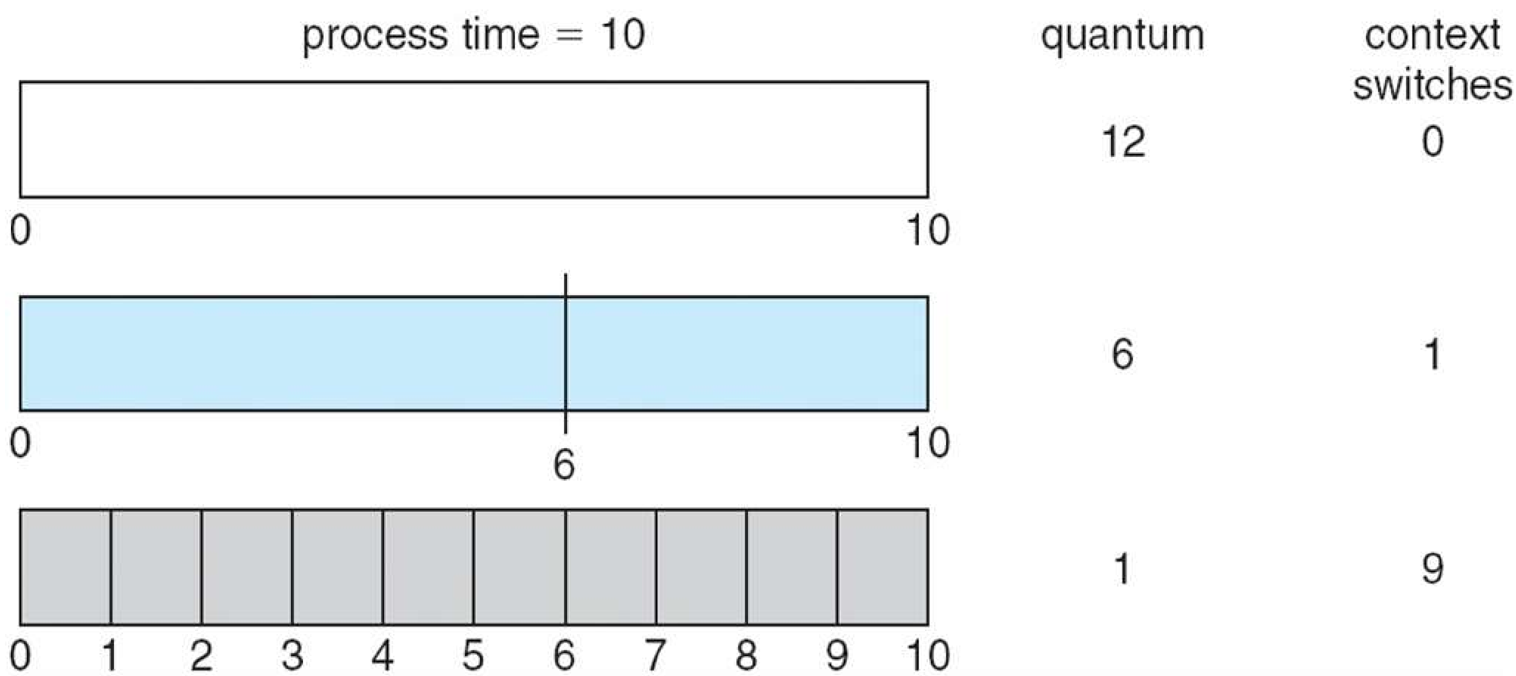



- **the average waiting time**
  - P1 waits for 6 milliseconds(10-4),
  - P2 waits for 4 milliseconds,
  - and P3 waits for 7 milliseconds.
- Thus, the average waiting time is 17/3 = 5.66 milliseconds.

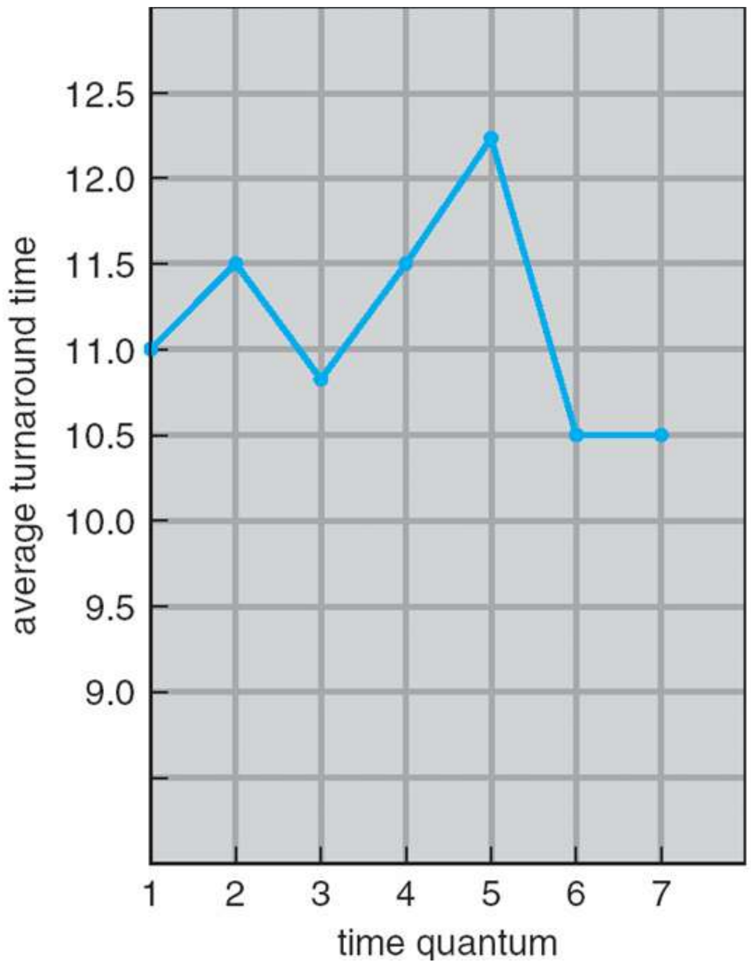
- Typically, **higher average turnaround** than SJF, but better ***response***

- q should be large compared to context switch time
- In modern machines, q is usually 10ms to 100ms, context switch < 10 ms

# Time Quantum and Context Switch Time



# Turnaround Time Varies With The Time Quantum



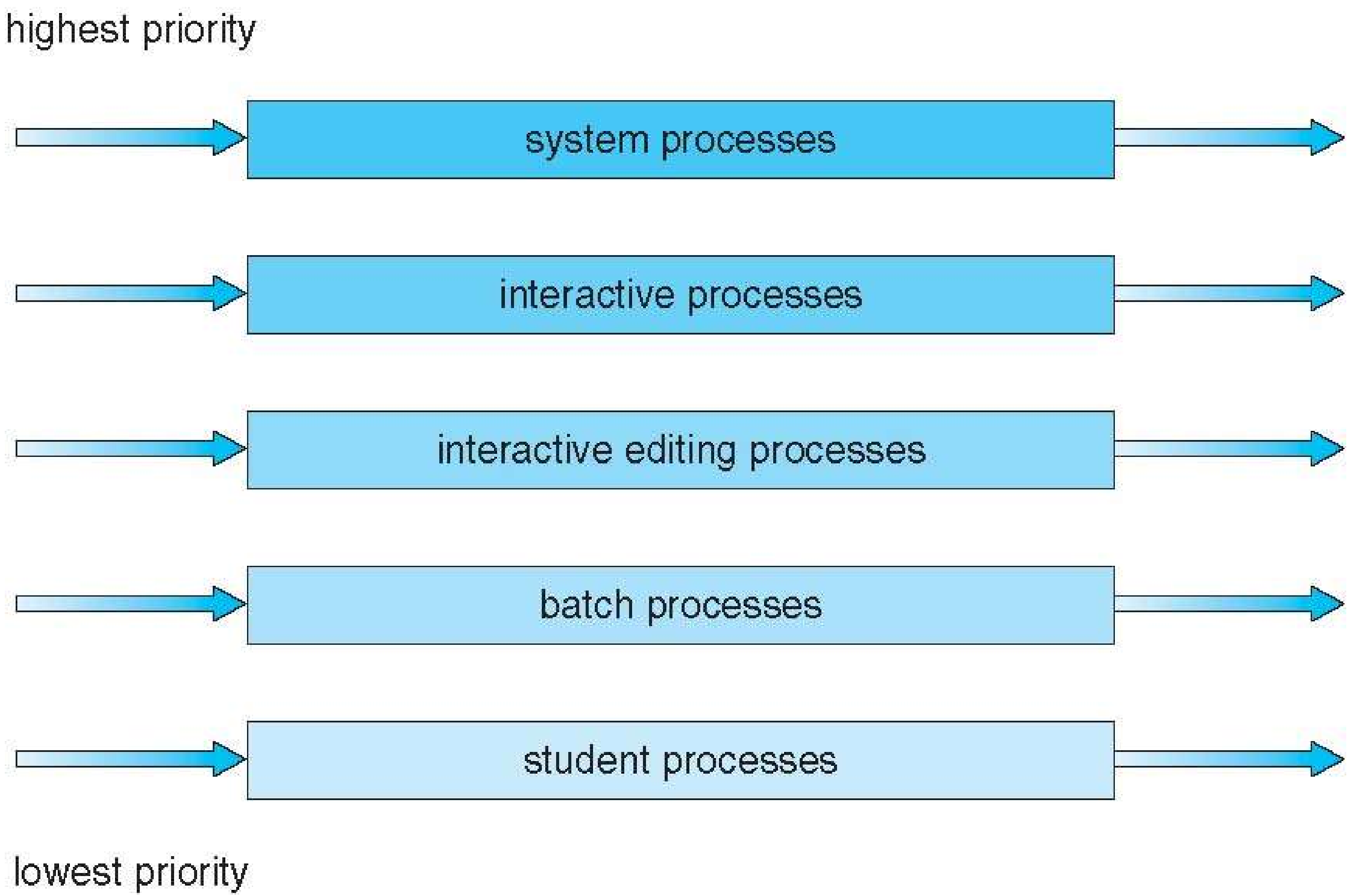

| process | time |
|---|---|
| $P_1$ | 6 |
| $P_2$ | 3 |
| $P_3$ | 1 |
| $P_4$ | 7 |

80% of CPU bursts
should be shorter than q

# Multilevel Queue

- Ready queue is partitioned into separate queues, eg:
  - **foreground** (interactive)
  - **background** (batch)
- Process permanently in a given queue
- Each queue has its own scheduling algorithm:
  - foreground – RR
  - background – FCFS
- Scheduling must be done between the queues:
  - Fixed priority 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., 80% to foreground in RR
  - 20% to background in FCFS

# Multilevel Queue Scheduling

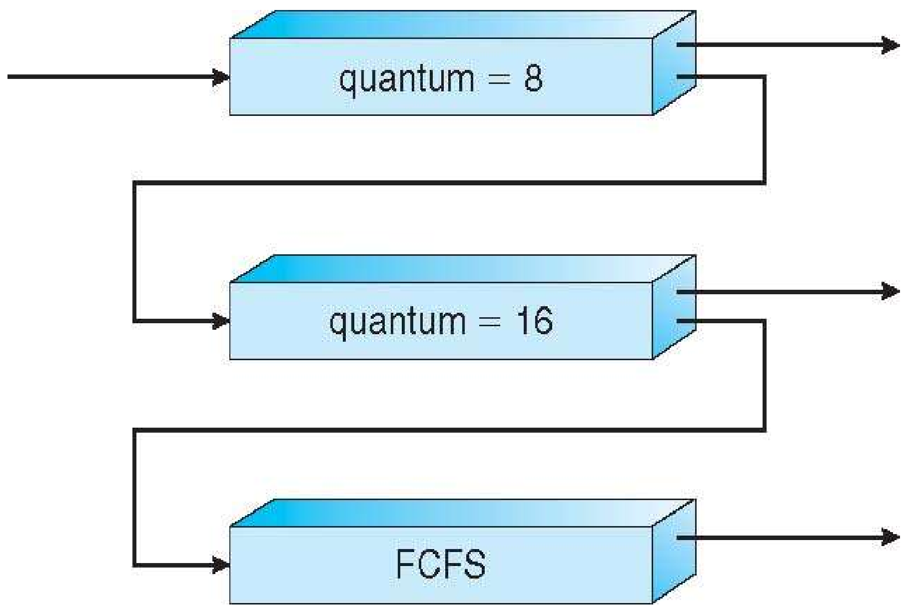


# Multilevel Feedback Queue

- 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
  - 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 $Q_2$



# 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

- API allows specifying either PCS or SCS during thread creation
  - PTHREAD_SCOPE_PROCESS schedules threads using PCS scheduling
  - PTHREAD_SCOPE_SYSTEM schedules threads using SCS scheduling
- Can be limited by OS – Linux and Mac OS X only allow PTHREAD_SCOPE_SYSTEM

# Pthread Scheduling API

```
#include <pthread.h>
#include <stdio.h>
#define NUM_THREADS 5
int main(int argc, char *argv[]) {
   int i, scope;
   pthread_t tid[NUM THREADS];
   pthread_attr_t attr;
   /* get the default attributes */
   pthread_attr_init(&attr);
   /* first inquire on the current scope */
   if (pthread_attr_getscope(&attr, &scope) != 0)
      fprintf(stderr, "Unable to get scheduling scope\n");
   else {
      if (scope == PTHREAD_SCOPE_PROCESS)
         printf("PTHREAD_SCOPE_PROCESS");
      else if (scope == PTHREAD_SCOPE_SYSTEM)
         printf("PTHREAD_SCOPE_SYSTEM");
      else
         fprintf(stderr, "Illegal scope value.\n");
   }
```

# Pthread Scheduling API

```
    /* set the scheduling algorithm to PCS or SCS */
    pthread_attr_setscope(&attr, PTHREAD_SCOPE_SYSTEM);
    /* create the threads */
    for (i = 0; i < NUM_THREADS; i++)
       pthread_create(&tid[i],&attr,runner,NULL);
    /* now join on each thread */
    for (i = 0; i < NUM_THREADS; i++)
       pthread_join(tid[i], NULL);
}
/* Each thread will begin control in this function */
void *runner(void *param)
{
    /* do some work ... */
    pthread_exit(0);
}
```

# End of Chapter 6