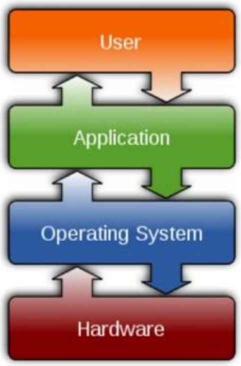
Introduction to Operating System

An operating system (OS) is the software component of a computer system that is responsible for the management and coordination of activities and the sharing of the resources of the computer. The operating system is the most important program that runs on a computer.

- Operating system is an interface between computer and user.
- It is responsible for the management and coordination of activities and the sharing of the resources of the computer.



Types of Operating System

- **Real-time operating system** is real-time operating system (RTOS) is an operating system that guarantees a certain capability within a specified time constraint. For example, an operating system might be designed to ensure that a certain object was available for a robot on an assembly line.

Real Time Operating Systems are categorized in two types i.e. Hard Real Time Operating Systems and soft Real Time Operating Systems.

• **Multi-user vs. Single-user** A multi-user operating system allows multiple users to access a computer system concurrently.

- Time-sharing system can be classified as multi-user systems as they enable a multiple user access to a computer through the sharing of time.
- Single-user operating systems, as opposed to a multi-user operating system, are usable by a single user at a time.

• Multi-tasking vs. Single-tasking:-

- When a single program is allowed to run at a time, the system is grouped under a single-tasking system
- While in case the operating system allows the execution of multiple tasks at one time, it is classified as a multi-tasking operating system.

• **Distributed**

A distributed operating system manages a group of independent computers and makes them appear to be a single computer.

The development of networked computers that could be linked and communicate with each other, gave rise to distributed computing

• Embedded

Embedded operating system (OS) is a specialized operating system designed to perform a specific task for a device that is not a computer. An embedded operating system's main job is to run the code that allows the device to do its job. he most common examples of embedded operating system around us include Windows Mobile/CE (handheld Personal Data Assistants)

Major Functions of Operating System

• **Resource management:-** The resource management function of an OS allocates computer resources such as CPU time, main memory, secondary storage, and input and output devices for use.

• **Data management** The data management functions of an OS govern the input and output of data and their location, storage, and retrieval. It also is responsible for storing and retrieving information on disk drives and for the organization of that information on the drive.

• **Job management** The job management function of an OS prepares, schedules, controls, and monitors jobs submitted for execution to ensure the most efficient processing. A job is a collection of one or more related programs and their data. Examples of Operating System

- MS-DOS
- Windows
- Mac OS
- Linux
- Solaris
- Android

PROCESSES

A process can be thought of as a program in execution. A process will need certain resources-such as CPU time, memory, files, and I/O devices-to accomplish its task. These resources are allocated to the process either when it is created or while it is executing.

A process is the unit of work in most systems. Such a system consists of a collection of processes: Operating-system processes execute system code, and user processes execute user code. All these processes may execute concurrently.
Although traditionally a process contained only a single *thread* of control as it ran, most modern operating systems now support processes that have multiple threads.

4.1. Process Concept

A batch system executes *jobs,* whereas a timeshared system has *user programs,* or *tasks.* Even on a single-user system, such as Microsoft Windows and Macintosh OS, a user may be able to run several programs at one time: a word processor, web browser, and e-mail package. Even if the user can execute only one program at a time, the operating system may need to support its own internal programmed activities, such as memory management. In many respects, all these activities are similar, so we call all of them *processes.*

4.1.1 The Process

A process is a program in execution. A process is more than the program code, which is sometimes known as the text section. It also includes the current activity, as represented by the value of the program counter and the contents of the processor's registers. In addition, a process generally includes the process stack, which contains temporary data (such as method parameters, return addresses, and local variables), and a data section, which contains global variables.

Although two processes may be associated with the same program, they are nevertheless considered two separate execution sequences. For instance, several users may be running different copies of the mail program, or the same user may invoke many copies of the editor program. Each of these is a separate process, and, although the text sections are equivalent, the data sections vary.

4.1.2 Process State

As a process executes, it changes state. The state of a process is defined in part by the current activity of that process. Each process may be in one of the following states:

- New: The process is being created.
- Running: Instructions are being executed.
- Waiting: The process is waiting for some event to occur (such as an I/O completion or reception of a signal).
- Ready: The process is waiting to be assigned to a processor.
- Terminated: The process has finished execution.

These state names are arbitrary, and they vary across operating systems. The states that they represent are found on all systems. Only one process can be *running* on any processor at any instant, although many processes may be *ready* and *waiting*. The state diagram corresponding to these states is presented in Figure 4.1.

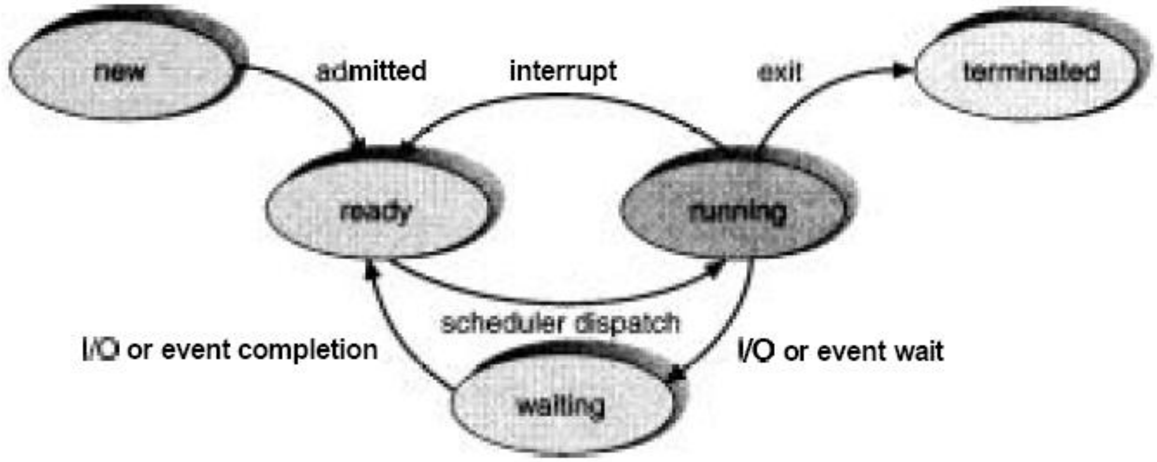


Figure 4.1 Diagram of process state.

4.1.3 Process Control Block

Each process is represented in the operating system by a **process control block** (PCB)-also called a task control block. A PCB is shown in Figure 4.2. It contains many pieces of information associated with a specific process, including these:

- **Process state:** The state may be new, ready, running, waiting, halted, and so on.
- **Program counter:** The counter indicates the address of the next instruction to be executed for this process.
- **CPU registers:** The registers vary in number and type, depending on the computer architecture. They include accumulators, index registers, stack pointers, and general-purpose registers, plus any condition-code information.

Along with the program counter, this state information must be saved when an interrupt occurs, to allow the process to be continued correctly afterward (Figure 4.3).

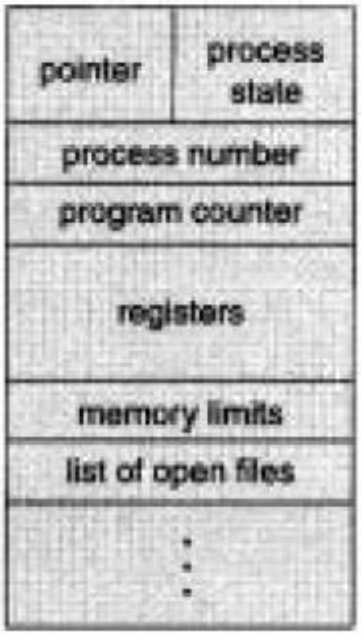


Figure 4.2 Process control block (PCB).

- **CPU-scheduling information:** This information includes a process priority, pointers to scheduling queues, and any other scheduling parameters.
- **Memory-management information:** This information may include such information as the value of the base and limit registers, the page tables, or the segment tables, depending on the memory system used by the operating system.
- **Accounting information:** This information includes the amount of CPU and real time used, time limits, account numbers, job or process numbers, and so on.

- **status information:** The information includes the list of I/O devices allocated to this process, a list of open files, and so on.

The PCB simply serves as the repository for any information that may vary
from process to process.

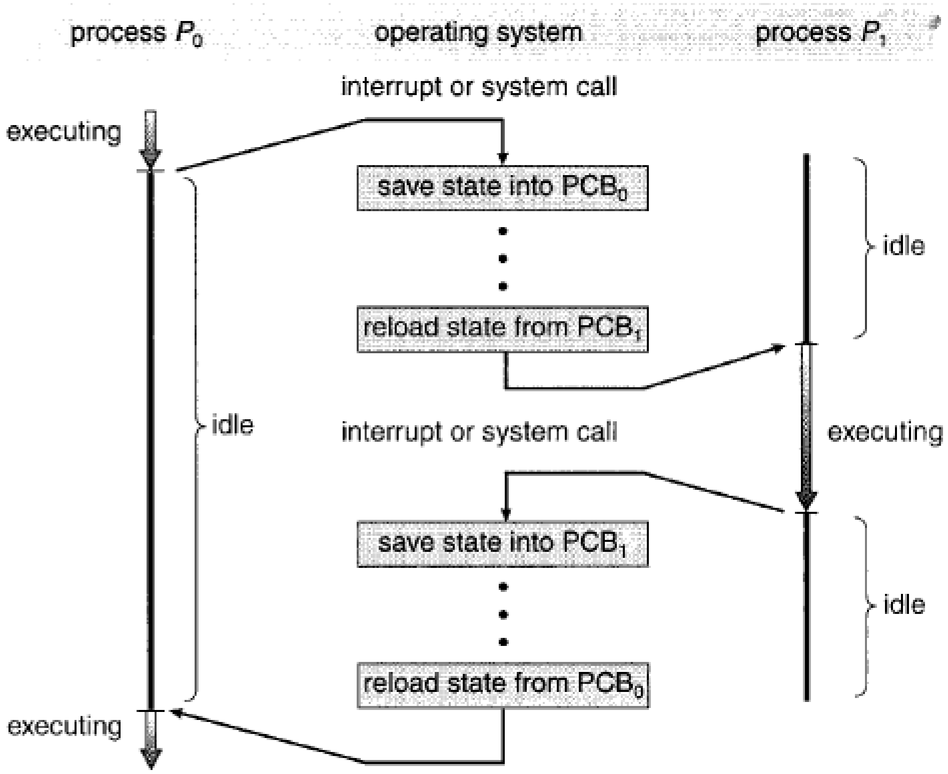


Figure 4.3 Diagram Showing CPU switch From Process to process.

4.1.4 Threads

The process model discussed so far has implied that a process is a program that performs a single thread of execution. For example, if a process is running a word-processor program, a single thread of instructions is being executed. This single thread of control allows the process to perform only one task at one time.

For example, the user could not simultaneously type in characters and run the spell checker within the same process. Many modern operating systems have extended the process concept to allow a process to have multiple threads of execution. They thus allow the process to perform more than one task at a time.

4.5 Interprocess Communication

we showed how cooperating processes can communicate in a shared-memory environment. The scheme requires that these processes share a common buffer pool, and that the code for implementing the buffer be written explicitly by the application programmer. Another way to achieve the same effect is for the operating system to provide the means for cooperating processes to communicate with each other via an interprocess communication (PC) facility.

IPC provides a mechanism to allow processes to communicate and to synchronize their actions without sharing the same address space. IPC is particularly useful in a distributed environment where the communicating processes may reside on different computers connected with a network. An example is a **chat** program used on the World Wide Web.

IPC is best provided by a message-passing system, and message systems can be defined in many ways.

4.5.1 Message-Passing System

The function of a message system is to allow processes to communicate with one another without the need to resort to shared data. In this scheme, services are provided as ordinary user processes. That is, the services operate outside of the kernel. Communication among the user processes is accomplished through the passing of messages. An IPC facility provides at least the two operations: send(message) and receive(message).

Messages sent by a process can be of either fixed or variable size. If only fixed-sized messages can be sent, the system-level implementation is straightforward. This restriction, however, makes the task of programming more difficult. On the other hand, variable-sized messages require a more complex system-level implementation, but the programming task becomes simpler.

If processes *P* and Q want to communicate, they must send messages to and receive messages from each other; a **communication link** must exist between them. This link can be implemented in a variety of ways. We are concerned here not with the link's physical implementation (such as shared memory, hardware bus, or network), but rather with its logical implementation. Here are several methods for logically implementing a link and the send/receive operations:

- Direct or indirect communication
- Symmetric or asymmetric communication
- Automatic or explicit buffering
- Send by copy or send by reference
- Fixed-sized or variable-sized messages

We look at each of these types of message systems next.

4.5.2 Naming

Processes that want to communicate must have a way to refer to each other. They can use either direct or indirect communication.

4.5.2.1 Direct Communication

With direct communication, each process that wants to communicate must explicitly name the recipient or sender of the communication. In this scheme, the **send** and **receive** primitives are defined as:

- **Send(P,message)-Send a message to process P.**
- **Receive (Q , message) -Receive a message from process Q.**

A communication link in this scheme has the following properties:

- A link is established automatically between every pair of processes that want to communicate. The processes need to know only each other's identity to communicate.
- A link is associated with exactly two processes.
- Exactly one link exists between each pair of processes.

This scheme exhibits symmetry in addressing; that is, both the sender and the receiver processes must name the other to communicate. A variant of this scheme employs asymmetry in addressing. Only the sender names the recipient; the recipient is not required to name the sender. In this scheme, the **send** and **receive** primitives are defined as follows:

- **Send(P,message)-** Send a message to process P.
- **Receive (id, message)** -Receive a **message** from any process; the variable

id is set to the name of the process with which communication has taken place.

The disadvantage in both symmetric and asymmetric schemes is the limited modularity of the resulting process definitions. Changing the name of a process may necessitate examining all other process definitions. All references to the old name must be found, so that they can be modified to the new name. This situation is not desirable from the viewpoint of separate compilation.

4.5.2.2 Indirect Communication

With indirect communication, the messages are sent to and received from mailboxes, or ports. A mailbox can be viewed abstractly as an object into which messages can be placed by processes and from which messages can be removed.

Each mailbox has a unique identification. In this scheme, a process can communicate with some other process via a number of different mailboxes.

Two processes can communicate only if they share a mailbox. The **send** and **receive** primitives are defined as follows:

- **send (A, message)** -Send a **message** to mailbox **A.**
- **receive (A, message)** -Receive a **message** from mailbox **A.**

In this scheme, a communication link has the following properties:

- A link is established between a pair of processes only if both members of the pair have a shared mailbox.
- A link may be associated with more than two processes.
- A number of different links may exist between each pair of communicating processes, with each link corresponding to one mailbox.

Now suppose that processes P1, P2, and P3 all share mailbox ***A.*** Process P1 sends a message to A, while P2 and P3 each execute a **receive** from A. Which process will receive the message sent by P1 ? The answer depends on the scheme that we choose:

- Allow a link to be associated with at most two processes.
- Allow at most one process at a time to execute a **receive** operation.
- Allow the system to select arbitrarily which process will receive the message (that is, either P2 or P3, but not both, will receive the message). The system may identify the receiver to the sender.

A mailbox may be owned either by a process or by the operating system. If the mailbox is owned by a process (that is, the mailbox is part of the address space of the process), then we distinguish between the owner (who can only receive messages through this mailbox) and the user (who can only send messages to the mailbox). Since each mailbox has a unique owner, there can be no confusion about who should receive a message sent to this mailbox. When a process that owns a mailbox terminates, the mailbox disappears. Any process that subsequently sends a message to this mailbox must be notified that the mailbox no longer exists.

On the other hand, a mailbox owned by the operating system is independent and is not attached to any particular process. The operating system then must provide a mechanism that allows a process to do the following:

- Create a new mailbox.
- Send and receive messages through the mailbox.
- Delete a mailbox.

The process that creates a new mailbox is that mailbox's owner by default. Initially, the owner is the only process that can receive messages through this mailbox. However, the ownership and receive privilege may be passed to other processes through appropriate system calls. Of course, this provision could result in multiple receivers for each mailbox.

4.5.3 Synchronization

Communication between processes takes place by calls to send and receive primitives. There are different design options for implementing each primitive. Message passing may be either blocking or nonblocking-also known as synchronous and asynchronous.

- Blocking send: The sending process is blocked until the message is received by the receiving process or by the mailbox.

- Nonblocking send: The sending process sends the message and resumes operation.
- Blocking receive: The receiver blocks until a message is available.
- Nonblocking receive: The receiver retrieves either a valid message or a null.

Different combinations of send and receive are possible.

4.5.4 Buffering

Whether the communication is direct or indirect, messages exchanged by communicating processes reside in a temporary queue. Basically, such a queue can be implemented in three ways:

- Zero capacity: The queue has maximum length 0; thus, the link cannot have any messages waiting in it. In this case, the sender must block until the recipient receives the message.
- Bounded capacity: The queue has finite length n; thus, at most n messages can reside in it. If the queue is not full when a new message is sent, the latter is placed in the queue (either the message is copied or a pointer to the message is kept), and the sender can continue execution without waiting. The link has a finite capacity, however. If the link is full, the sender must block until space is available in the queue.
- Unbounded capacity: The queue has potentially infinite length; thus, any number of messages can wait in it. The sender never blocks.

The zero-capacity case is sometimes referred to as a message system with no buffering; the other cases are referred to as automatic buffering.

CPU SCHEDULING

CPU scheduling is the basis of multiprogrammed operating systems. By switching the CPU among processes, the operating system can make the computer more productive.

6.1 Basic Concepts

The objective of multiprogramming is to have some process running at all times, in order to maximize CPU utilization. In a uniprocessor system, only one process may run at a time; any other processes must wait until the CPU is free and can be rescheduled.

The idea of multiprogramming is relatively simple. A process is executed until it must wait, typically for the completion of some I/O request. In a simple computer system, the CPU would then sit idle; all this waiting time is wasted. With multiprogramming, we try to use this time productively. Several processes are kept in memory at one time. When one process has to wait, the operating system takes the CPU away from that process and gives the CPU to another process. This pattern continues.

Scheduling 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.

6.1.1 CPU-I/O Burst Cycle

The success of CPU scheduling depends on the following observed property of processes: Process execution consists of a **cycle** of CPU execution and I/O wait. Processes alternate between these two states. Process execution begins with a **CPU**

burst. That is followed by an ***I/O* burst,** then another CPU burst, then another I/O burst, and so on. Eventually, the last CPU burst will end with a system request to terminate execution, rather than with another I/O burst (Figure 6.1). The durations of these CPU bursts have been extensively measured. Although they vary greatly by process and by computer. This distribution can help us select an appropriate CPU-scheduling algorithm.

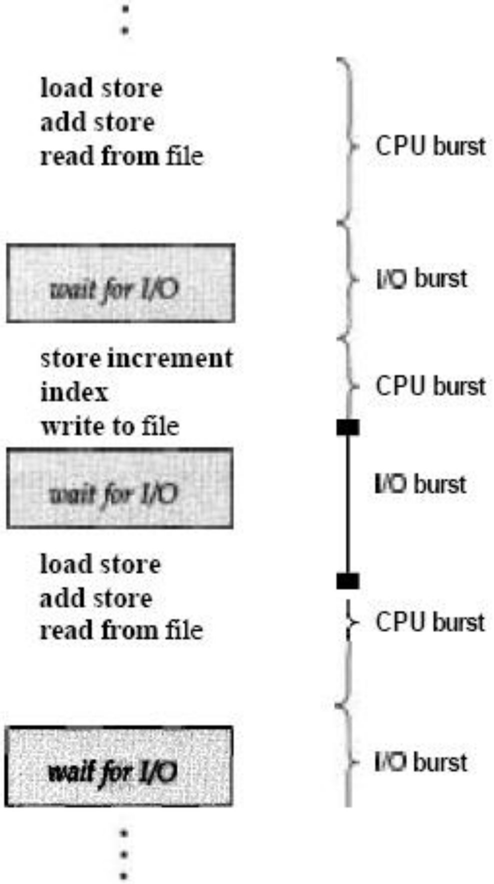


Figure 6.1 Alternating sequence of CPU and I/O bursts.

6.1.2 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 from among the processes in memory that are ready to execute, and allocates the CPU to one of them.

The ready queue is not necessarily a first-in, first-out (FIFO) queue. A ready queue may be implemented as a FIFO queue, a priority queue, a tree, or simply an unordered linked list. Conceptually, however, all the processes in the ready queue are lined up waiting for a chance to run on the CPU. The records in the queues are generally process control blocks (PCBs) of the processes.

6.1.3 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, I/O request, or invocation of wait for the termination of one of the child processes)
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, completion of I/O)
4. When a process terminates

In circumstances 1 and 4, there is no choice in terms of scheduling. **A** new process (if one exists in the ready queue) must be selected for execution. There
is a choice, however, in circumstances 2 and **3.**

When scheduling takes place only under circumstances 1 and 4, we say the scheduling scheme is **nonpreemptive;** otherwise, the scheduling scheme 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. This scheduling method is used by the Microsoft Windows 3.1 and by the Apple Macintosh operating systems. It is the only method that can be used on certain hardware platforms,because it does not require the special hardware (for example, a timer) needed for preemptive scheduling.

Preemptive scheduling incurs a cost. Consider the case of two processes sharing data. One may be in the midst of updating the data when it is preempted and the second process is run. The second process may try to read the data, which are currently in an inconsistent state. New mechanisms thus are needed to coordinate access to shared data.

Preemption also has an effect on the design of the operating-system kernel. During the processing of a system call, the kernel may be busy with an activity on behalf of a process. Such activities may involve changing important kernel data (for instance, I/O queues). What happens if the process is preempted in the middle of these changes, and the kernel (or the device driver) needs to read or modify the same structure? Chaos could ensue. Some operating systems, including most versions of UNIX, deal with this problem by waiting either for a system call to complete, or for an I/O block to take place, before doing a context switch. This scheme ensures that the kernel structure is simple, since the kernel will not preempt a process while the kernel data structures are in an inconsistent state. Unfortunately, this kernel-execution model is a poor one for supporting real-time computing and multiprocessing.

6.1.4 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. This function involves:

- Switching context
- Switching to user mode
- Jumping to the proper location in the user program to restart that program

The dispatcher should be as fast as possible, given that 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**.

6.2 . Scheduling Criteria

Different CPU-scheduling algorithms have different properties and may favor one class of processes over another. In choosing which algorithm to use in a particular situation, we must consider the properties of the various algorithms.

Many criteria have been suggested for comparing CPU-scheduling algorithms. The characteristics used for comparison can make a substantial difference in the determination of the best algorithm. The criteria include the following:

CPU utilization: We want to keep the CPU as busy as possible. CPU utilization may range from 0 to 100 percent. In a real system, it should range from 40 percent (for a lightly loaded system) to 90 percent (for a heavily used system).

Throughput: If the CPU is busy executing processes, then work is being done. One measure of work is the number of processes completed per time unit, called throughput. For long processes, this rate may be 1 process per hour; for short transactions, throughput might be 10 processes per second.

a Turnaround time: From the point of view of a particular process, the important criterion is how long it takes to execute that process. The interval from the time of submission of a process to the time of completion is the turnaround time. Turnaround time is the sum of the periods spent waiting to get into memory, waiting in the ready queue, executing on the CPU, and doing I/O.

Waiting time: The CPU-scheduling algorithm does not affect the amount of time during which a process executes or does I/O; it affects only the amount of time that a process spends waiting in the ready queue. Waiting time is the sum of the periods spent waiting in the ready queue.

a Response time: In an interactive system, turnaround time may not be the best criterion. Often, a process can produce some output fairly early, and can continue computing new results while previous results are being output to the user. Thus, another measure is the time from the submission of a request until the first response is produced. This measure, called response time, is the amount of time it takes to start responding, but not the time that it takes to output that response. The turnaround time is generally limited by the speed of the output device.

We want to maximize CPU utilization and throughput, and to minimize turnaround time, waiting time, and response time. In most cases, we optimize the average measure. However, in some circumstances we want to optimize the minimum or maximum values, rather than the average. For example, to guarantee that all users get good service, we may want to minimize the maximum response time.

For interactive systems (such as time-sharing systems), some analysts suggest that minimizing the variance in the response time is more important than minimizing the average response time. A system with reasonable and predictable response time may be considered more desirable than a system that is faster on the average, but is highly variable. However, little work has been done on CPU-scheduling algorithms to minimize variance.

6.3 Scheduling Algorithms

CPU scheduling deals with the problem of deciding which of the processes in the ready queue is to be allocated the CPU.

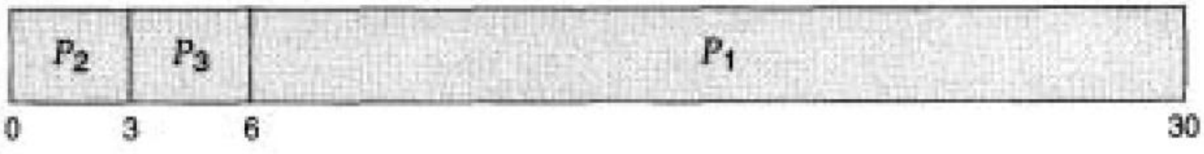
6.3.1 First-Come, First-Served Scheduling

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. 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 time given in milliseconds:

Process	Burst Time
P1	**24**
P2	**3**
P3	**3**

If the processes arrive in the order P1, P2, P3, and are served in FCFS order,we get the result shown in the following Gantt chart:

The waiting time is 0 milliseconds for process P1, **24** milliseconds for process P2, and **27** milliseconds for process P3. Thus, the average waiting time is (0 + 24 + **27)/3** = **17** milliseconds. If the processes arrive in the order P2, P3, Pl, 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 a FCFS policy is generally not minimal, and may vary substantially if the process 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. The CPU-bound process will get the CPU and hold it. During this time, all the other processes will finish their I/O and 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 very 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. the other processes wait for the one big process to get off the CPU. This effect results in lower CPU and device utilization than might be possible if the shorter processes were allowed to go first.

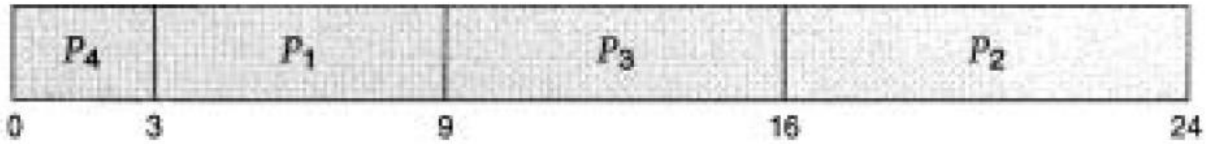
The FCFS scheduling algorithm is nonpreemptive. Once the CPU has been allocated to a process, that process keeps the CPU until it releases the CPU, either by terminating or by requesting I/O. The FCFS algorithm is particularly troublesome for time-sharing systems, where each user needs to get a share of the CPU at regular intervals. It would be disastrous to allow one process to keep the CPU for an extended period.

6.3.2 Shortest-Job-First Scheduling

A different approach to CPU scheduling is the shortest-job-first (SJF) scheduling algorithm. This algorithm associates with each process the length of the latter's next CPU burst. When the CPU is available, it is assigned to the process that has the smallest next CPU burst. If two processes have the same length next CPU burst, FCFS scheduling is used to break the tie. As an example, consider the following set of processes, with the length of the CPU-burst time given in milliseconds:

Process	Burst Time
P1	6
P2	8
p3	7
p4	3

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



The waiting time is 3 milliseconds for process P1, 16 milliseconds for process P2,9 milliseconds for process P3, and 0 milliseconds for process P4. Thus, the average waiting time is (3 + 16 + 9 + 0)/4 = 7 milliseconds. If we were using the FCFS scheduling scheme, then 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. By moving a short process before a long one, the waiting time of the short process decreases 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. For long-term (or job) scheduling in a batch system, we can use as the length the process time limit that a user specifies when he submits the job. SJF scheduling is used frequently in long-term scheduling.

Although the SJF algorithm is optimal, it cannot be implemented at the level of short-term CPU scheduling. There is no way to know the length of the next CPU burst. One approach is to try to approximate SJF scheduling. We may not know the length of the next CPU burst, but we may be able to predict its value.

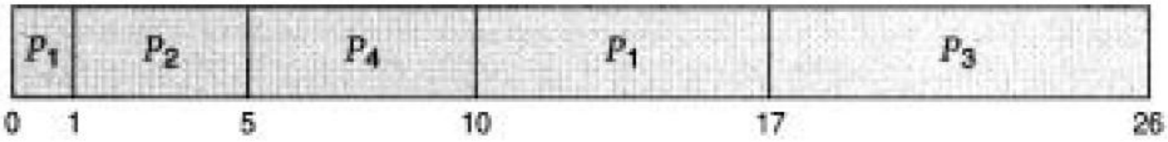
We expect that the next CPU burst will be similar in length to the previous ones. Thus, by computing an approximation of the length of the next CPU burst, we can pick the process with the shortest predicted CPU burst.

The SJF algorithm may be either *preemptive* or *nonpreemptive.* The choice arises when a new process arrives at the ready queue while a previous process is executing. The new process may have a shorter next CPU burst 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.

As an example, consider the following four processes, with the length of the CPU-burst time given in milliseconds:

Process	**Arrival Time**	**Burst Time**
P1	0	8
P2	1	4
P3	2	9
p4	3	5

If the processes arrive at the ready queue at the times shown and need the indicated burst times, then the resulting preemptive SJF schedule is as depicted in the following Gantt chart:



Process P1 is started at time 0, since it is the only process in the queue. Process P2 arrives at time 1. The remaining time for process P1 (7 milliseconds) is larger than the time required by process P2 (4 milliseconds), so process P1 is preempted, and process P2 is scheduled. The average waiting time for this example is ((10 - 1) + (1 - 1) + (17 - 2) + (5 - 3))/4 = 26/4 = 6.5 milliseconds. A nonpreemptive SJF scheduling would result in an average waiting time of 7.75 milliseconds.

6.3.3 Priority Scheduling

The SJF algorithm is a special case of the general priority-scheduling algorithm.

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.

An SJF algorithm is simply a priority algorithm where the priority (p) is the inverse of the (predicted) next CPU burst. The larger the CPU burst, the lower the priority, and vice versa.

Priorities are generally some fixed range of numbers, such as 0 to 7, or 0 to 4,095. However, there is no general agreement on whether 0 is the highest or lowest priority. Some systems use low numbers to represent low priority; others use low numbers for high priority. This difference can lead to confusion. In this text, we use low numbers to represent high priority.

As an example, consider the following set of processes, assumed to have arrived at time 0, in the order P1, P2, ..., Pn, with the length of the CPU-burst time 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 lacking the CPU can be considered blocked-waiting for the CPU. A priority-scheduling algorithm can leave some low-priority processes waiting indefinitely for the CPU. In a heavily loaded computer system, a steady stream of higher-priority processes can prevent a low-priority process from ever getting the CPU. Generally, one of two things will happen. Either the process will eventually be run, or the computer system will eventually crash and lose all unfinished low-priority processes.

A solution to the problem of indefinite blockage of low-priority processes is aging. Aging is a technique of gradually increasing the priority of processes that wait in the system for a long time. For example, if priorities range from 127 (low) to 0 (high), we could decrement the priority of a waiting process by 1 every 15 minutes. Eventually, even a process with an initial priority of 127 would have the highest priority in the system and would be executed. In fact, it would take no more than 32 hours for a priority 127 process to age to a priority 0 process.

6.3.4 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 switch between processes. A small unit of time, called a time quantum (or time slice), is defined. A time quantum is generally from 10 to 100 milliseconds. The ready queue is treated as a circular queue. The CPU scheduler goes around the ready queue, allocating the CPU to each process for a time interval of up to 1 time quantum.

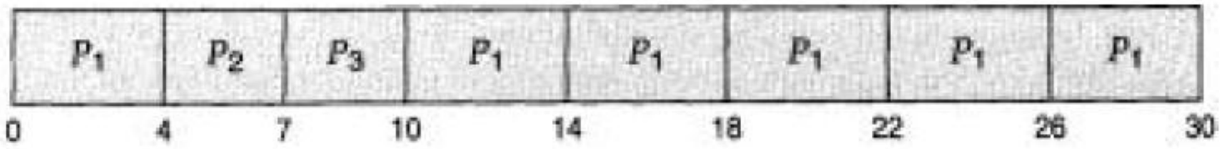
To implement RR scheduling, we keep the ready queue as a FIFO queue of processes. New processes are added to the tail of the ready queue. The CPU scheduler picks the first process from the ready queue, sets a timer to interrupt after 1 time quantum, and dispatches the process.

One of two things will then happen. The process may have a CPU burst of less than 1 time quantum. In this case, the process itself will release the CPU voluntarily. The scheduler will then proceed to the next process in the ready queue. Otherwise, if the CPU burst of the currently running process is longer than 1 time quantum, the timer will go off and will cause an interrupt to the operating system. A context switch will be executed, and the process will be put at the tail of the ready queue. The CPU scheduler will then select the next process in the ready queue.

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

Process	**Burst Time**
P1	24
P2	**3**
P3	**3**

If we use a time quantum of 4 milliseconds, then process P1 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 P2. Since process P2 does not need 4 milliseconds, it quits before its time quantum expires. The CPU is then given to the next process, process P3. Once each process has received 1 time quantum, the CPU is returned to process P1 for an additional time quantum. The resulting RR schedule is



In the RR scheduling algorithm, no process is allocated the CPU for more than ***1*** time quantum in a row. If a process' CPU burst exceeds ***1*** time quantum, that process is preempted and is put back in the ready queue. The RR scheduling algorithm is preemptive.

If there are ***n*** processes in the ready queue and the time quantum is q, then each process gets ***l/n*** of the CPU time in chunks of at most q time units. Each process must wait no longer than ***(n - 1)*** x ***q*** time units until its next time quantum. For example, if there are five processes, with a time quantum of ***20*** milliseconds, then 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 very large (infinite), the RR policy is the same as the FCFS policy. If the time quantum is very small (say ***1*** microsecond), the ***RR*** approach is called processor sharing, and appears to the users as though each of *n* processes has its own processor running at ***l/n*** the speed of the real processor.

In software, however, we need also to consider the effect of context switching on the performance of RR scheduling. Let us assume that we have only one process of 10 time units. If the quantum is 12 time units, the process finishes in less than 1 time quantum, with no overhead. If the quantum is 6 time units, however, the process requires 2 quantam, resulting in 1 context switch. If the time quantum is 1 time unit, then 9 context switches will occur, slowing the execution of the process accordingly .Thus, we want the time quantum to be large with respect to the context switch time. 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 switch.

Turnaround time also depends on the size of the time quantum. The average turnaround time of a set of processes does not necessarily improve as the time-quantum size increases. In general, the average turnaround time can be improved if most processes finish their next CPU burst in a single time quantum.

Deadlocks

In a multiprogramming environment, several processes may compete for a finite number of resources. **A** process requests resources; if the resources are not available at that time, the process enters a wait state. Waiting processes may never again change state, because the resources they have requested are held by other waiting processes. This situation is called a **deadlock.**

Necessary Conditions

A deadlock situation can arise if the following four conditions hold simultaneously in a system:

1. Mutual exclusion: At least one resource must be held in a non-sharable mode; that is, only one process at a time can use the resource. If another process requests that resource, the requesting process must be delayed until the resource has been released.

2. Hold and wait: A process must be holding at least one resource and waiting to acquire additional resources that are currently being held by other processes.

3. No preemption: Resources cannot be preempted; that is, a resource can be released only voluntarily by the process holding it, after that process has completed its task.

4. Circular wait: A set {P0, P1, ..., Pn) of waiting processes must exist such that P0 is waiting for a resource that is held by P1, P1 is waiting for a resource that is held by P2, ..., Pn-1 is waiting for a resource that is held by Pn,, and Pn, is waiting for a resource that is held by P0.

We emphasize that all four conditions must hold for a deadlock to occur. The circular-wait condition implies the hold-and-wait condition, so the four conditions are not completely independent.

Deadlock Prevention

The deadlock to occur, each of the four necessary conditions must hold. By ensuring that at least one of these conditions cannot hold, we can prevent the occurrence of a deadlock.

Mutual Exclusion

The mutual-exclusion condition must hold for non sharable resources. For example, a printer cannot be simultaneously shared by several processes. Sharable resources, on the other hand, do not require mutually exclusive access, and thus cannot be involved in a deadlock. Read-only files are a good example of a sharable resource. If several processes attempt to open a read-only file at the same time, they can be granted simultaneous access to the file. A process never needs to wait for a sharable resource. In general, however, we cannot prevent deadlocks by denying the mutual-exclusion condition: Some resources are nonsharable.

hold and Wait

To ensure that the hold-and-wait condition never occurs in the system, we must guarantee that, whenever a process requests a resource, it does not hold any other resources. One protocol that can be used requires each process to request and be allocated all its resources before it begins execution. We can implement this provision by requiring that system calls requesting resources for a process precede all other system calls.

An alternative protocol allows a process to request resources only when the process has none. A process may request some resources and use them. Before it can request any additional resources, however, it must release all the resources that it is currently allocated.

To illustrate the difference between these two protocols, we consider a process that copies data from a tape drive to a disk file, sorts the disk file, and then prints the results to a printer. If all resources must be requested at the beginning of the process, then the process must initially request the tape drive, disk file, and printer. It will hold the printer for its entire execution, even though it needs the printer only at the end.

The second method allows the process to request initially only the tape drive and disk file. It copies from the tape drive to the disk, and then releases both the tape drive and the disk file. The process must then again request the disk file and the printer. After copying the disk file to the printer, it releases these two resources and terminates.

These protocols have two main disadvantages. First, resource utilization may be low, since many of the resources may be allocated but unused for a long period. In the example given, for instance, we can release the tape drive and disk file, and then again request the disk file and printer, only if we can be sure that our data will remain on the disk file. If we cannot be assured that they will, then we must request all resources at the beginning for both protocols. Second, starvation is possible. A process that needs several popular resources may have to wait indefinitely, because at least one of the resources that it needs is always allocated to some other process.

No Preemption

The third necessary condition is that there be no preemption of resources that have already been allocated. To ensure that this condition does not hold, we can use the following protocol. If a process is holding some resources and requests another resource that cannot be immediately allocated to it (that is, the process must wait), then all resources currently being held are preempted. In other words, these resources are implicitly released. The preempted resources are added to the list of resources for which the process is waiting. The process will be restarted only when it can regain its old resources, as well as the new ones that it is requesting.

Alternatively, if a process requests some resources, we first check whether they are available. If they are, we allocate them. If they are not available, we check whether they are allocated to some other process that is waiting for additional resources. If so, we preempt the desired resources from the waiting process and allocate them to the requesting process. If the resources are not either available or held by a waiting process, the requesting process must wait.

While it is waiting, some of its resources may be preempted, but only if another process requests them. A process can be restarted only when it is allocated the new resources it is requesting and recovers any resources that were preempted while it was waiting.

This protocol is often applied to resources whose state can be easily saved and restored later, such as CPU registers and memory space. It cannot generally be applied to such resources as printers and tape drives.

Circular Wait

The fourth and final condition for deadlocks is the circular-wait condition. One way to ensure that this condition never holds is to impose a total ordering of all resource types, and to require that each process requests resources in an increasing order of enumeration.

Let R = {R1, R2, ..., Rm) be the set of resource types. We assign to each resource type a unique integer number, which allows us to compare two resources and to determine whether one precedes another in our ordering. Formally, we define a one-to-one function F: R + N, where N is the set of natural numbers. For example, if the set of resource types R includes tape drives, disk drives, and printers, then the function F might be defined as follows:

F(tape drive) = 1,

F(disk drive) = 5,

F(printer) = 12.

We can now consider the following protocol to prevent deadlocks: Each process can request resources only in an increasing order of enumeration. That is, a process can initially request any number of instances of a resource type,

say Ri. After that, the process can request instances of resource type Ri if and only if F(Rj) > F(Ri). If several instances of the same resource type are needed, a single request for all of them must be issued. For example, using the function defined previously, a process that wants to use the tape drive and printer at the same time must first request the tape drive and then request the printer.

Alternatively, we can require that, whenever a process requests an instance of resource type Rj, it has released any resources Ri such that F(Ri) >= F(Rj).

If these two protocols are used, then the circular-wait condition cannot hold.

Resource-Allocation Graph

Deadlocks can be described more precisely in terms of a directed graph called a graph. This graph consists of a set of vertices V and a set of edges E. The set of vertices V is partitioned into two different types of nodes: P == { P1, P2, ... , Pn}, the set consisting of all the active processes in the system, and R == {R1, R2, ... , Rm}, the set consisting of all resource types in the system.

A directed edge from process Pi to resource type Rj is denoted by Pi→ Rj; it signifies that process Pi has requested an instance of resource type Rj and is currently waiting for that resource. A directed edge from resource type Rj to process Pi is denoted by Rj → Pi ; it signifies that an instance of resource type R1 has been allocated to process Pi. A directed edge Pi → Rj is called a request edge; a directed edge Rj → Pi is called an assignment edge.

Pictorially we represent each process P; as a circle and each resource type Rj as a rectangle. Since resource type Ri may have more than one instance, we represent each such instance as a dot within the rectangle. Note that a request edge points to only the rectangle R1, whereas an assignment edge must also designate one of the dots in the rectangle.

When process P; requests an instance of resource type Ri, a request edge is inserted in the resource-allocation graph. When this request can be fulfilled, the request edge is instantaneously transformed to an assignment edge. When the process no longer needs access to the resource, it releases the resource; as a result, the assignment edge is deleted. The resource-allocation graph shown in Figure below depicts the following situation.

The sets P, K and E:

P == {P1, P2, P3}

R== {R1, R2, R3, R4}

$$E = \{P_1 \rightarrow R_1, P_2 \rightarrow R_3, R_1 \rightarrow P_2, R_2 \rightarrow P_2, R_2 \rightarrow P_1, R_3 \rightarrow P_3\}$$

Resource instances:

- One instance of resource type R1
- Two instances of resource type R2
- One instance of resource type R3
- Three instances of resource type R4

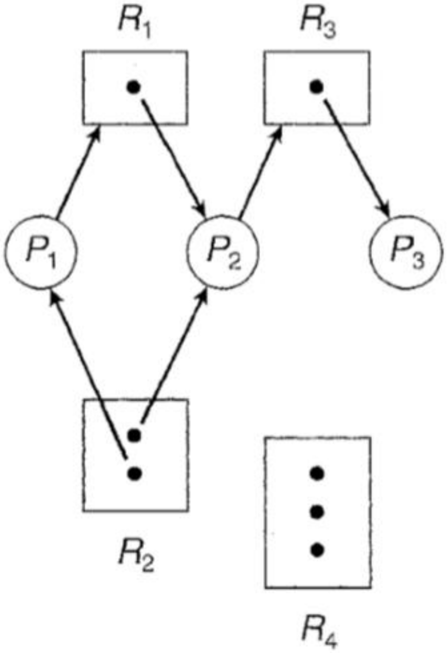


Figure (8.1): Resource Allocation Graph

Process states:

- Process P1 is holding an instance of resource type R2 and is waiting for an instance of resource type R1.

- Process P2 is holding an instance of R1 and an instance of R2 and is waiting for an instance of R3.
- Process P3 is holding an instance of R3.

Given the definition of a resource-allocation graph, it can be shown that, if the graph contains no cycles, then no process in the system is deadlocked. If the graph does contain a cycle, then a deadlock may exist. If each resource type has exactly one instance, then a cycle implies that a deadlock has occurred. If the cycle involves only a set of resource types, each of which has only a single instance, then a deadlock has occurred. Each process involved in the cycle is deadlocked. In this case, a cycle in the graph is both a necessary and a sufficient condition for the existence of deadlock. If each resource type has several instances, then a cycle does not necessarily imply that a deadlock has occurred. In this case, a cycle in. the graph is a necessary but not a sufficient condition for the existence of deadlock. To illustrate this concept, we return to the resource-allocation graph depicted in Figure 8.1 . Suppose that process P3 requests an instance of resource type R2. Since no resource instance is currently available, a request edge P3 → R2 is added to the graph (Figure 8.2). At this point, two minimal cycles exist in the system:

$$P_1 \rightarrow R_1 \rightarrow P_2 \rightarrow R_3 \rightarrow P_3 \rightarrow R_2 \rightarrow P_1$$
$$P_2 \rightarrow R_3 \rightarrow P_3 \rightarrow R_2 \rightarrow P_2$$

e

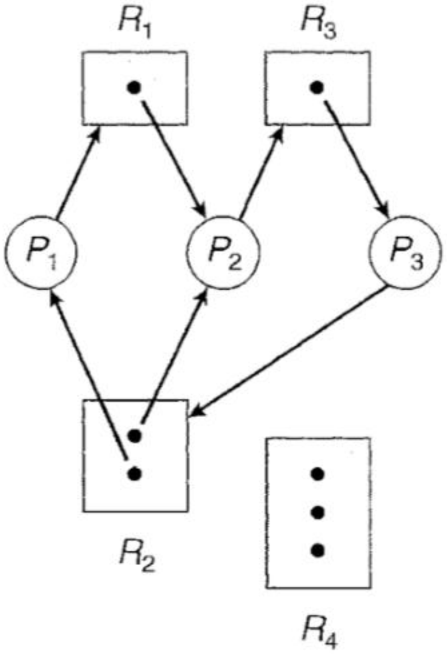


Figure 8.2 Resource allocation Graph with a deadlock

Processes P1, P2, and P3 are deadlocked. Process P2 is waiting for the resource R3, which is held by process P3. Process P3 is waiting for either process P1 or process P2 to release resource R2. In addition, process P1 is waiting for process .P2 to release resource R1. Now consider the resource-allocation graph in Figure 8.3. In this example, we also have a cycle:

$$P_1 \rightarrow R_1 \rightarrow P_3 \rightarrow R_2 \rightarrow P_1$$

However, there is no deadlock. Observe that process P4 may release its instance of resource type R2. That resource can then be allocated to P3, breaking the cycle. In summary, if a resource-allocation graph does not have a cycle, then the system is not in a deadlocked state. If there is a cycle, then the system may or may not be in a deadlocked state.

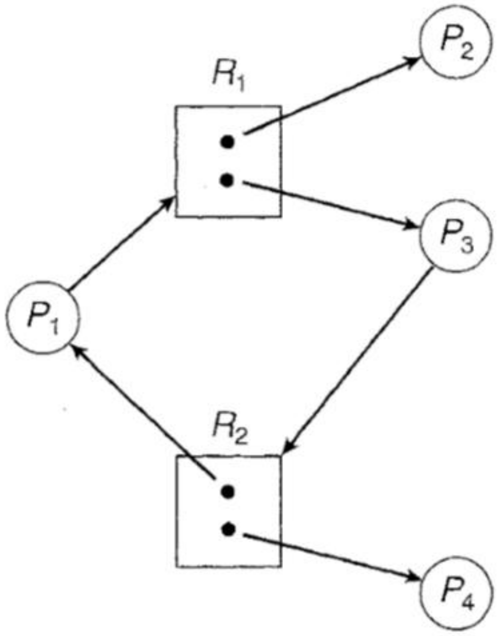


Figure 8.3 Resource-allocation graph with a cycle but no deadlock