

Process
Management: CPU
Scheduling

Overview

Scheduling of this kind is a fundamental operating-system function.

Almost all computer resources are scheduled before use.

The CPU is, of course, one of the primary computer resources. Thus, its scheduling is central to operating-system design.

CPU Scheduler

Whenever the CPU becomes idle, the operating system must select one of the processes in the ready queue to be executed.

The selection process is carried out by the **short-term scheduler, or CPU scheduler.**

The scheduler selects a process from the processes in memory that are ready to execute and allocates the CPU to that process.

Note that the ready queue is not necessarily a first-in, first-out (FIFO) queue. As we shall see when we consider the various scheduling algorithms, a ready queue can be implemented as a FIFO queue, a priority queue, a tree, or simply an unordered linked list.

Preemptive Scheduling

CPU-scheduling decisions may take place under the following four circumstances:

1. When a process switches from the running state to the waiting state (for example, as the result of an I/O request).
2. When a process switches from the running state to the ready state (for example, when an interrupt occurs)
3. When a process switches from the waiting state to the ready state (for example, at completion of I/O)
4. When a process terminates.

When scheduling takes place only under circumstances 1 and 4, we say that the scheduling scheme is **nonpreemptive or cooperative**. Otherwise, it is **preemptive**.

Under 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.

Dispatcher

Another component involved in the CPU-scheduling function is the **dispatcher**.

The dispatcher is the module that gives control of the CPU to the process selected by the short-term scheduler.

The dispatcher should be as fast as possible, since it is invoked during every process switch. The time it takes for the dispatcher to stop one process and start another running is known as the **dispatch latency**.

Scheduling Algorithms

1) First-Come, First-Served Scheduling

By far the simplest CPU-scheduling algorithm is the **first-come, first-served (FCFS) scheduling algorithm**.

With this scheme, the process that requests the CPU first is allocated the CPU first.

The implementation of the FCFS policy is easily managed with a FIFO queue. When a process enters the ready queue, its PCB is linked onto the tail of the queue. When the CPU is free, it is allocated to the process at the head of the queue. The running process is then removed from the queue.

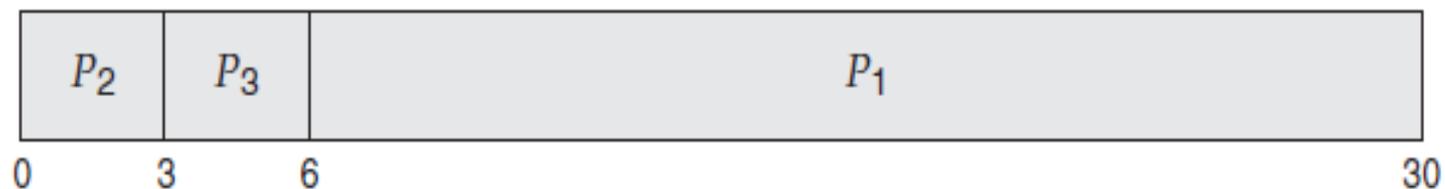
On the negative side, the average waiting time under the FCFS policy is often quite long. Consider the following set of processes that arrive at time 0, with the length of the CPU burst given in milliseconds:

<u>Process</u>	<u>Burst Time</u>
<i>P1</i>	24
<i>P2</i>	3
<i>P3</i>	3

If the processes arrive in the order P_1, P_2, P_3 , and are served in FCFS order, we get the result shown in the following **Gantt chart**, which is a bar chart that illustrates a particular schedule, including the start and finish times of each of the participating processes:



The waiting time is 0 milliseconds for process P_1 , 24 milliseconds for process P_2 , and 27 milliseconds for process P_3 . Thus, the average waiting time is $(0 + 24 + 27)/3 = 17$ milliseconds. If the processes arrive in the order P_2, P_3, P_1 , however, the results will be as shown in the following Gantt chart:



The average waiting time is now $(6 + 0 + 3)/3 = 3$ milliseconds. This reduction is substantial. 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.

In addition, consider the performance of FCFS scheduling in a dynamic situation.

Assume we have one CPU-bound process and many I/O-bound processes. As the processes flow around the system, the following scenario may result.

- ❑ The CPU-bound process will get and hold the CPU. During this time, all the other processes will finish their I/O and will move into the ready queue, waiting for the CPU.
- ❑ While the processes wait in the ready queue, the I/O devices are idle. Eventually, the CPU-bound process finishes its CPU burst and moves to an I/O device.

- ❑ All the I/O-bound processes, which have short CPU bursts, execute quickly and move back to the I/O queues. At this point, the CPU sits idle.
- ❑ The CPU-bound process will then move back to the ready queue and be allocated the CPU. Again, all the I/O processes end up waiting in the ready queue until the CPU-bound process is done.

This effect results in lower CPU and device utilization than might be possible if the shorter processes were allowed to go first.

Note that the FCFS scheduling algorithm is nonpreemptive.

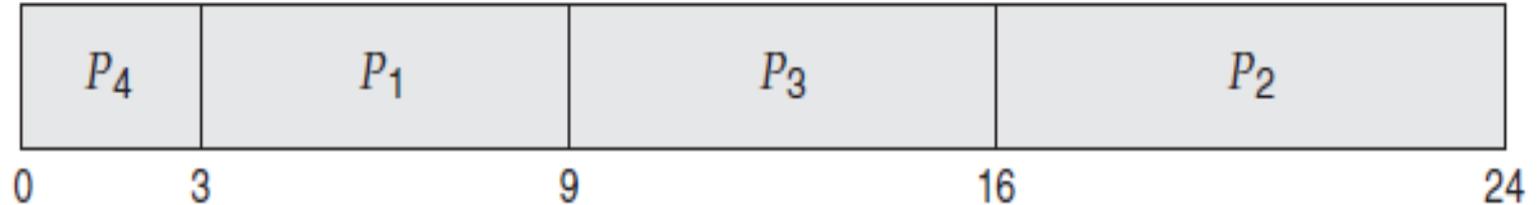
Once the CPU has been allocated to a process, that process keeps the CPU until it releases the CPU, either by terminating or by requesting I/O. The **FCFS algorithm is thus particularly troublesome for time-sharing systems**, where it is important that each user get a share of the CPU at regular intervals.

2) Shortest-Job-First Scheduling

This algorithm associates with each process the length of the process's next CPU burst. When the CPU is available, it is assigned to the process that has the smallest next CPU burst. If the next CPU bursts of two processes are the same, FCFS scheduling is used to break the tie.

<u>Process</u>	<u>Burst Time</u>
P_1	6
P_2	8
P_3	7
P_4	3

Using SJF scheduling, we would schedule these processes according to the following Gantt chart:



The waiting time is 3 milliseconds for process P_1 , 16 milliseconds for process P_2 , 9 milliseconds for process P_3 , and 0 milliseconds for process P_4 . Thus, the average waiting time is $(3 + 16 + 9 + 0)/4 = 7$ milliseconds. By comparison, if we were using the FCFS scheduling scheme, the average waiting time would be 10.25 milliseconds.

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 a long 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.

The **real difficulty** with the SJF algorithm is knowing the length of the next CPU request. It cannot be implemented, there is no way to know the length of the next CPU burst. One approach to this problem is to try to approximate SJF scheduling.

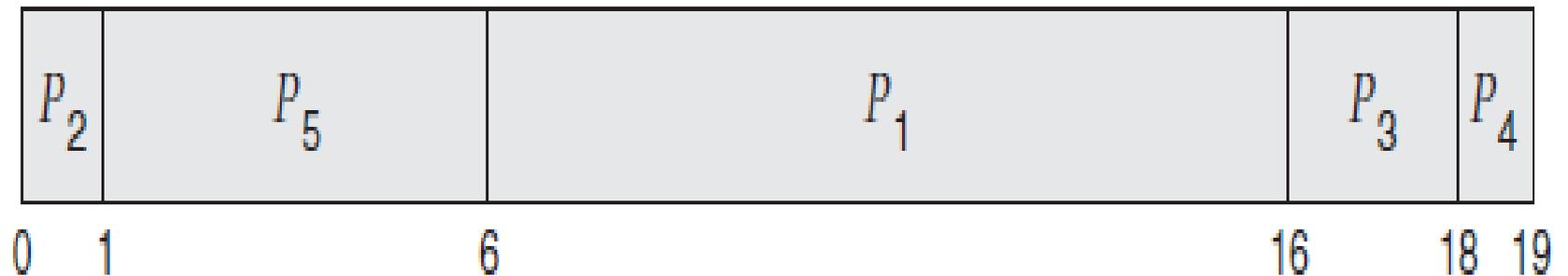
3) Priority Scheduling

A priority is associated with each process, and the CPU is allocated to the process with the highest priority. Equal-priority processes are scheduled in FCFS order.

As an **example**, consider the following set of processes, assumed to have arrived at time 0 in the order $P1, P2, \dots, P5$, with the length of the CPU burst given in milliseconds:

Process	Burst Time	Priority
$P1$	10	3
$P2$	1	1
$P3$	2	4
$P4$	1	5
$P5$	5	2

Using priority scheduling, we would schedule these processes according to the following Gantt chart:



The average waiting time is 8.2 milliseconds.

Priority scheduling can be either **preemptive or nonpreemptive**.

When a process arrives at the ready queue, its priority is compared with the priority of the currently running process.

A preemptive priority scheduling algorithm will preempt the CPU if the priority of the newly arrived process is higher than the priority of the currently running process.

A nonpreemptive priority scheduling algorithm will simply put the new process at the head of the ready queue.

A major problem with priority scheduling algorithms is **indefinite blocking**, or **starvation**.

A process that is ready to run but waiting for the CPU can be considered blocked. A priority scheduling algorithm can leave some low priority processes waiting indefinitely. In a heavily loaded computer system, a steady stream of higher-priority processes can prevent a low-priority process from ever getting the CPU.

A solution to the problem of indefinite blockage of low-priority processes is **aging**.

Aging involves gradually increasing the priority of processes that wait in the system for a long time.

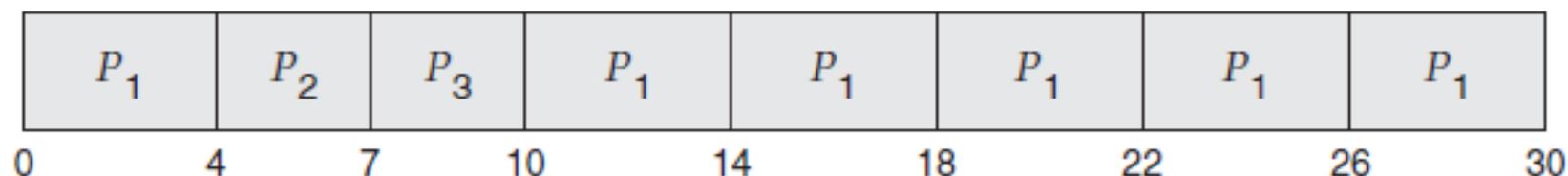
4) Round-Robin Scheduling

The **round-robin (RR) scheduling algorithm** is designed especially for timesharing systems. It is similar to FCFS scheduling, but preemption is added to enable the system to switch between processes. A small unit of time, called a **time quantum or time slice**, is defined.

The average waiting time under the RR policy is often long. Consider the following set of processes that arrive at time 0, with the length of the CPU burst given in milliseconds:

<u>Process</u>	<u>Burst Time</u>
P_1	24
P_2	3
P_3	3

If we use a time quantum of 4 milliseconds, then process P_1 gets the first 4 milliseconds. Since it requires another 20 milliseconds, it is preempted after the first time quantum, and the CPU is given to the next process in the queue, process P_2 . Process P_2 does not need 4 milliseconds, so it quits before its time quantum expires. The CPU is then given to the next process, process P_3 . Once each process has received 1 time quantum, the CPU is returned to process P_1 for an additional time quantum. The resulting RR schedule is as follows:



Let's calculate the average waiting time for this schedule. P_1 waits for 6 milliseconds ($10 - 4$), P_2 waits for 4 milliseconds, and P_3 waits for 7 milliseconds. Thus, the average waiting time is $17/3 = 5.66$ milliseconds.