UNIT – II

PROCESS MANAGEMENT: Process concepts- Operations on processes, IPC, Process Scheduling (**T1: Ch-3).**

PROCESS COORDINATION: Process synchronization- critical section problem, Peterson's solution, synchronization hardware, semaphores, classic problems of synchronization, readers and writers problem, dining philosopher's problem, monitors **(T1: Ch-5**).

Introduction

Process:

A **process**, which is a program in execution. A process is the unit of work in a modern time-sharing system. A system therefore consists of a collection of processes: operating system processes executing system code and user processes executing user code. Potentially, all these processes can execute concurrently, with the CPU (or CPUs) multiplexed among them. By switching the CPU between processes, the operating system can make the computer more productive.

A process is also known as job or task. 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. A process generally also includes the process **stack**, which contains temporary data (such as function parameters, return addresses, and local variables), and a **data section**, which contains global variables. A process may also include a **heap**, which is memory that is dynamically allocated during process run time. The structure of a process in memory is shown in Figure 3.1.

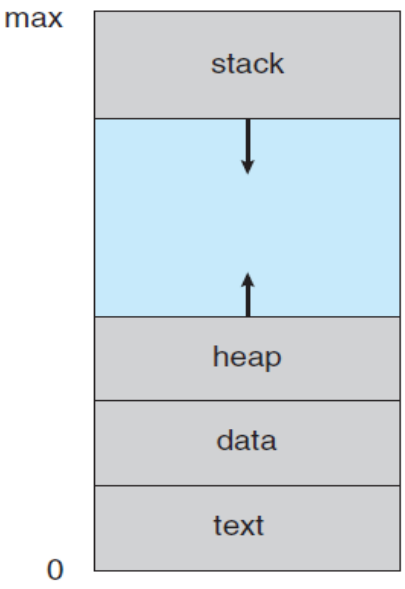


Figure 3.1 Process in memory.

We emphasize that a program by itself is not a process. A program is a ***passive*** entity, such as a file containing a list of instructions stored on disk (often called an **executable file**). In contrast, a process is an ***active*** entity, with a program counter specifying the next instruction to execute and a set of associated resources. A program becomes a process when an executable file is loaded into memory.

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. A 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.

It is important to realize that only one process can be *running* on any processor at any instant. Many processes may be *ready* and *waiting*, however. The state diagram corresponding to these states is presented in Figure 3.2.

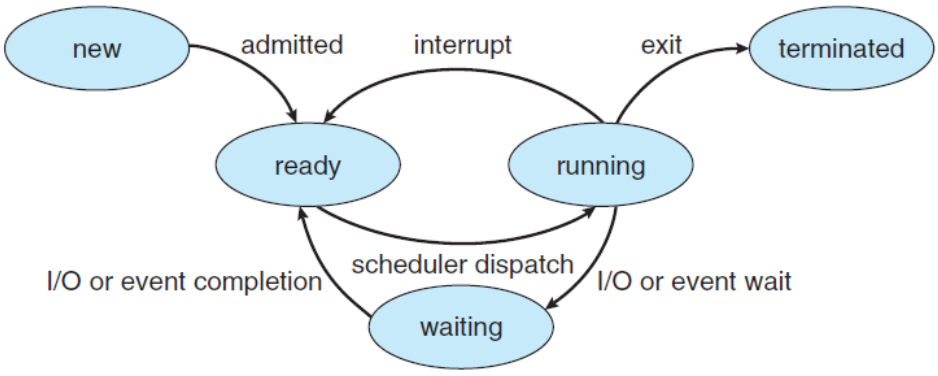


Figure 3.2 Diagram of process state.

2.3 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 3.3. It contains many pieces of information associated with a specific process, including these:

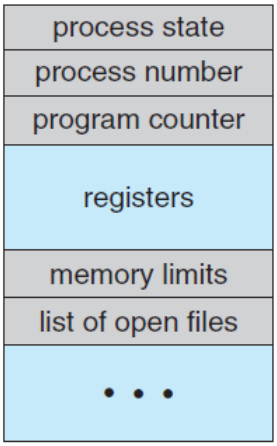


Figure 3.3 Process control block (PCB).

Process state. The state may be new, ready, running, and 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 3.4).

• **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 items as the value of the base and limit registers and 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.

• **I/O status information**. This information includes the list of I/O devices allocated to the process, a list of open files, and so on.

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

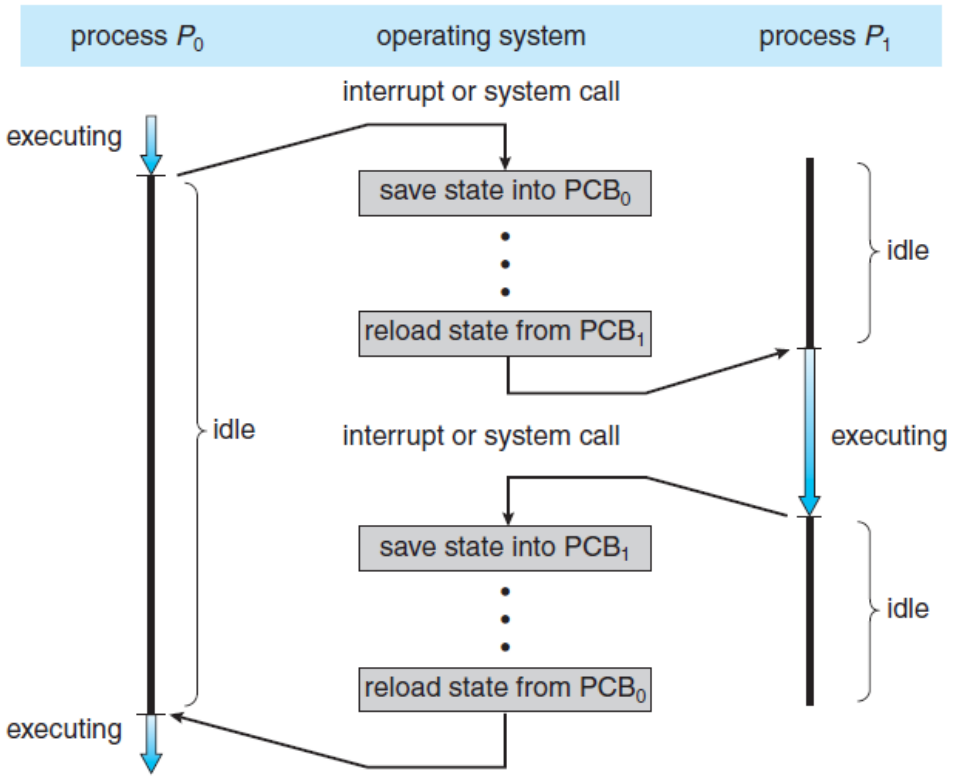


Figure 3.4 Diagram showing CPU switch from process to process.

Threads

The process model discussed so far has implied that a process is a program that performs a single **thread** of execution. For example, when 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 a time. The user cannot simultaneously type in characters and run the spell checker within the same process, for example. Most modern operating systems have extended the process concept to allow a process to have multiple threads of execution and thus to perform more than one task at a time. This feature is especially beneficial on multicore systems, where multiple threads can run in parallel.

Process	Thread
Process is considered heavy weight	Thread is considered light weight
Unit of Resource Allocation and of protection	Unit of CPU utilization
Process creation is very costly in terms of resources	Thread creation is very economical
Program executing as process are relatively slow	Programs executing using thread are comparatively faster
Process cannot access the memory area belonging to another process	Thread can access the memory area belonging to another thread within the same process
Process switching is time consuming	Thread switching is faster
One Process can contain several threads	One thread can belong to exactly one process

2.4 Operations on Processes

The processes in most systems can execute concurrently, and they may be created and deleted dynamically.

Process Creation

During the course of execution, a process may create several new processes. As mentioned earlier, the creating process is called a parent process, and the new processes are called the children of that process. Each of these new processes may in turn create other processes, forming a **tree** of processes. Most operating systems (including UNIX, Linux, and Windows) identify processes according to a unique **process identifier** (or **pid**), which is typically an integer number. The pid provides a unique value for each process in the system, and it can be used as an index to access various attributes of a process within the kernel.

When a process creates a new process, two possibilities for execution exist:

1. The parent continues to execute concurrently with its children.
2. The parent waits until some or all of its children have terminated.

Process Termination

A process terminates when it finishes executing its final statement and asks the operating system to delete it by using the exit() system call. At that point, the process may return a status value (typically an integer) to its parent process (via the wait() system call). All the

resources of the process—including physical and virtual memory, open files, and I/O buffers—are deallocated by the operating system.

A parent may terminate the execution of one of its children for a variety of reasons, such as these:

- The child has exceeded its usage of some of the resources that it has been allocated. (To determine whether this has occurred, the parent must have a mechanism to inspect the state of its children.)
- The task assigned to the child is no longer required.
- The parent is exiting, and the operating system does not allow a child to continue if its parent terminates.

Some systems do not allow a child to exist if its parent has terminated. In such systems, if a process terminates (either normally or abnormally), then all its children must also be terminated. This phenomenon, referred to as **cascading termination**, is normally initiated by the operating system. A process that has terminated, but whose parent has not yet called wait(), is known as a **zombie** process. All processes transition to this state when they terminate, but generally they exist as zombies only briefly.

2.2 Inter process Communication

Processes executing concurrently in the operating system may be either independent processes or cooperating processes. A process is ***independent*** if it cannot affect or be affected by the other processes executing in the system. Any process that does not share data with any other process is independent. A process is ***cooperating*** if it can affect or be affected by the other processes executing in the system. Clearly, any process that shares data with other processes is a cooperating process.

There are several reasons for providing an environment that allows process cooperation:

- **Information sharing**. Since several users may be interested in the same piece of information (for instance, a shared file), we must provide an environment to allow concurrent access to such information.
- **Computation speedup**. If we want a particular task to run faster, we must break it into subtasks, each of which will be executing in parallel with the others. Notice that such a speedup can be achieved only if the computer has multiple processing cores.
- **Modularity**. We may want to construct the system in a modular fashion, dividing the system functions into separate processes or threads.

- **Convenience**. Even an individual user may work on many tasks at the same time. For instance, a user may be editing, listening to music, and compiling in parallel.

Cooperating processes require an **inter process communication (IPC)** mechanism that will allow them to exchange data and information. There are two fundamental models of inter process communication: **shared memory** and **message passing**. In the shared-memory model, a region of memory that is shared by cooperating processes is established. Processes can then exchange information by reading and writing data to the shared region. In the message-passing model, communication takes place by means of messages exchanged between the cooperating processes.

The two communications models are contrasted in Figure 3.12.

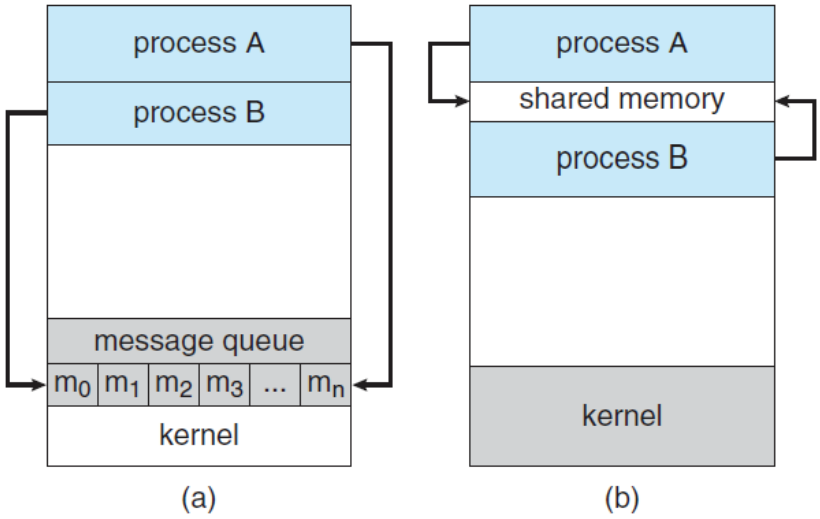
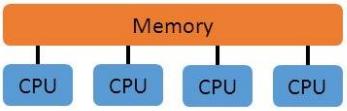


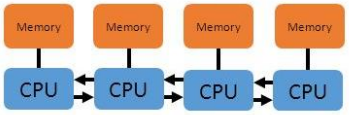
Figure 3.12 Communications models. (a) Message passing. (b) Shared memory.

Shared Memory vs. Message Passing

- **Shared Memory**
  - Implicit communication via memory operations (load/store/lock)
  - Global address space



- **Message Passing**
  - Communicate data among a set of processors without the need for a global memory
  - Each process has its own local memory and communicated with others using messages



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To illustrate the concept of cooperating processes, let's consider the producer–consumer problem, which is a common paradigm for cooperating processes. A **producer** process produces information that is consumed by a **consumer** process. For example, a compiler may produce assembly code that is consumed by an assembler. The assembler, in turn, may produce object modules that are consumed by the loader.

One solution to the producer–consumer problem uses shared memory. To allow producer and consumer processes to run concurrently, we must have available a buffer of items that can be filled by the producer and emptied by the consumer. This buffer will reside in a region of memory that is shared by the producer and consumer processes. A producer can produce one item while the consumer is consuming another item. The producer and consumer must be synchronized, so that the consumer does not try to consume an item that has not yet been produced.

Two types of buffers can be used. The **unbounded buffer** places no practical limit on the size of the buffer. The consumer may have to wait for new items, but the producer can always produce new items. The **bounded buffer** assumes a fixed buffer size. In this case, the consumer must wait if the buffer is empty, and the producer must wait if the buffer is full.

Message passing provides a mechanism to allow processes to communicate and to synchronize their actions without sharing the same address space. It is particularly useful in a distributed environment, where the communicating processes may reside on different

computers connected by a network. For example, an Internet chat program could be designed so that chat participants communicate with one another by exchanging messages. A message-passing facility provides at least two operations:

send(message) receive(message)

Messages sent by a process can be either fixed or variable in size. 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.

2.3 Process Scheduling

The objective of multiprogramming is to have some process running at all times, to maximize CPU utilization. The objective of time sharing is to switch the CPU among processes so frequently that users can interact with each program while it is running. To meet these objectives, the **process scheduler** selects an available process (possibly from a set of several available processes) for program execution on the CPU. For a single-processor system, there will never be more than one running process. If there are more processes, the rest will have to wait until the CPU is free and can be rescheduled.

Scheduling Queues

As processes enter the system, they are put into a **job queue**, which consists of all processes in the system. The processes that are residing in main memory and are ready and waiting to execute are kept on a list called the **ready queue**. This queue is generally stored as a linked list. A ready-queue header contains pointers to the first and final PCBs in the list. Each PCB includes a pointer field that points to the next PCB in the ready queue. The list of processes waiting for a particular I/O device is called a **device queue**.

A common representation of process scheduling is a **queueing diagram**, such as that in Figure 3.6. Each rectangular box represents a queue. Two types of queues are present: the ready queue and a set of device queues. The circles represent the resources that serve the queues, and the arrows indicate the flow of processes in the system.

A new process is initially put in the ready queue. It waits there until it is selected for execution, or **dispatched**. Once the process is allocated the CPU and is executing, one of several events could occur:

- The process could issue an I/O request and then be placed in an I/O queue.
- The process could create a new child process and wait for the child's termination.
- The process could be removed forcibly from the CPU, as a result of an interrupt, and be put back in the ready queue.

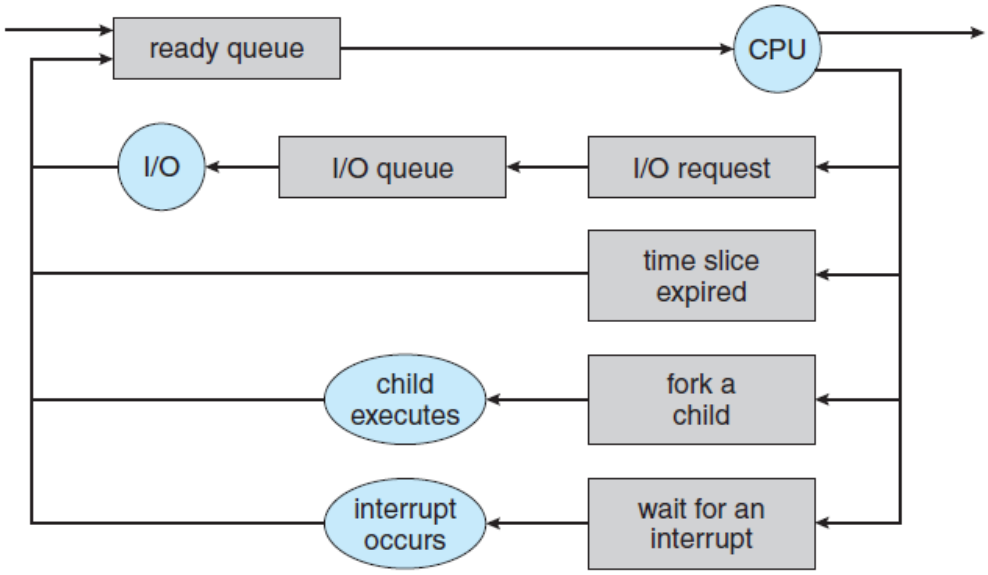


Figure 3.6 Queueing-diagram representation of process scheduling.

Schedulers

A process migrates among the various scheduling queues throughout its lifetime. The operating system must select, for scheduling purposes, processes from these queues in some fashion. The selection process is carried out by the appropriate **scheduler**.

Often, in a batch system, more processes are submitted than can be executed immediately. These processes are spooled to a mass-storage device (typically a disk), where they are kept for later execution. The **long-term scheduler**, or **job scheduler**, selects processes from this pool and loads them into memory for execution. The **short-term scheduler**, or **CPU scheduler**, selects from among the processes that are ready to execute and allocates the CPU to one of them. The long-term scheduler executes much less frequently; minutes may separate the creation of one new process and the next. The long-term scheduler controls the **degree of multiprogramming** (the number of processes in memory).

It is important that the long-term scheduler make a careful selection. In general, most processes can be described as either I/O bound or CPU bound. An **I/O-bound process** is one that spends more of its time doing I/O than it spends doing computations. A **CPU-bound process**, in contrast, generates I/O requests infrequently, using more of its time doing computations. It is important that the long-term scheduler select a good ***process mix*** of I/O-bound and CPU-bound processes. The system with the best performance will thus have a combination of CPU-bound and I/O-bound processes.

Aspects :	Long Term Scheduler	Medium Term Scheduler	Short Term Scheduler
Called as	It is a job scheduler	It is a process swapping	It is a CPU scheduler
Speed	Speed is lesser than short term scheduler	Speed is in between both short and long term scheduler	Speed is fastest among two other scheduler
Multiprogramming	It controls the degree of multiprogramming	It reduces the degree of multiprogramming	It provides lesser control over degree of multiprogramming
Time-sharing system	It is almost absent or minimal in time sharing system	It is a part of Time sharing system	It is also minimal in time sharing system
Processes	It selects processes from pool and loads them into memory for execution	It can reintroduce the process into memory and execution can be continued	It selects those processes which are ready to execute

Context Switch

Interrupts cause the operating system to change a CPU from its current task and to run a kernel routine. Such operations happen frequently on general-purpose systems. When an interrupt occurs, the system needs to save the current **context** of the process running on the CPU so that it can restore that context when its processing is done, essentially suspending the process and then resuming it.

Switching the CPU to another process requires performing a state save of the current process and a state restore of a different process. This task is known as a **context switch**. When a context switch occurs, the kernel saves the context of the old process in its PCB and loads the saved context of the new process scheduled to run. Context-switch times are highly dependent on hardware support.

2.4 Process synchronization

A situation where several processes access and manipulate the same data concurrently and the outcome of the execution depends on the particular order in which the access takes place, is called a **race condition**. To guard against the race condition we need to ensure that only one process at a time can be manipulating the variable counter. To make such a guarantee, we require that the processes be synchronized in some way.

2.4.1 The Critical-Section Problem

We begin our consideration of process synchronization by discussing the so called critical-section problem. Consider a system consisting of *n* processes {*P*0, *P*1, ..., *Pn*−1}. Each process has a segment of code, called a **critical section**, in which the process may be changing common variables, updating a table, writing a file, and so on. The important feature of the system is that, when one process is executing in its critical section, no other process is allowed to execute in its critical section. That is, no two processes are executing in their critical sections at the same time. The ***critical-section problem*** is to design a protocol that the processes can use to cooperate. Each process must request permission to enter its critical section.

The section of code implementing this request is the **entry section**. The critical section may be followed by an **exit section**. The remaining code is the **remainder section**. The general structure of a typical process *Pi* is shown in Figure 5.1. The entry section and exit section are enclosed in boxes to highlight these important segments of code.

```
do {
        entry section
            critical section
        exit section
            remainder section
} while (true);
```

Figure 5.1 General structure of a typical process P_i.

A solution to the critical-section problem must satisfy the following three requirements:

1. **Mutual exclusion**. If process *Pi* is executing in its critical section, then no other processes can be executing in their critical sections.
2. **Progress**. If no process is executing in its critical section and some processes wish to enter their critical sections, then only those processes that are not executing in their remainder sections can participate in deciding which will enter its critical section next, and this selection cannot be postponed indefinitely.
3. **Bounded waiting**. There exists a bound, or limit, on the number of times that other processes are allowed to enter their critical sections after a process has made a request to enter its critical section and before that request is granted.

Two general approaches are used to handle critical sections in operating systems:

1) **Preemptive kernels** and
2) **non-Preemptive kernels**.

A preemptive (**preemption** is the act of temporarily interrupting a task being carried out by a **computer** system) kernel allows a process to be preempted while it is running in kernel mode. A nonpreemptive kernel does not allow a process running in kernel mode to preempted; a kernel-mode process will run until it exits kernel mode, blocks, or voluntarily yields control of the CPU.

2.4.2 Peterson's Solution

A classic software-based solution to the critical-section problem known as **Peterson's solution**. Because of the way modern computer architectures perform basic machine-language instructions, such as load and store, there are no guarantees that Peterson's solution will work correctly on such architectures. However, we present the solution because it provides a good algorithmic description of solving the critical-section problem and illustrates some of the complexities involved in designing software that addresses the requirements of mutual exclusion, progress, and bounded waiting.

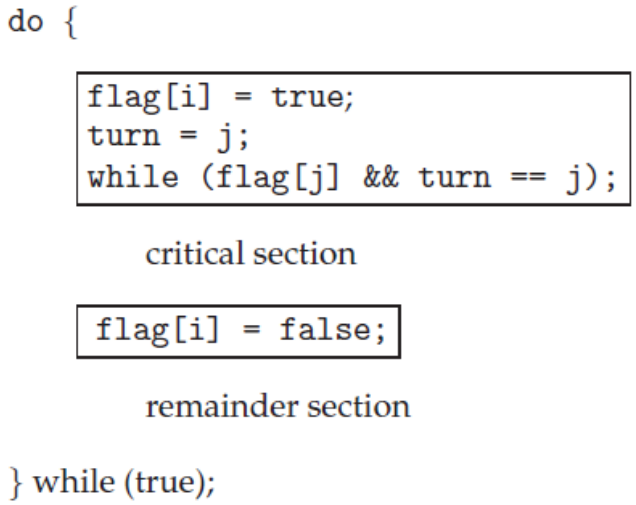


Figure 5.2 The structure of process P_i in Peterson's solution.

Peterson's Solution is a classical software based solution to the critical section problem. In Peterson's solution, we have two shared variables:

boolean flag[i] :Initialized to FALSE, initially no one is interested in entering the critical section

int turn : The process whose turn is to enter the critical section.

```
// code for producer (j)
// producer j is ready
// to produce an item
flag[j] = true;

// but consumer (i) can consume an item
turn = i;

// if consumer is ready to consume an item
// and if its consumer's turn
while (flag[i] == true && turn == i)
    {
// then producer will wait }
    // otherwise producer will produce
   // an item and put it into buffer (critical Section)
```

```
   // Now, producer is out of critical section
   flag[j] = false;
   // end of code for producer
   //---------------------------------------------------------
   // code for consumer i
   // consumer i is ready
   // to consume an item
   flag[i] = true;
   // but producer (j) can produce an item
   turn = j;

   // if producer is ready to produce an item
   // and if its producer's turn
   while (flag[j] == true && turn == j)
      {
// then consumer will wait }
      // otherwise consumer will consume
      // an item from buffer (critical Section)
      // Now, consumer is out of critical section
      flag[i] = false;
// end of code for consumer
```

Explanation of Peterson's algorithm –

Peterson's Algorithm is used to synchronize two processes. It uses two variables, a bool array flag of size 2 and an int variable turn to accomplish it. In the solution i represents the Consumer and j represents the Producer. Initially the flags are false. When a process wants to execute it's critical section, it sets it's flag to true and turn as the index of the other process. This means that the process wants to execute but it will allow the other process to run first. The process performs busy waiting until the other process has finished it's own critical section.

After this the current process enters it's critical section and adds or removes a random number from the shared buffer. After completing the critical section, it sets it's own flag to false, indication it does not wish to execute anymore.

Synchronization Hardware

However, as mentioned, software-based solutions such as Peterson's are not guaranteed to work on modern computer architectures. In the following discussions, we explore several more solutions to the critical-section problem using techniques ranging from hardware to software-based APIs available to both kernel developers and application programmers. All these solutions are based on the premise of **locking** —that is, protecting critical regions through the use of locks.

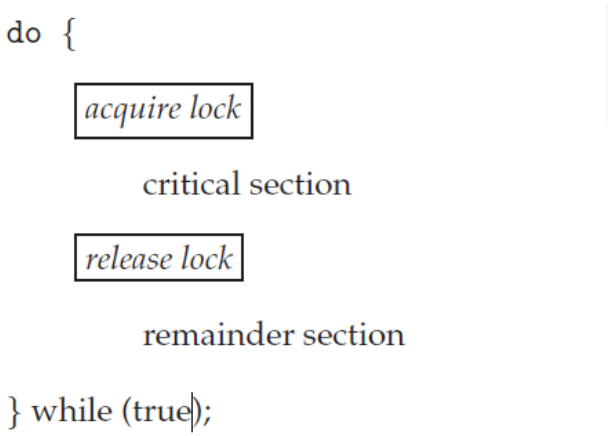
Mutex Locks

operating-systems designers build software tools to solve the critical-section problem. The simplest of these tools is the **mutex lock**. (In fact, the term ***mutex*** is short for ***mut***ual ***ex***clusion.) We use the mutex lock to protect critical regions and thus prevent race conditions. That is, a process must acquire the lock before entering a critical section; it releases the lock when it exits the critical section. The acquire()function acquires the lock, and the release() function releases the lock.

A mutex lock has a boolean variable available whose value indicates if the lock is available or not. If the lock is available, a call to acquire() succeeds, and the lock is then considered unavailable. A process that attempts to acquire an unavailable lock is blocked until the lock is released.

The definition of acquire() is as follows:

```
acquire() {
while (!available)
; /* busy wait */
available = false;;
}
```



Solution to the critical-section problem using mutex locks.

The definition of release() is as follows:

release() *{*

available = true;

}

The main disadvantage of the implementation given here is that it requires **busy waiting**. While a process is in its critical section, any other process that tries to enter its critical section must loop continuously in the call to acquire(). In fact, this type of mutex lock is also called a **spinlock** because the process "spins" while waiting for the lock to become available.

Semaphores

Mutex locks, as we mentioned earlier, are generally considered the simplest of synchronization tools. In this section, we examine a more robust tool that can behave similarly to a mutex lock but can also provide more sophisticated ways for processes to synchronize their activities.

A **semaphore** S is an integer variable that, apart from initialization, is accessed only through two standard atomic operations: wait() and signal(). The wait() operation was originally termed P; signal() was originally called V . The definition of wait() is as follows:

wait(S) *{*

while (S <= 0)

; // busy wait

S--;

}

The definition of signal() is as follows:

```
signal(S) {
S++;
}
```

All modifications to the integer value of the semaphore in the wait() and signal() operations must be executed indivisibly. That is, when one process modifies the semaphore value, no other process can simultaneously modify that same semaphore value. In addition, in the case of wait(S), the testing of the integer value of S (S ≤ 0), as well as its possible modification (S--), must be executed without interruption.

Semaphore Usage

Operating systems often distinguish between counting and binary semaphores. The value of a **counting semaphore** can range over an unrestricted domain. The value of a **binary semaphore** can range only between 0 and 1. Thus, binary semaphores behave similarly to mutex locks. In fact, on systems that do not provide mutex locks, binary semaphores can be used instead for providing mutual exclusion.

Counting semaphores can be used to control access to a given resource consisting of a finite number of instances. The semaphore is initialized to the number of resources available. Each process that wishes to use a resource performs a wait() operation on the semaphore (thereby decrementing the count). When a process releases a resource, it performs a signal() operation (incrementing the count). When the count for the semaphore goes to 0, all resources are being used. After that, processes that wish to use a resource will block until the count becomes greater than 0.

We can also use semaphores to solve various synchronization problems. For example, consider two concurrently running processes: *P*1 with a statement *S*1 and *P*2 with a statement *S*2. Suppose we require that *S*2 be executed only after *S*1 has completed. We can implement this scheme readily by letting *P*1 and *P*2 share a common semaphore synch, initialized to 0. In process *P*1, we insert the statements

```
S1;
signal(synch);
```

In process *P*2, we insert the statements

```
wait(synch);
```

*S*2;

Because synch is initialized to 0, *P*2 will execute *S*2 only after *P*1 has invoked signal(synch), which is after statement *S*1 has been executed.

Deadlocks and Starvation

The implementation of a semaphore with a waiting queue may result in a situation where two or more processes are waiting indefinitely for an event that can be caused only by one of the waiting processes. The event in question is the execution of a signal() operation. When such a state is reached, these processes are said to be **deadlocked**.

To illustrate this, consider a system consisting of two processes, *P*0 and *P*1, each accessing two semaphores, S and Q, set to the value 1:

P_0	P_1
wait(S);	wait(Q);
wait(Q);	wait(S);
.	.
.	.
.	.
signal(S);	signal(Q);
signal(Q);	signal(S);

Suppose that *P*0 executes wait(S) and then *P*1 executes wait(Q).When *P*0 executes wait(Q), it must wait until *P*1 executes signal(Q). Similarly, when *P*1 executes wait(S), it must wait until *P*0 executes signal(S). Since these signal() operations cannot be executed, *P*0 and *P*1 are deadlocked. We say that a set of processes is in a deadlocked state when every process in the set is waiting for an event that can be caused only by another process in the set.

Another problem related to deadlocks is **indefinite blocking** or **starvation**, a situation in which processes wait indefinitely within the semaphore. Indefinite blocking may occur if we remove processes from the list associated with a semaphore in LIFO (last-in, first-out) order.

Priority Inversion

A scheduling challenge arises when a higher-priority process needs to read or modify kernel data that are currently being accessed by a lower-priority process—or a chain of lower-priority processes. Since kernel data are typically protected with a lock, the higher-priority

process will have to wait for a lower-priority one to finish with the resource. The situation becomes more complicated if the lower-priority process is preempted in favor of another process with a higher priority.

As an example, assume we have three processes—*L*, *M*, and *H*—whose priorities follow the order $L < M < H$. Assume that process *H* requires resource *R*, which is currently being accessed by process *L*. Ordinarily, process *H* would wait for *L* to finish using resource *R*. However, now suppose that process *M* becomes runnable, thereby preempting process *L*. Indirectly, a process with a lower priority—process *M*—has affected how long process *H* must wait for *L* to relinquish resource *R*. This problem is known as **priority inversion**. It occurs only in systems with more than two priorities, so one solution is to have only two priorities.

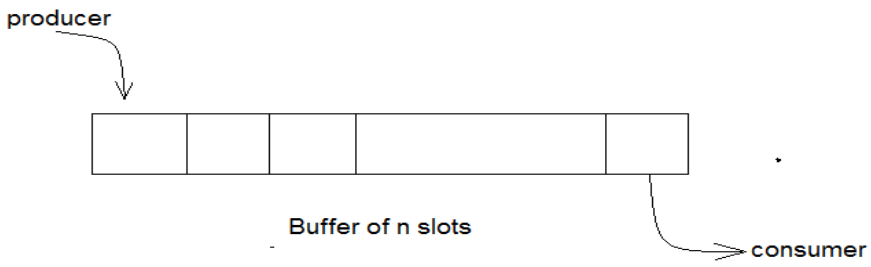
Classic Problems of Synchronization

Bounded Buffer Problem

Bounded buffer problem, which is also called **producer consumer problem**, is one of the classic problems of synchronization. Let's start by understanding the problem here, before moving on to the solution and program code.

What is the Problem Statement?

There is a buffer of n slots and each slot is capable of storing one unit of data. There are two processes running, namely, **producer** and **consumer**, which are operating on the buffer.



Bounded Buffer Problem

A producer tries to insert data into an empty slot of the buffer. A consumer tries to remove data from a filled slot in the buffer. As you might have guessed by now, those two processes won't produce the expected output if they are being executed concurrently.

There needs to be a way to make the producer and consumer work in an independent manner.

Here's a Solution

One solution of this problem is to use semaphores. The semaphores which will be used here are:

- m, a **binary semaphore** which is used to acquire and release the lock.
- empty, a **counting semaphore** whose initial value is the number of slots in the buffer, since, initially all slots are empty.
- full, a **counting semaphore** whose initial value is 0.

At any instant, the current value of empty represents the number of empty slots in the buffer and full represents the number of occupied slots in the buffer.

The Producer Operation

The pseudocode of the producer function looks like this:

```
do
{
   // wait until empty > 0 and then decrement 'empty'
   wait(empty);
   // acquire lock
   wait(mutex);
      /* perform the insert operation in a slot */
      // release lock
   signal(mutex);
   // increment 'full'
   signal(full);
}
while(TRUE);
```

- it decrements the **empty** semaphore because, there will now be one less empty slot, since the producer is going to insert data in one of those slots.
- Then, it acquires lock on the buffer, so that the consumer cannot access the buffer until producer completes its operation.
- After performing the insert operation, the lock is released and the value of **full** is incremented because the producer has just filled a slot in the buffer.

The Consumer Operation

The pseudocode for the consumer function looks like this:

```
do
{
   // wait until full > 0 and then decrement 'full'
   wait(full);
   // acquire the lock
   wait(mutex);
      /* perform the remove operation in a slot */
      // release the lock
   signal(mutex);
   // increment 'empty'
   signal(empty);
}
while(TRUE);
```

- The consumer waits until there is at least one full slot in the buffer.
- Then it decrements the **full** semaphore because the number of occupied slots will be decreased by one, after the consumer completes its operation.
- After that, the consumer acquires lock on the buffer.
- Following that, the consumer completes the removal operation so that the data from one of the full slots is removed.
- Then, the consumer releases the lock.

- Finally, the **empty** semaphore is incremented by 1, because the consumer has just removed data from an occupied slot, thus making it empty.

What is Readers Writer Problem?

Readers writer problem is another example of a classic synchronization problem. There are many variants of this problem, one of which is examined below.

The Problem Statement

There is a shared resource which should be accessed by multiple processes. There are two types of processes in this context. They are **reader** and **writer**. Any number of **readers** can read from the shared resource simultaneously, but only one **writer** can write to the shared resource. When a **writer**is writing data to the resource, no other process can access the resource. A **writer** cannot write to the resource if there are non-zero number of readers accessing the resource at that time.

The Solution

From the above problem statement, it is evident that readers have higher priority than writer. If a writer wants to write to the resource, it must wait until there are no readers currently accessing that resource.

Here, we use one **mutex** m and a **semaphore** w. An integer variable read_count is used to maintain the number of readers currently accessing the resource. The variable read_count is initialized to 0. A value of 1 is given initially to m and w.

Instead of having the process to acquire lock on the shared resource, we use the mutex m to make the process to acquire and release lock whenever it is updating the read_count variable.

The code for the **writer** process looks like this:

```
while(TRUE)
{
   wait(w);
  /* perform the write operation */
  signal(w);
}
```

And, the code for the reader process looks like this:

```
while(TRUE)
```

```
{
   //acquire lock
   wait(m);
   read_count++;
   if(read_count == 1)
      wait(w);
      //release lock
   signal(m);
      /* perform the reading operation */
      // acquire lock
   wait(m);
   read_count--;
   if(read_count == 0)
      signal(w);

   // release lock
   signal(m);
}
```

Here is the Code uncoded(explained)

- As seen above in the code for the writer, the writer just waits on the **w** semaphore until it gets a chance to write to the resource.
- After performing the write operation, it increments **w** so that the next writer can access the resource.
- On the other hand, in the code for the reader, the lock is acquired whenever the **read_count** is updated by a process.
- When a reader wants to access the resource, first it increments the **read_count** value, then accesses the resource and then decrements the **read_count** value.
- The semaphore **w** is used by the first reader which enters the critical section and the last reader which exits the critical section.
- The reason for this is, when the first readers enters the critical section, the writer is blocked from the resource. Only new readers can access the resource now.

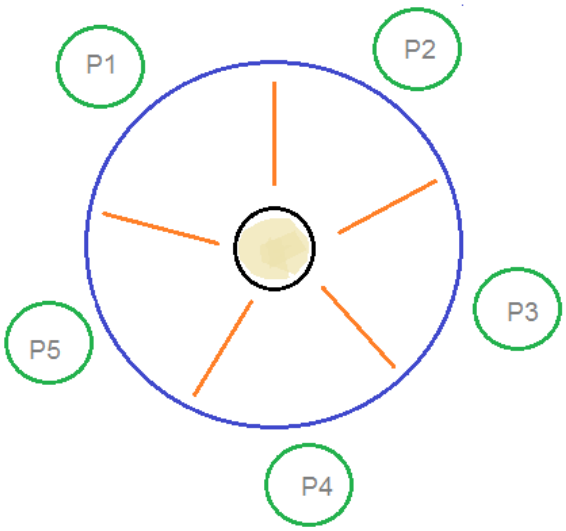
- Similarly, when the last reader exits the critical section, it signals the writer using the **w** semaphore because there are zero readers now and a writer can have the chance to access the resource.

Dining Philosophers Problem

The dining philosophers problem is another classic synchronization problem which is used to evaluate situations where there is a need of allocating multiple resources to multiple processes.

What is the Problem Statement?

Consider there are five philosophers sitting around a circular dining table. The dining table has five chopsticks and a bowl of rice in the middle as shown in the below figure.



Dining Philosophers Problem

At any instant, a philosopher is either eating or thinking. When a philosopher wants to eat, he uses two chopsticks - one from their left and one from their right. When a philosopher wants to think, he keeps down both chopsticks at their original place.

Here's the Solution

From the problem statement, it is clear that a philosopher can think for an indefinite amount of time. But when a philosopher starts eating, he has to stop at some point of time. The philosopher is in an endless cycle of thinking and eating.

An array of five semaphores, stick[5], for each of the five chopsticks.

The code for each philosopher looks like:

```
while(TRUE)
{
   wait(stick[i]);
   /*
      mod is used because if i=5, next
      chopstick is 1 (dining table is circular)
   */
   wait(stick[(i+1) % 5]);
                /* eat */
   signal(stick[i]);
     signal(stick[(i+1) % 5]);
   /* think */
}
```

When a philosopher wants to eat the rice, he will wait for the chopstick at his left and picks up that chopstick. Then he waits for the right chopstick to be available, and then picks it too. After eating, he puts both the chopsticks down.

But if all five philosophers are hungry simultaneously, and each of them pickup one chopstick, then a deadlock situation occurs because they will be waiting for another chopstick forever. The possible solutions for this are:

- A philosopher must be allowed to pick up the chopsticks only if both the left and right chopsticks are available.
- Allow only four philosophers to sit at the table. That way, if all the four philosophers pick up four chopsticks, there will be one chopstick left on the table. So, one philosopher can start eating and eventually, two chopsticks will be available. In this way, deadlocks can be avoided.

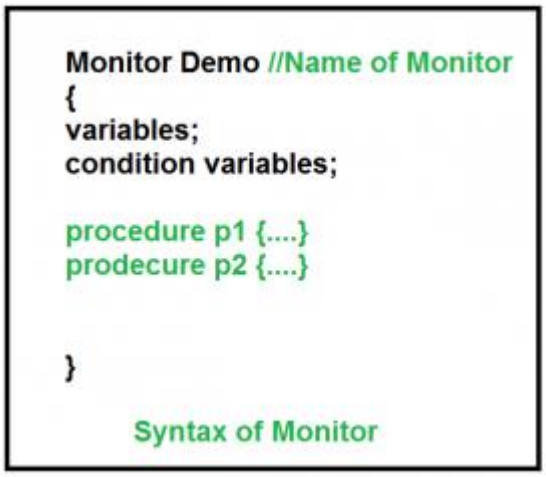
Process Synchronization | Monitors

Monitor is one of the ways to achieve Process synchronization. Monitor is supported by programming languages to achieve mutual exclusion between processes. For example Java Synchronized methods. Java provides wait() and notify() constructs.

1. It is the collection of condition variables and procedures combined together in a special kind of module or a package.
2. The processes running outside the monitor can't access the internal variable of monitor but can call procedures of the monitor.

3. Only one process at a time can execute code inside monitors.

Syntax of Monitor



Condition Variables

Two different operations are performed on the condition variables of the monitor.

1. Wait.
2. signal.

let say we have 2 condition variables

condition x, y; //Declaring variable

Wait operation

x.wait() : Process performing wait operation on any condition variable are suspended. The suspended processes are placed in block queue of that condition variable.

Note: Each condition variable has its unique block queue.

Signal operation

x.signal(): When a process performs signal operation on condition variable, one of the blocked processes is given chance.

If (x block queue empty)

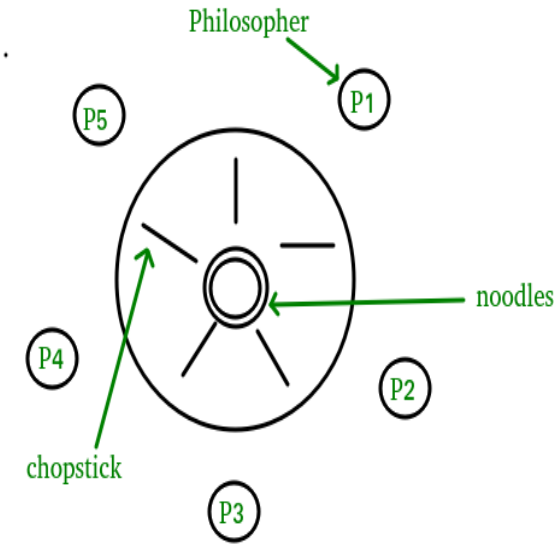
// Ignore signal

else

// Resume a process from block queue.

Dining-Philosophers Solution Using Monitors

Dining-Philosophers Problem – N philosophers seated around a circular table



- There is one chopstick between each philosopher
- A philosopher must pick up its two nearest chopsticks in order to eat
- A philosopher must pick up first one chopstick, then the second one, not both at once

We need an algorithm for allocating these limited resources(chopsticks) among several processes(philosophers) such that solution is free from deadlock and free from starvation.

There exist some algorithm to solve Dining – Philosopher Problem, but they may have deadlock situation. Also, a deadlock-free solution is not necessarily starvation-free. Semaphores can result in deadlock due to programming errors. Monitors alone are not sufficiency to solve this, we need monitors with *condition variables*

Monitor-based Solution to Dining Philosophers

We illustrate monitor concepts by presenting a deadlock-free solution to the dining-philosophers problem. Monitor is used to control access to state variables and condition variables. It only tells when to enter and exit the segment. This solution imposes the restriction that a philosopher may pick up her chopsticks only if both of them are available.

To code this solution, we need to distinguish among three states in which we may find a philosopher. For this purpose, we introduce the following data structure:

THINKING – When philosopher doesn't want to gain access to either fork.

HUNGRY – When philosopher wants to enter the critical section.

EATING – When philosopher has got both the forks, i.e., he has entered the section.

Philosopher i can set the variable state[i] = EATING only if her two neighbors are not eating (state[(i+4) % 5] != EATING) and (state[(i+1) % 5] != EATING).

```
// Dining-Philosophers Solution Using Monitors
monitor DP
{
        status state[5];
        condition self[5];
        // Pickup chopsticks
        Pickup(int i)
        {
                // indicate that I'm hungry
                state[i] = hungry;
                // set state to eating in test()
                // only if my left and right neighbors
                // are not eating
                test(i);
                // if unable to eat, wait to be signaled
                if (state[i] != eating)
                        self[i].wait;
        }

        // Put down chopsticks
        Putdown(int i)
        {
                // indicate that I'm thinking
                state[i] = thinking;
                // if right neighbor R=(i+1)%5 is hungry and
                // both of R's neighbors are not eating,
```

```
            // set R's state to eating and wake it up by
            // signaling R's CV
            test((i + 1) % 5);
            test((i + 4) % 5);
        }
        test(int i)
        {
            if (state[(i + 1) % 5] != eating
                && state[(i + 4) % 5] != eating
                && state[i] == hungry) {
                // indicate that I'm eating
                state[i] = eating;
                // signal() has no effect during Pickup(),
                // but is important to wake up waiting
                // hungry philosophers during Putdown()
                self[i].signal();
            }
        }
        init()
        {
            // Execution of Pickup(), Putdown() and test()
            // are all mutually exclusive,
            // i.e. only one at a time can be executing
for
        i = 0 to 4
            // Verify that this monitor-based solution is
            // deadlock free and mutually exclusive in that
            // no 2 neighbors can eat simultaneously
            state[i] = thinking;
        }
```

```
} // end of monitor
```

Above Program is a monitor solution to the dining-philosopher problem.

We also need to declare

```
condition self[5];
```

This allows philosopher i to delay herself when she is hungry but is unable to obtain the chopsticks she needs. We are now in a position to describe our solution to the dining-philosophers problem. The distribution of the chopsticks is controlled by the monitor Dining Philosophers. Each philosopher, before starting to eat, must invoke the operation pickup(). This act may result in the suspension of the philosopher process. After the successful completion of the operation, the philosopher may eat. Following this, the philosopher invokes the putdown() operation. Thus, philosopher i must invoke the operations pickup() and putdown() in the following sequence:

```
DiningPhilosophers.pickup(i);

        ...

        eat

        ...

DiningPhilosophers.putdown(i);
```

It is easy to show that this solution ensures that **no two neighbors** are eating simultaneously and that no deadlocks will occur. We note, however, that it is possible for a philosopher to starve to death.