CSE 325: Operating Systems
3rd Year Computer Engineering
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LECTURE #7

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Chapter 6: CPU Scheduling

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Basic Concepts

Scheduling Criteria

Scheduling Algorithms

Thread Scheduling

Multiple-Processor Scheduling

Real-Time CPU Scheduling

Objectives

To introduce CPU scheduling, which is the basis for multiprogrammed operating systems

To describe various CPU-scheduling algorithms

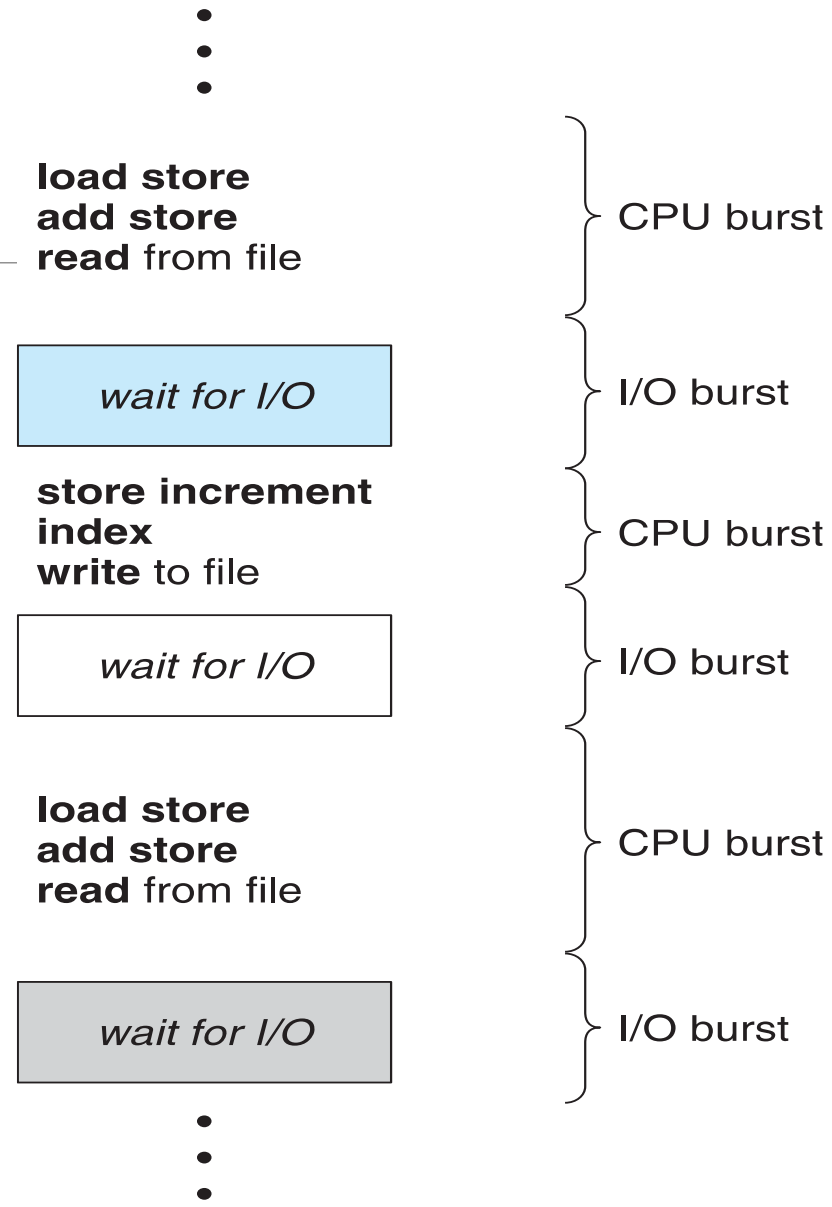
Basic Concepts

Maximum CPU utilization obtained with multiprogramming

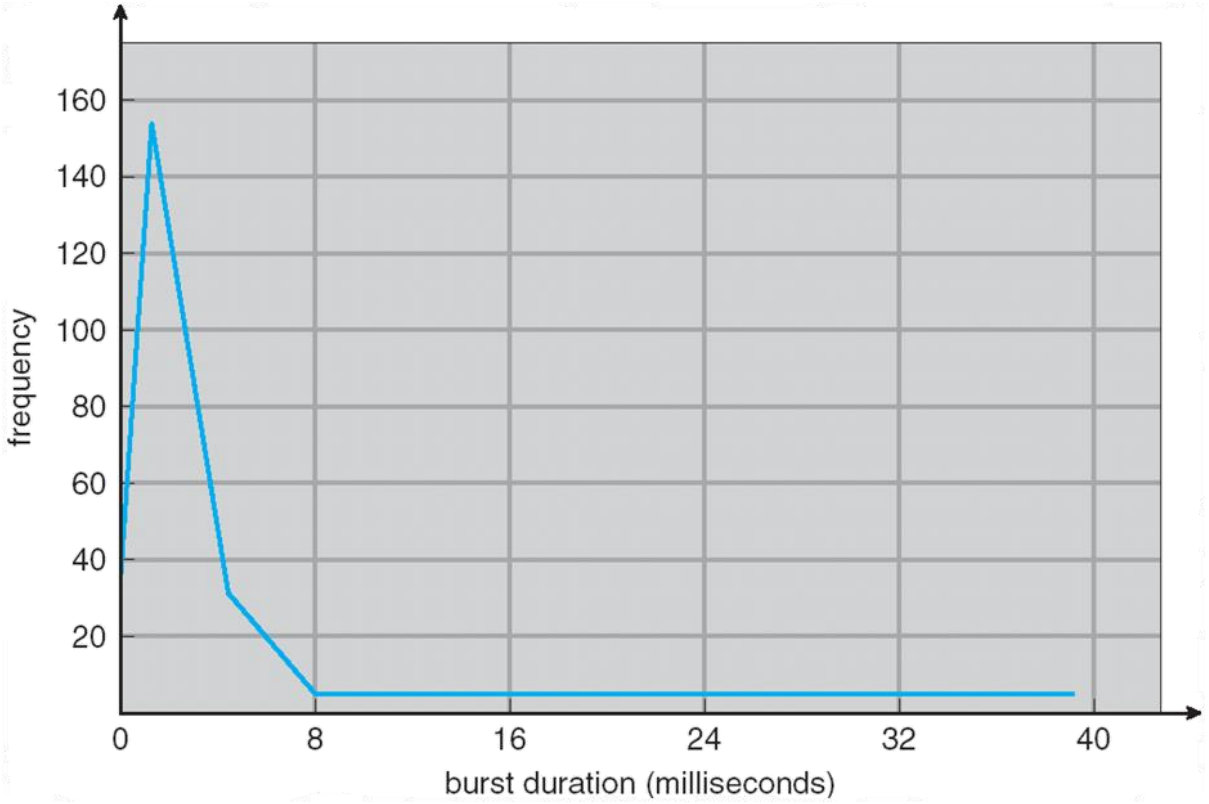
CPU–I/O Burst Cycle – Process execution consists of a cycle of CPU execution and I/O wait

CPU burst followed by I/O burst

CPU burst distribution is of main concern



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

CPU scheduling decisions may take place when a process:

1. Switches from running to waiting state
2. Switches from running to ready state
3. Switches from waiting to ready
4. Terminates

Scheduling under 1 and 4 is nonpreemptive

All other scheduling is preemptive

- Consider access to shared data
- Consider preemption while in kernel mode
- Consider interrupts occurring during crucial OS activities

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

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

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

- Max CPU utilization
- Max throughput
- Min turnaround time
- Min waiting time
- Min response time

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

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

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

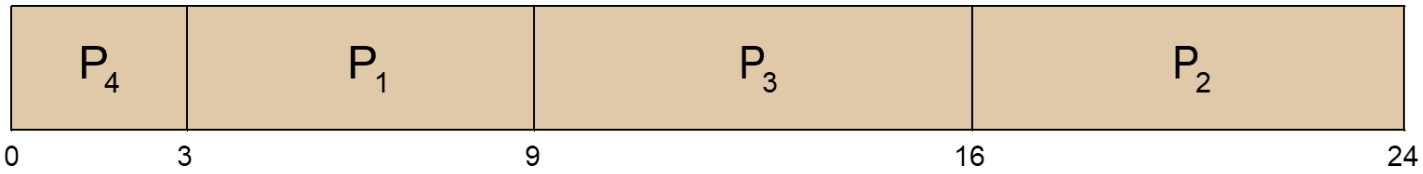
SJF is optimal – gives minimum average waiting time for a given set of processes

- The difficulty is knowing the length of the next CPU request
- Could ask the user

Example of SJF

Process	Burst Time
P1	6
P2	8
P3	7
P4	3

SJF scheduling chart



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

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

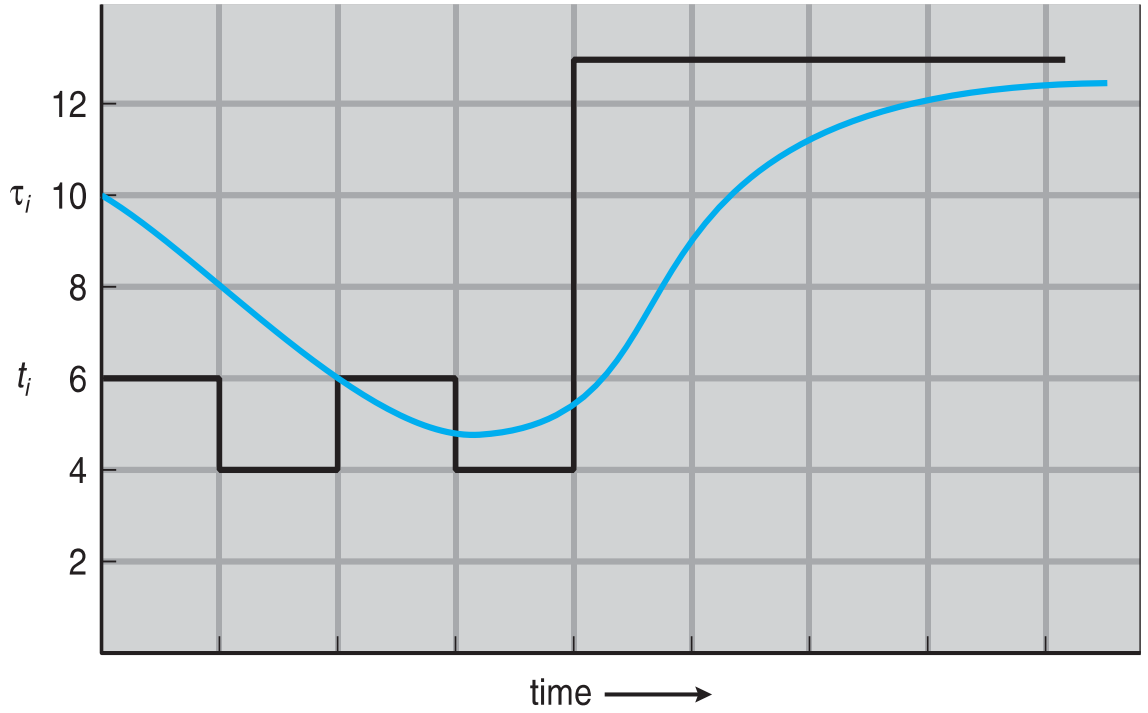
Can be done by using the length of previous CPU bursts, using exponential averaging

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

Commonly, α set to ½

Preemptive version called shortest-remaining-time-first

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

$\alpha = 0$

- $\tau_{n+1} = \tau_n$
- 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:

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

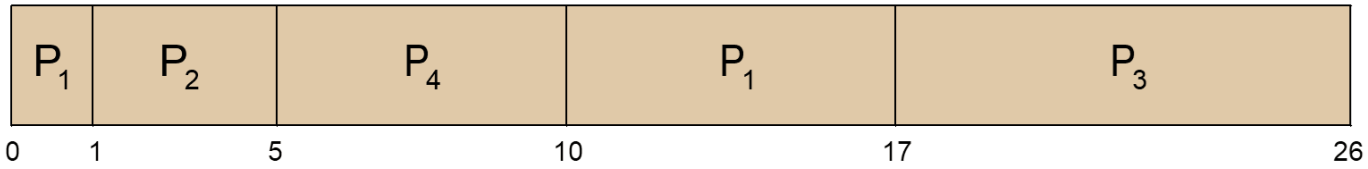
Since both α and $(1 - \alpha)$ are less than or equal to 1, each successive term has less weight than its predecessor

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
P1	0	8
P2	1	4
P3	2	9
P4	3	5

Preemptive SJF Gantt Chart



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

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

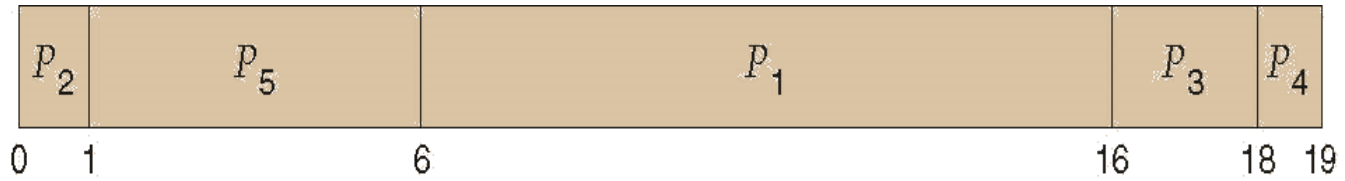
Problem ≡ Starvation – low priority processes may never execute

Solution ≡ Aging – as time progresses increase the priority of the process

Example of Priority Scheduling

Process	Burst Time	Priority
P1	10	3
P2	1	1
P3	2	4
P4	1	5
P5	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. No process waits more than (n-1)q time units.

Timer interrupts every quantum to schedule next process

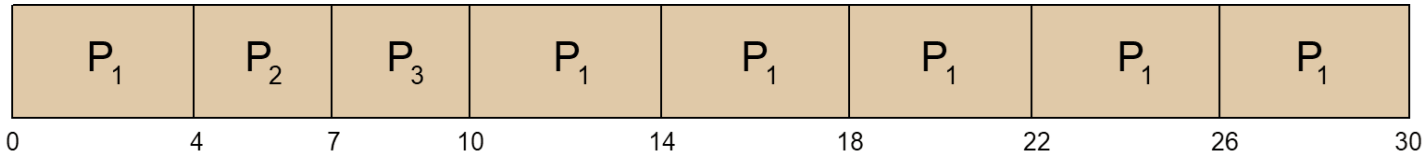
Performance

- 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
P1	24
P2	3
P3	3

The Gantt chart is:

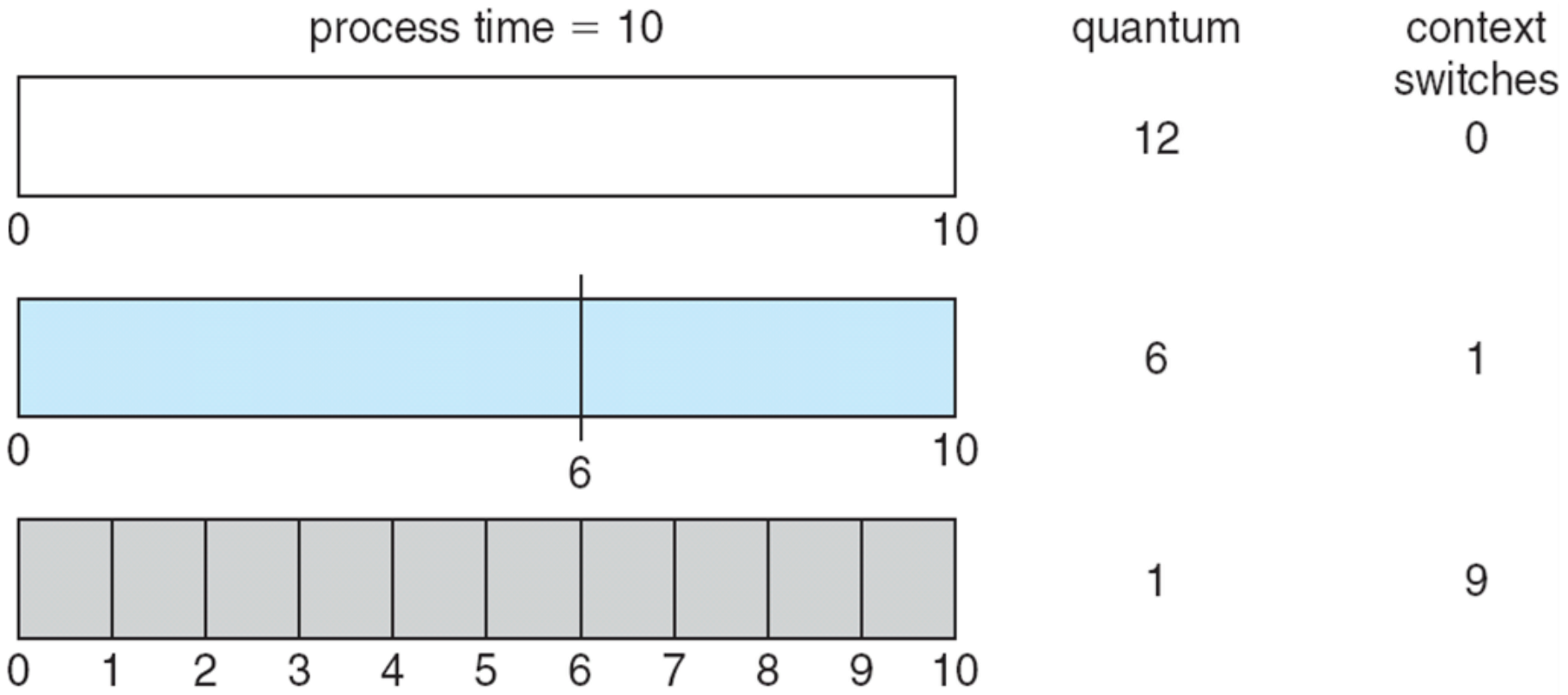


Typically, higher average turnaround than SJF, but better response

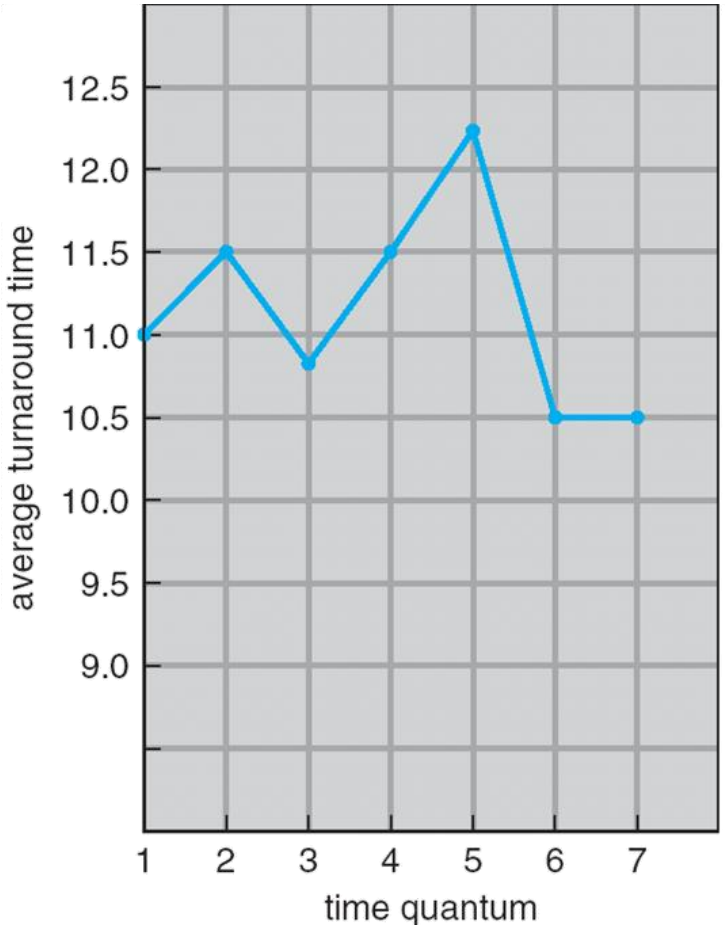
q should be large compared to context switch time

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 q

Multilevel Queue

Ready queue is partitioned into separate queues, eg:

- foreground (interactive)
- background (batch)

Process permanently in a given queue

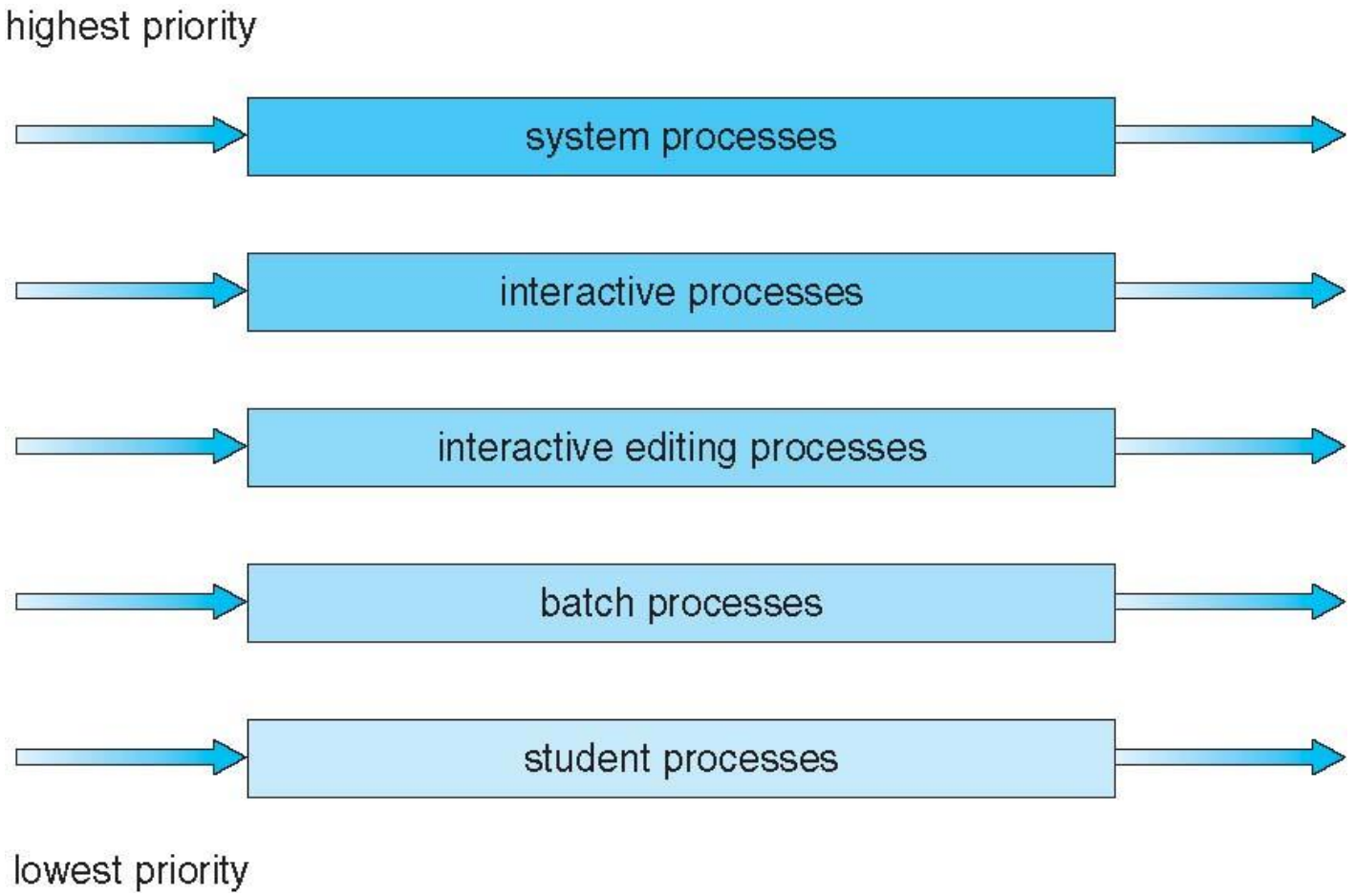
Each queue has its own scheduling algorithm:

- 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

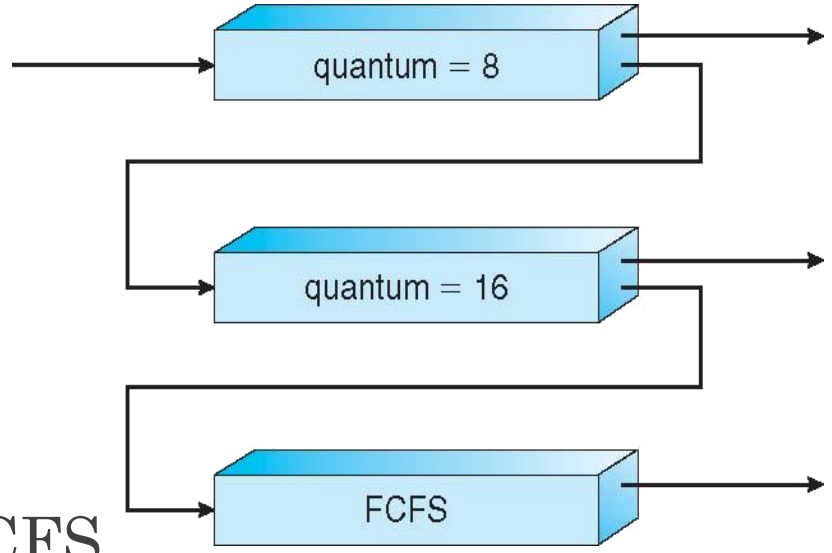
Multilevel-feedback-queue scheduler defined by the following parameters:

- 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:

- Q0 – RR with time quantum 8 milliseconds
- Q1 – RR time quantum 16 milliseconds
- Q2 – FCFS



Scheduling

- A new job enters queue Q0 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 Q1
- At Q1 job is again served FCFS and receives 16 additional milliseconds
  - If it still does not complete, it is preempted and moved to queue Q2

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);
}
```

Multiple-Processor Scheduling

CPU scheduling more complex when multiple CPUs are available

Homogeneous processors within a multiprocessor

Asymmetric multiprocessing – only one processor accesses the system data structures, alleviating the need for data sharing

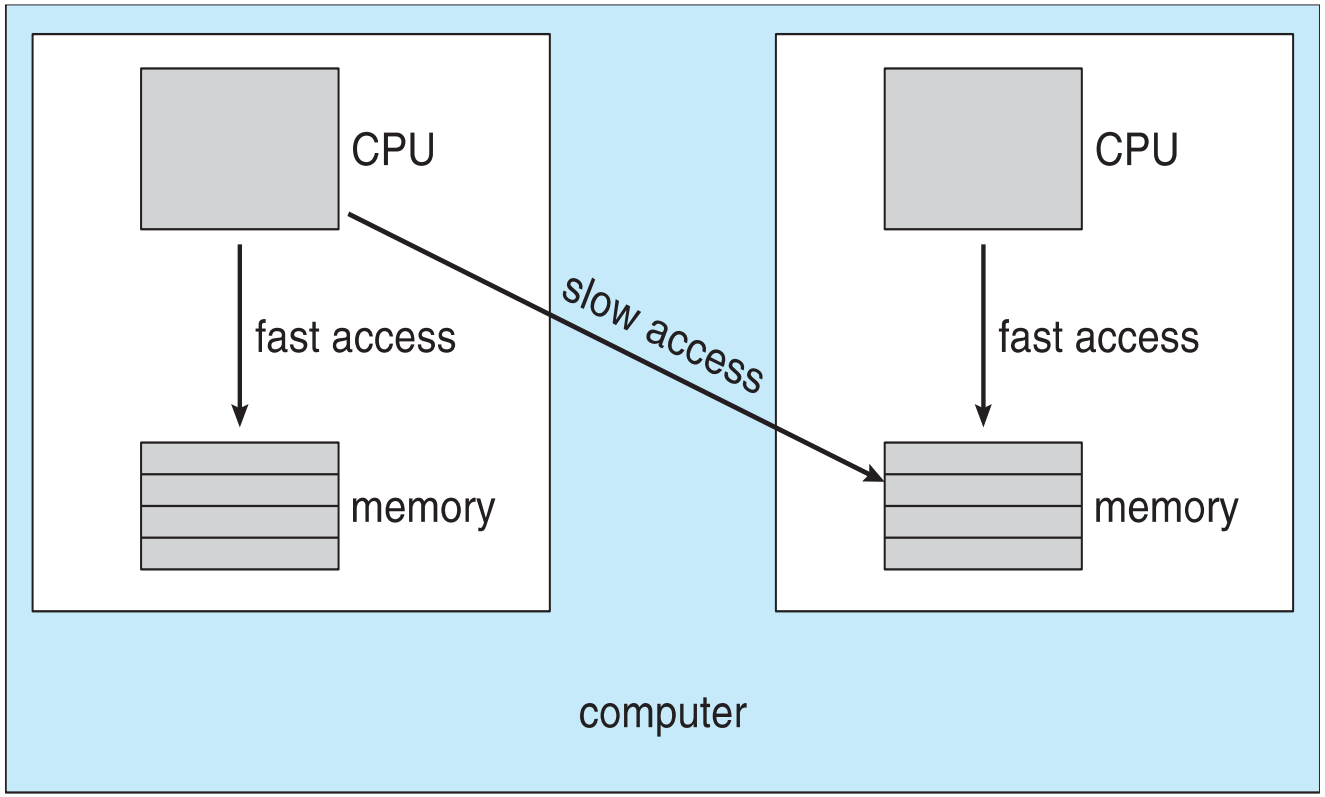
Symmetric multiprocessing (SMP) – each processor is self-scheduling, all processes in common ready queue, or each has its own private queue of ready processes

- Currently, most common

Processor affinity – process has affinity for processor on which it is currently running

- soft affinity
- hard affinity
- Variations including processor sets

NUMA and CPU Scheduling



Note that memory-placement algorithms can also consider affinity

Multiple-Processor Scheduling – Load Balancing

If SMP, need to keep all CPUs loaded for efficiency

Load balancing attempts to keep workload evenly distributed

Push migration – periodic task checks load on each processor, and if found pushes task from overloaded CPU to other CPUs

Pull migration – idle processors pulls waiting task from busy processor

Multicore Processors

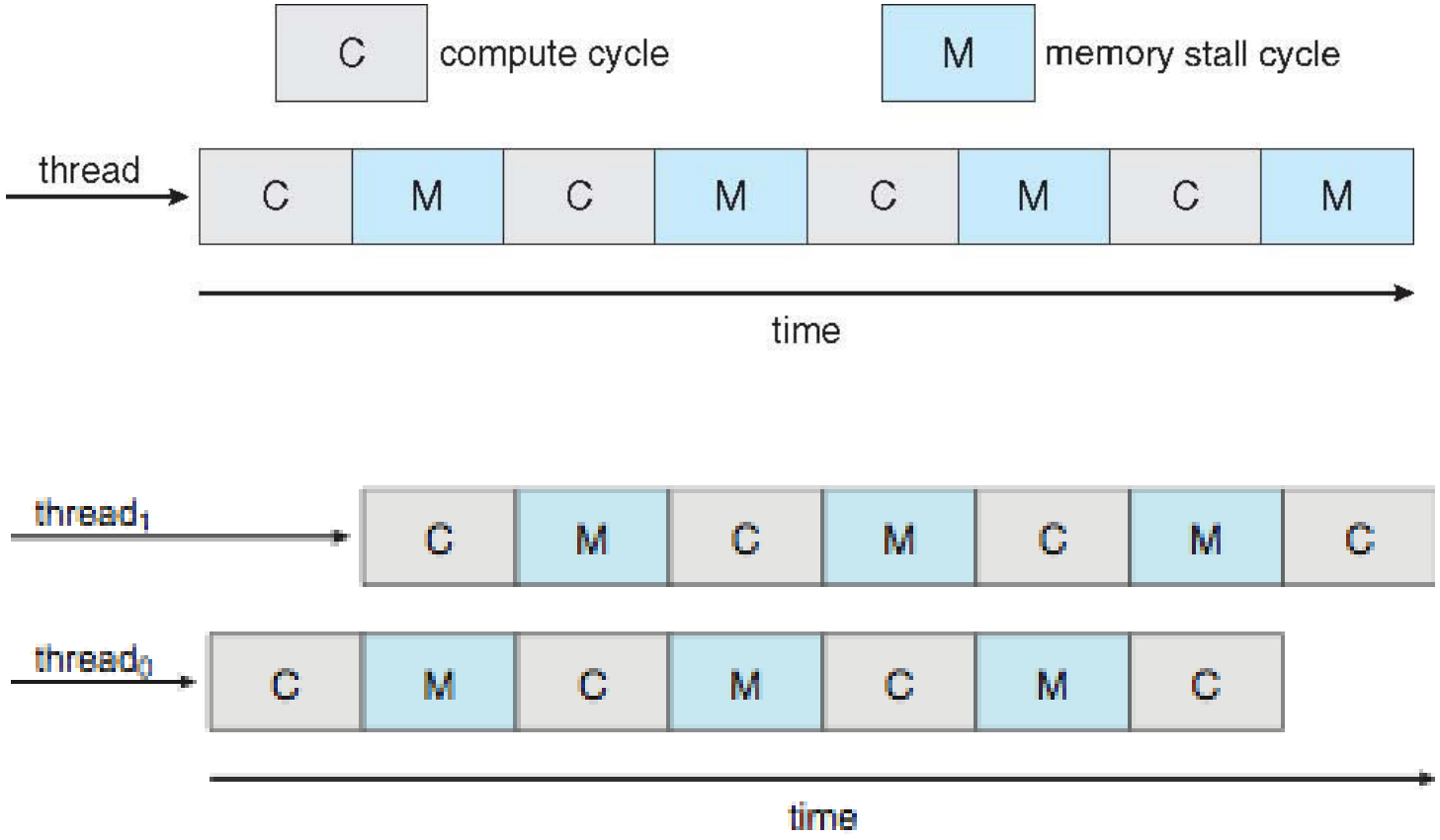
Recent trend to place multiple processor cores on same physical chip

Faster and consumes less power

Multiple threads per core also growing

- Takes advantage of memory stall to make progress on another thread while memory retrieve happens

Multithreaded Multicore System



Real-Time CPU Scheduling

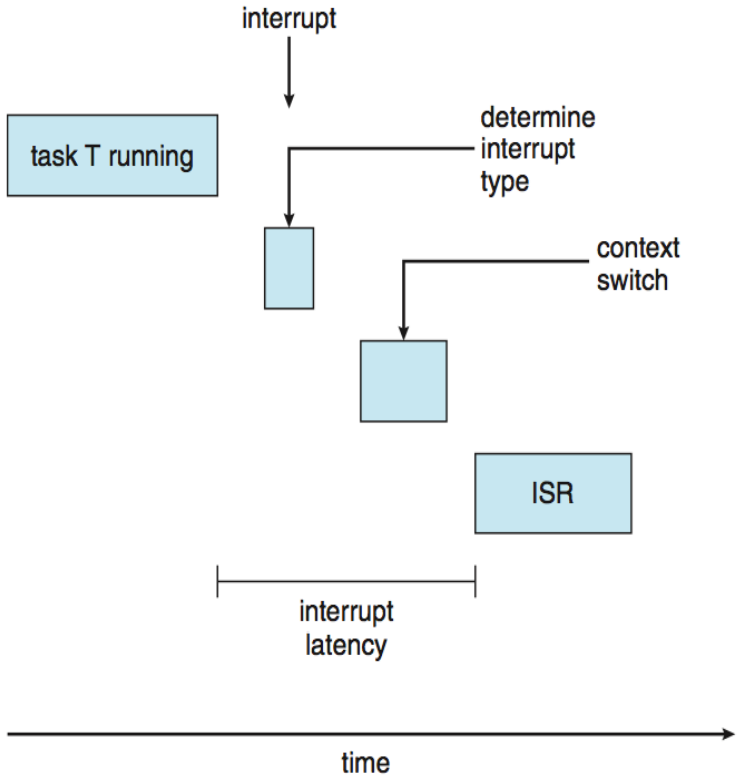
Can present obvious challenges

Soft real-time systems – no guarantee as to when critical real-time process will be scheduled

Hard real-time systems – task must be serviced by its deadline

Two types of latencies affect performance

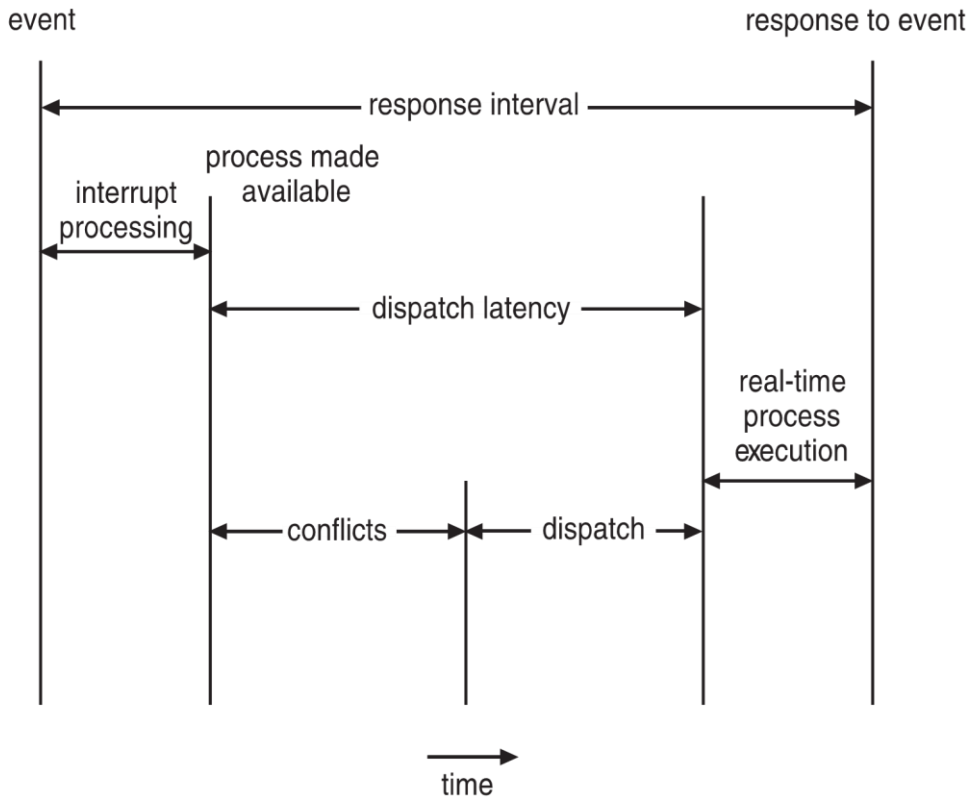
1. Interrupt latency – time from arrival of interrupt to start of routine that services interrupt
2. Dispatch latency – time for schedule to take current process off CPU and switch to another



Real-Time CPU Scheduling (Cont.)

Conflict phase of dispatch latency:

1. Preemption of any process running in kernel mode
2. Release by low-priority process of resources needed by high-priority processes



Priority-based Scheduling

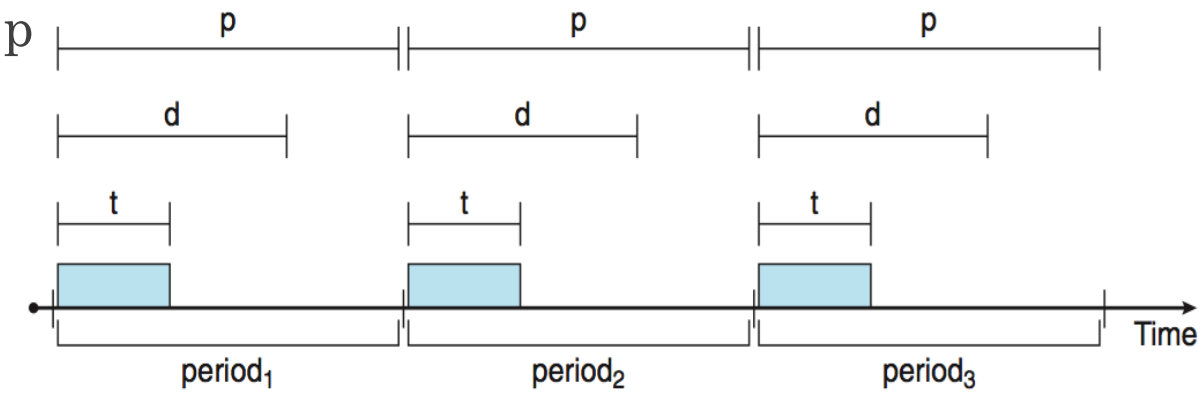
For real-time scheduling, scheduler must support preemptive, priority-based scheduling

- But only guarantees soft real-time

For hard real-time must also provide ability to meet deadlines

Processes have new characteristics: periodic ones require CPU at constant intervals

- Has processing time t, deadline d, period p
- $0 \leq t \leq d \leq p$
- Rate of periodic task is 1/p



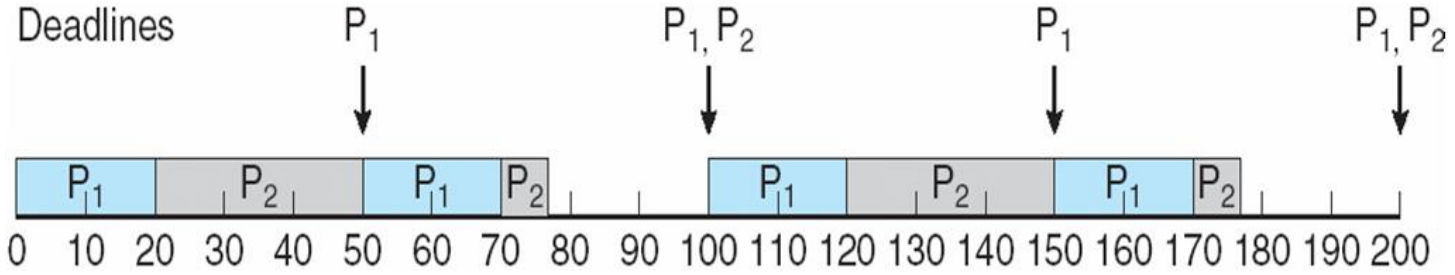
Rate Montonic Scheduling

A priority is assigned based on the inverse of its period

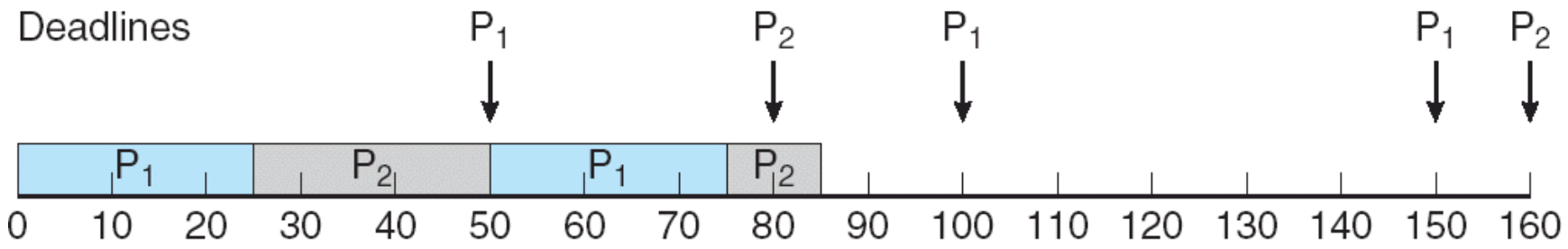
Shorter periods = higher priority;

Longer periods = lower priority

P1 is assigned a higher priority than P2.



Missed Deadlines with Rate Monotonic Scheduling

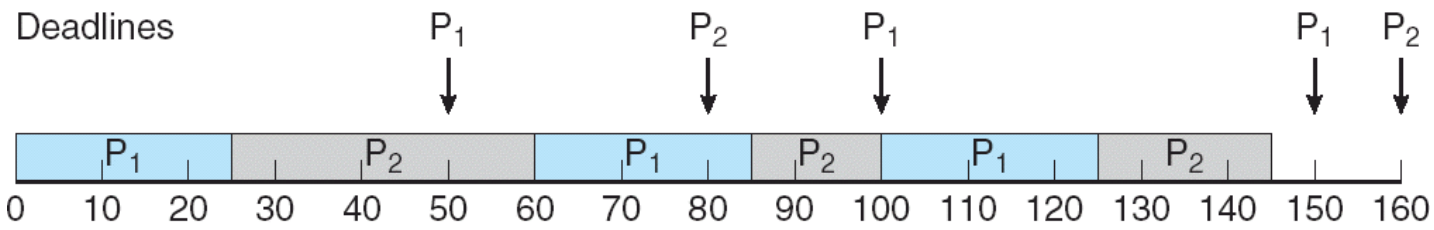


Earliest Deadline First Scheduling (EDF)

Priorities are assigned according to deadlines:

the earlier the deadline, the higher the priority;

the later the deadline, the lower the priority



Proportional Share Scheduling

T shares are allocated among all processes in the system

An application receives N shares where N < T

This ensures each application will receive N / T of the total processor time

End of Chapter 6