Unit2

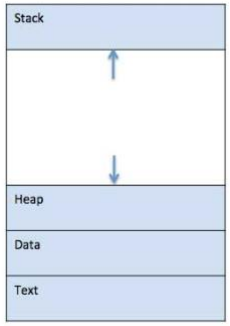
PROCESS MANAGEMENT:

Process Concept

A process is basically a program in execution. The execution of a process must progress in a sequential fashion. To put it in simple terms, we write our computer programs in a text file and when we execute this program, it becomes a process which performs all the tasks mentioned in the program.

When a program is loaded into the memory and it becomes a process, it can be divided into four sections ─ stack, heap, text and data. The following image shows a simplified layout of a process inside main memory

PROCES CONTROL BLOCK



Stack

The process Stack contains the temporary data such as method/function parameters, return address and local variables.

Heap

This is dynamically allocated memory to a process during its run time.

Text

This includes the current activity represented by the value of Program Counter and the contents of the processor's registers

Data

This section contains the global and static variables.

Program

A program is a piece of code which may be a single line or millions of lines. A computer program is usually written by a computer programmer in a programming language. For example, here is a simple program written in C programming language

A computer program is a collection of instructions that performs a specific task when executed by a computer. When we compare a program with a process, we can conclude that a process is a dynamic instance of a computer program.

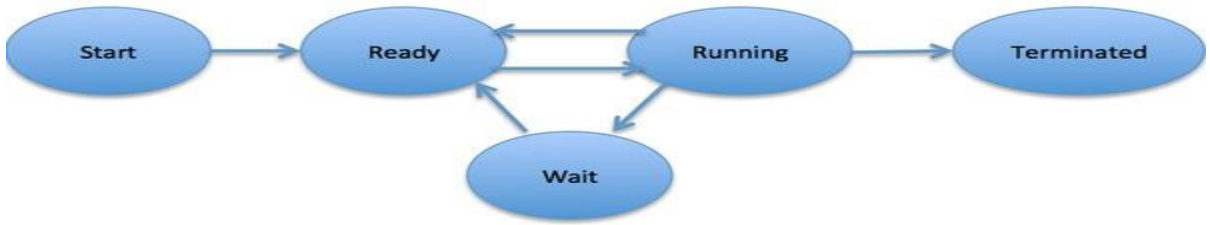
A part of a computer program that performs a well-defined task is known as an **algorithm**. A collection of computer programs, libraries and related data are referred to as a **software**.

Process Life Cycle

When a process executes, it passes through different states. These stages may differ in different operating systems, and the names of these states are also not standardized.

In general, a process can have one of the following five states at a time.

S.N.	State & Description
1	**Start** This is the initial state when a process is first started/created.
2	**Ready** The process is waiting to be assigned to a processor. Ready processes are waiting to have the processor allocated to them by the operating system so that they can run. Process may come into this state after **Start** state or while running it by but interrupted by the scheduler to assign CPU to some other process.
3	**Running** Once the process has been assigned to a processor by the OS scheduler, the process state is set to running and the processor executes its instructions.
4	**Waiting** Process moves into the waiting state if it needs to wait for a resource, such as waiting for user input, or waiting for a file to become available.
5	**Terminated or Exit** Once the process finishes its execution, or it is terminated by the operating system, it is moved to the terminated state where it waits to be removed from main memory.



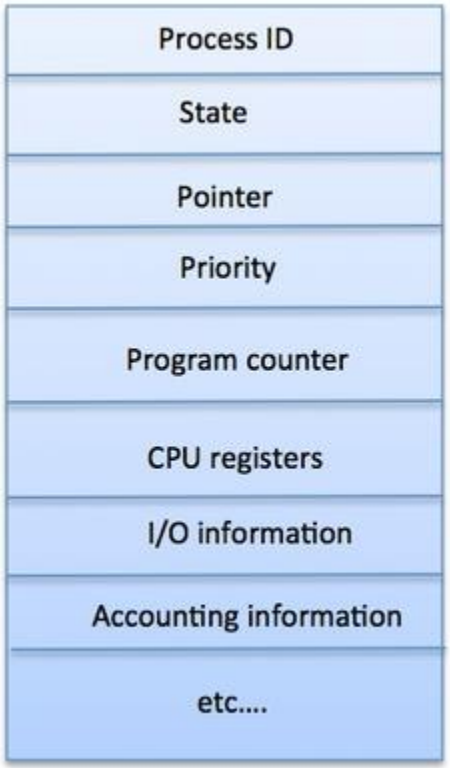
Process Control Block (PCB)

A Process Control Block is a data structure maintained by the Operating System for every process. The PCB is identified by an integer process ID (PID). A PCB keeps all the information needed to keep track of a process as listed below in the table −

S.N.	Information & Description
1	**Process State** The current state of the process i.e., whether it is ready, running, waiting, or whatever.
2	**Process privileges** This is required to allow/disallow access to system resources.
3	**Process ID** Unique identification for each of the process in the operating system.
4	**Pointer** A pointer to parent process.
5	**Program Counter** Program Counter is a pointer to the address of the next instruction to be executed for this process.
6	**CPU registers** Various CPU registers where process need to be stored for execution for running state.
7	**CPU Scheduling Information** Process priority and other scheduling information which is required to schedule the process.
8	**Memory management information** This includes the information of page table, memory limits, Segment table depending on memory used by the operating system.

9	**Accounting information** This includes the amount of CPU used for process execution, time limits, execution ID etc.
10	**IO status information** This includes a list of I/O devices allocated to the process.

The architecture of a PCB is completely dependent on Operating System and may contain different information in different operating systems. Here is a simplified diagram of a PCB −



The PCB is maintained for a process throughout its lifetime, and is deleted once the process terminates.

Process Scheduling

The process scheduling is the activity of the process manager that handles the removal of the running process from the CPU and the selection of another process on the basis of a particular strategy.

Process scheduling is an essential part of a Multiprogramming operating systems. Such operating systems allow more than one process to be loaded into the executable memory at a time and the loaded process shares the CPU using time multiplexing.

Categories of Scheduling

There are two categories of scheduling:

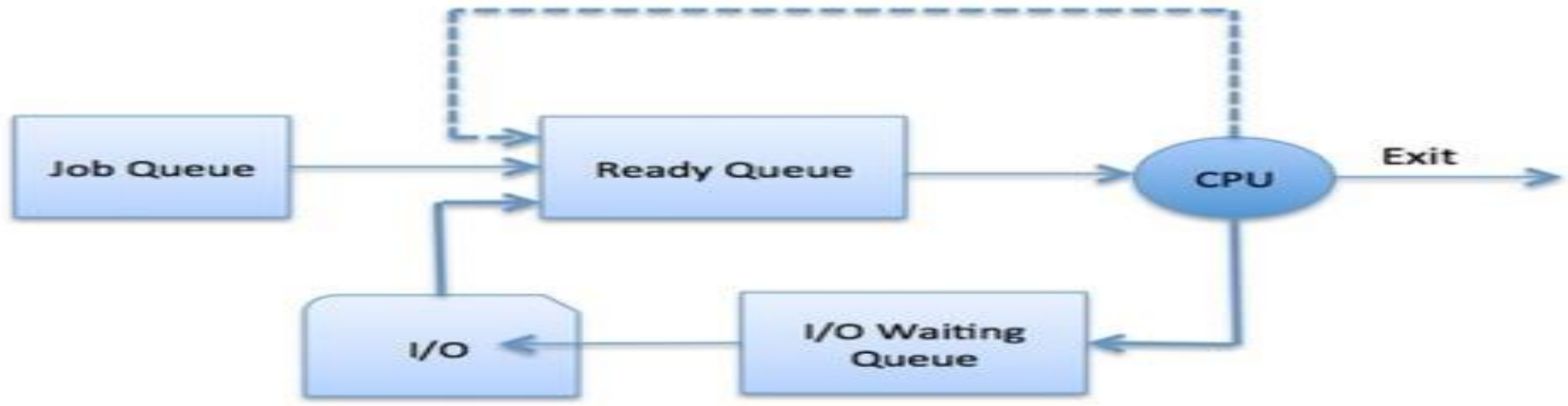
1. **Non-preemptive:** Here the resource can't be taken from a process until the process completes execution. The switching of resources occurs when the running process terminates and moves to a waiting state.
2. **Preemptive:** Here the OS allocates the resources to a process for a fixed amount of time. During resource allocation, the process switches from running state to ready state or from waiting state to ready state. This switching occurs as the CPU may give priority to other processes and replace the process with higher priority with the running process.

Process Scheduling Queues

The OS maintains all Process Control Blocks (PCBs) in Process Scheduling Queues. The OS maintains a separate queue for each of the process states and PCBs of all processes in the same execution state are placed in the same queue. When the state of a process is changed, its PCB is unlinked from its current queue and moved to its new state queue.

The Operating System maintains the following important process scheduling queues −

- **Job queue** − This queue keeps all the processes in the system.
- **Ready queue** − This queue keeps a set of all processes residing in main memory, ready and waiting to execute. A new process is always put in this queue.
- **Device queues** − The processes which are blocked due to unavailability of an I/O device constitute this queue.



The OS can use different policies to manage each queue (FIFO, Round Robin, Priority, etc.). The OS scheduler determines how to move processes between the ready and run queues which can only have one entry per processor core on the system; in the above diagram, it has been merged with the CPU.

Schedulers

Schedulers are special system software which handle process scheduling in various ways. Their main task is to select the jobs to be submitted into the system and to decide which process to run. Schedulers are of three types −

- Long-Term Scheduler
- Short-Term Scheduler
- Medium-Term Scheduler

Long Term Scheduler

It is also called a **job scheduler**. A long-term scheduler determines which programs are admitted to the system for processing. It selects processes from the queue and loads them into memory for execution. Process loads into the memory for CPU scheduling.

The primary objective of the job scheduler is to provide a balanced mix of jobs, such as I/O bound and processor bound. It also controls the degree of multiprogramming. If the degree of multiprogramming is stable, then the average rate of process creation must be equal to the average departure rate of processes leaving the system.

On some systems, the long-term scheduler may not be available or minimal. Time-sharing operating systems have no long term scheduler. When a process changes the state from new to ready, then there is use of long-term scheduler.

Short Term Scheduler

It is also called as **CPU scheduler**. Its main objective is to increase system performance in accordance with the chosen set of criteria. It is the change of ready state to running state of the process. CPU scheduler selects a process among the processes that are ready to execute and allocates CPU to one of them.

Short-term schedulers, also known as dispatchers, make the decision of which process to execute next. Short-term schedulers are faster than long-term schedulers.

Medium Term Scheduler

Medium-term scheduling is a part of **swapping**. It removes the processes from the memory. It reduces the degree of multiprogramming. The medium-term scheduler is in-charge of handling the swapped out-processes.

A running process may become suspended if it makes an I/O request. A suspended processes cannot make any progress towards completion. In this condition, to remove the process from memory and make space for other processes, the suspended process is moved to the secondary storage. This process is called **swapping**, and the process is said to be swapped out or rolled out. Swapping may be necessary to improve the process mix.

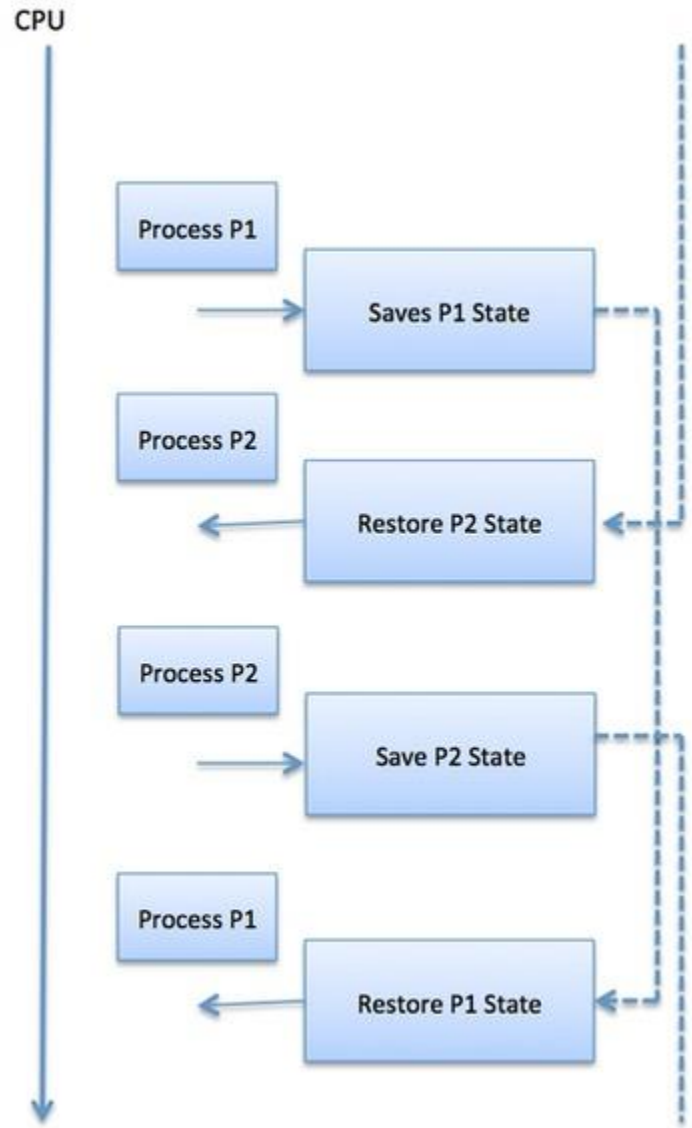
Comparison among Scheduler

S.N.	Long-Term Scheduler	Short-Term Scheduler	Medium-Term Scheduler
1	It is a job scheduler	It is a CPU scheduler	It is a process swapping scheduler.
2	Speed is lesser than short term scheduler	Speed is fastest among other two	Speed is in between both short and long term scheduler.
3	It controls the degree of multiprogramming	It provides lesser control over degree of multiprogramming	It reduces the degree of multiprogramming.
4	It is almost absent or minimal in time sharing system	It is also minimal in time sharing system	It is a part of Time sharing systems.
5	It selects processes from pool and loads them into memory for execution	It selects those processes which are ready to execute	It can re-introduce the process into memory and execution can be continued.

Context Switching

A context switching is the mechanism to store and restore the state or context of a CPU in Process Control block so that a process execution can be resumed from the same point at a later time. Using this technique, a context switcher enables multiple processes to share a single CPU. Context switching is an essential part of a multitasking operating system features.

When the scheduler switches the CPU from executing one process to execute another, the state from the current running process is stored into the process control block. After this, the state for the process to run next is loaded from its own PCB and used to set the PC, registers, etc. At that point, the second process can start executing.



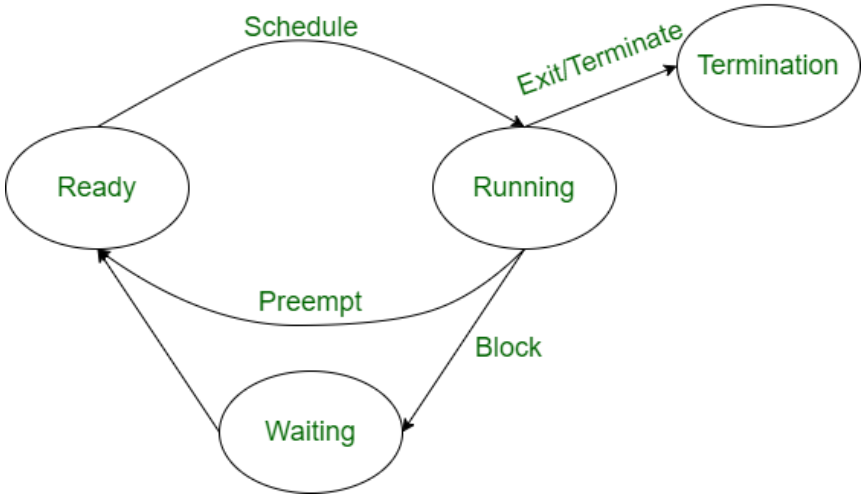
Context switches are computationally intensive since register and memory state must be saved and restored. To avoid the amount of context switching time, some hardware systems employ two or more sets of processor registers. When the process is switched, the following information is stored for later use.

- Program Counter
- Scheduling information
- Base and limit register value
- Currently used register
- Changed State
- I/O State information

- Accounting information

Operations on Processes

Operation on a Process: The execution of a process is a complex activity. It involves various operations. Following are the operations that are performed



while execution of a process:

1. Creation: This is the initial step of process execution activity. Process creation means the construction of a new process for the execution. This might be performed by system, user or old process itself. There are several events that leads to the process creation. Some of the such events are following:

- When we start the computer, system creates several background processes.
- A user may request to create a new process.
- A process can create a new process itself while executing.
- Batch system takes initiation of a batch job.

2. Scheduling/Dispatching: The event or activity in which the state of the process is changed from ready to running. It means the operating system puts the process from ready state into the running state. Dispatching is done by operating system when the resources are free or the process has higher priority than the ongoing process. There are various other cases in which the process in running state is preempted and process in ready state is dispatched by the operating system.

3. Blocking: When a process invokes an input-output system call that blocks the process and operating system put in block mode. Block mode is basically a mode where process waits for input-output. Hence on the demand of process itself, operating system blocks the process and dispatches another process to the processor. Hence, in process blocking operation, the operating system puts the process in 'waiting' state.

4. Preemption: When a timeout occurs that means the process hadn't been terminated in the allotted time interval and next process is ready to execute, then the operating system preempts the process. This operation is only valid where CPU scheduling supports preemption. Basically this happens in priority scheduling where on the incoming of high priority process the ongoing process is preempted. Hence, in process preemption operation, the operating system puts the process in 'ready' state.

5. Termination: Process termination is the activity of ending the process. In other words, process termination is the relaxation of computer resources taken by the process for the execution. Like creation, in termination also there may be several events that may lead to the process termination. Some of them are:

- Process completes its execution fully and it indicates to the OS that it has finished.
- Operating system itself terminates the process due to service errors.
- There may be problem in hardware that terminates the process.
- One process can be terminated by another process.

Interprocess Communication

A process can be of two types:

- Independent process.
- Co-operating process.

An independent process is not affected by the execution of other processes while a co-operating process can be affected by other executing processes. Though one can think that those processes, which are running independently, will execute very efficiently, in reality, there are many situations when co-operative nature can be utilized for increasing computational speed, convenience, and modularity. Inter-process communication (IPC) is a mechanism that allows processes to communicate with each other and synchronize their actions. The communication between these processes can be seen as a method of co-operation between them. Processes can communicate with each other through both:

1. Shared Memory
2. Message passing

Figure 1 below shows a basic structure of communication between processes via the shared memory method and via the message passing method.

An operating system can implement both methods of communication. First, we will discuss the shared memory methods of communication and then message passing. Communication between processes using shared memory requires processes to share some variable, and it completely depends on how the programmer will implement it. One way of communication using shared memory can be imagined like this: Suppose process1 and process2 are executing simultaneously, and they share some resources or use some information from another process. Process1 generates information about certain computations or resources being used and keeps it as a record in shared memory. When process2 needs to use the shared information, it will check in the record stored in shared memory and take note of the information generated by process1 and act accordingly. Processes can use shared memory for extracting information as a record from another process as well as for delivering any specific information to other processes.
Let's discuss an example of communication between processes using the shared memory method.

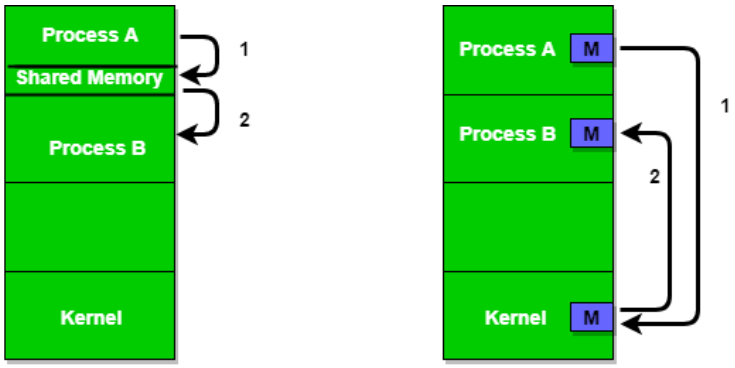


Figure 1 - Shared Memory and Message Passing

i) Shared Memory Method

Ex: Producer-Consumer problem

There are two processes: Producer and Consumer. The producer produces some items and the Consumer consumes that item. The two processes share a common space or memory location known as a buffer where the item produced by the Producer is stored and from which the Consumer consumes the item if needed. There are two versions of this problem: the first one is known as the unbounded buffer problem in which the Producer can keep on producing items and there is no limit on the size of the buffer, the second one is known as the bounded buffer problem in which the Producer can produce up to a certain number of items before it starts waiting for Consumer to consume it. We will discuss the bounded buffer problem. First, the Producer and the Consumer will share some common memory, then the producer will start producing items. If the total produced item is equal to the size of the buffer,

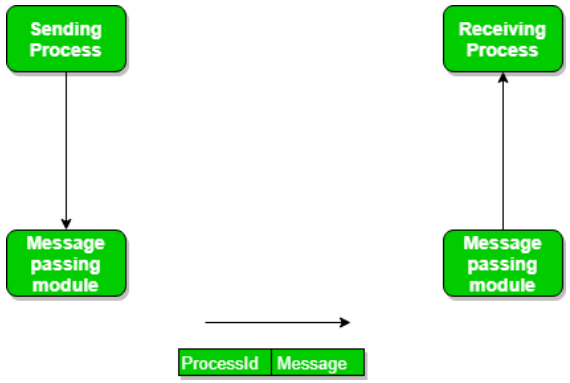
the producer will wait to get it consumed by the Consumer. Similarly, the consumer will first check for the availability of the item. If no item is available, the Consumer will wait for the Producer to produce it. If there are items available, Consumer will consume them. The pseudo-code to demonstrate is provided below:

Shared Data between the two Processes

ii) Messaging Passing Method

Now, We will start our discussion of the communication between processes via message passing. In this method, processes communicate with each other without using any kind of shared memory. If two processes p1 and p2 want to communicate with each other, they proceed as follows:

- Establish a communication link (if a link already exists, no need to establish it again.)
- Start exchanging messages using basic primitives.
  We need at least two primitives:
  – **send**(message, destination) or **send**(message)
  – **receive**(message, host) or **receive**(message)



The message size can be of fixed size or of variable size. If it is of fixed size, it is easy for an OS designer but complicated for a programmer and if it is of variable size then it is easy for a programmer but complicated for the OS designer. A standard message can have two parts: **header and body.**

The **header part** is used for storing message type, destination id, source id, message length, and control information. The control information contains information like what to do if runs out of buffer space, sequence number, priority. Generally, message is sent using FIFO style.

Message Passing through Communication Link.

Direct and Indirect Communication link

Now, We will start our discussion about the methods of implementing communication links. While implementing the link, there are some questions that need to be kept in mind like :

1. How are links established?
2. Can a link be associated with more than two processes?
3. How many links can there be between every pair of communicating processes?
4. What is the capacity of a link? Is the size of a message that the link can accommodate fixed or variable?
5. Is a link unidirectional or bi-directional?

A link has some capacity that determines the number of messages that can reside in it temporarily for which every link has a queue associated with it which can be of zero capacity, bounded capacity, or unbounded capacity. In zero capacity, the sender waits until the receiver informs the sender that it has received the message. In non-zero capacity cases, a process does not know whether a message has been received or not after the send operation. For this, the sender must communicate with the receiver explicitly. Implementation of the link depends on the situation, it can be either a direct communication link or an in-directed communication link.

Direct Communication links are implemented when the processes use a specific process identifier for the communication, but it is hard to identify the sender ahead of time.

For example the print server.
In-direct Communication is done via a shared mailbox (port), which consists of a queue of messages. The sender keeps the message in mailbox and the receiver picks them up.

Communication in Client– Server Systems

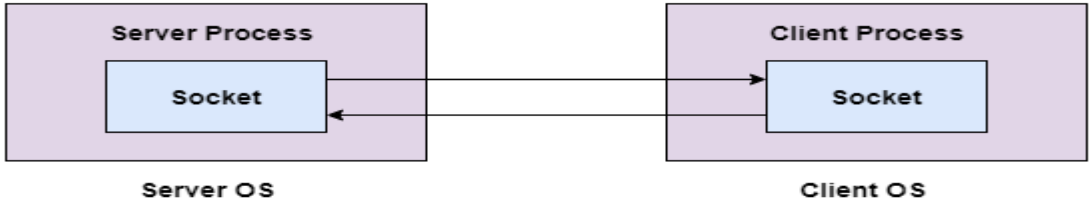
Client/Server communication involves two components, namely a client and a server. They are usually multiple clients in communication with a single server. The clients send requests to the server and the server responds to the client requests.

There are three main methods to client/server communication. These are given as follows −

Sockets

Sockets facilitate communication between two processes on the same machine or different machines. They are used in a client/server framework and consist of the IP address and port number. Many application protocols use sockets for data connection and data transfer between a client and a server.

Socket communication is quite low-level as sockets only transfer an unstructured byte stream across processes. The structure on the byte stream is imposed by the client and server applications.
A diagram that illustrates sockets is as follows −

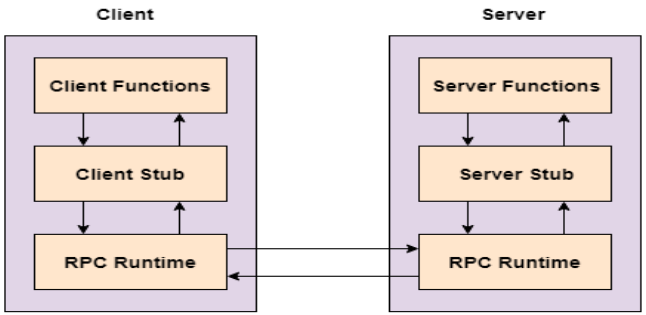


Remote Procedure Calls

These are interprocess communication techniques that are used for client-server based applications. A remote procedure call is also known as a subroutine call or a function call.

A client has a request that the RPC translates and sends to the server. This request may be a procedure or a function call to a remote server. When the server receives the request, it sends the required response back to the client.

A diagram that illustrates remote procedure calls is given as follows −



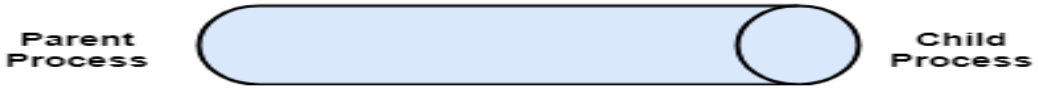
Pipes

These are interprocess communication methods that contain two end points. Data is entered from one end of the pipe by a process and consumed from the other end by the other process.

The two different types of pipes are ordinary pipes and named pipes. Ordinary pipes only allow one way communication. For two way communication, two pipes are required. Ordinary pipes have a parent child relationship between the processes as the pipes can only be accessed by processes that created or inherited them.

Named pipes are more powerful than ordinary pipes and allow two way communication. These pipes exist even after the processes using them have terminated. They need to be explicitly deleted when not required anymore.

A diagram that demonstrates pipes are given as follows −



Threads:

Within a program, a **Thread** is a separate execution path. It is a lightweight process that the operating system can schedule and run concurrently with other threads. The operating system creates and manages threads, and they share the same memory and resources as the program that created them. This enables multiple threads to collaborate and work efficiently within a single program.

A thread is a single sequence stream within a process. Threads are also called lightweight processes as they possess some of the properties of processes. Each thread belongs to exactly one process. In an operating system that supports multithreading, the process can consist of many threads.

Why Do We Need Thread?

- Threads run in parallel improving the application performance. Each such thread has its own CPU state and stack, but they share the address space of the process and the environment.
- Threads can share common data so they do not need to use interprocess communication. Like the processes, threads also have states like ready, executing, blocked, etc.
- Priority can be assigned to the threads just like the process, and the highest priority thread is scheduled first.
- Each thread has its own Thread Control Block (TCB). Like the process, a context switch occurs for the thread, and register contents are saved in (TCB). As threads share the same address space and resources, synchronization is also required for the various activities of the thread.

Why Multi-Threading?

A thread is also known as a lightweight process. The idea is to achieve parallelism by dividing a process into multiple threads. For example, in a browser, multiple tabs can be different threads. MS Word uses multiple threads: one thread to format the text, another thread to process inputs, etc. More advantages of multithreading are discussed below.

Multithreading is a technique used in operating systems to improve the performance and responsiveness of computer systems. Multithreading allows multiple threads (i.e., lightweight processes) to share the same resources of a single process, such as the CPU, memory, and I/O devices.

Multicore Programming

Multicore programming helps to create concurrent systems for deployment on multicore processor and multiprocessor systems. A multicore processor system is basically a single processor with multiple execution cores in one chip. It has multiple processors on the motherboard or chip. A Field-Programmable Gate

Array (FPGA) is might be included in a multiprocessor system. A FPGA is an integrated circuit containing an array of programmable logic blocks and a hierarchy of reconfigurable interconnects. Input data is processed by to produce outputs. It can be a processor in a multicore or multiprocessor system, or a FPGA.

The multicore programming approach has following advantages −

- Multicore and FPGA processing helps to increase the performance of an embedded system.
- Also helps to achieve scalability, so the system can take advantage of increasing numbers of cores and FPGA processing power over time.

Concurrent systems that we create using multicore programming have multiple tasks executing in parallel. This is known as concurrent execution. When multiple parallel tasks are executed by a processor, it is known as multitasking. A CPU scheduler, handles the tasks that execute in parallel. The CPU implements tasks using operating system threads. So that tasks can execute independently but have some data transfer between them, such as data transfer between a data acquisition module and controller for the system. Data transfer occurs when there is a data dependency.

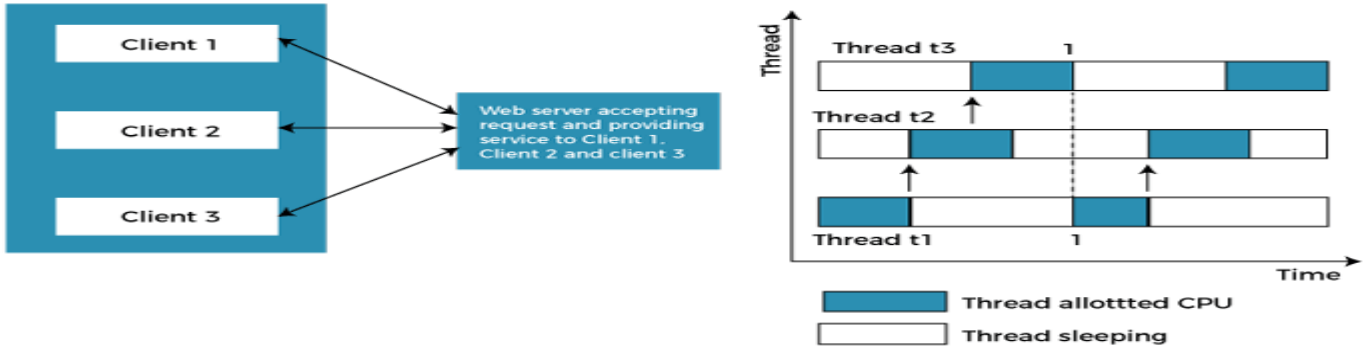
, Multithreading Models

Multithreading Model:

Multithreading allows the application to divide its task into individual threads. In multi-threads, the same process or task can be done by the number of threads, or we can say that there is more than one thread to perform the task in multithreading. With the use of multithreading, multitasking can be achieved.

The main drawback of single threading systems is that only one task can be performed at a time, so to overcome the drawback of this single threading, there is multithreading that allows multiple tasks to be performed.

For example:



In the above example, client1, client2, and client3 are accessing the web server without any waiting. In multithreading, several tasks can run at the same time.

In an operating system, threads are divided into the user-level thread and the Kernel-level thread. User-level threads handled independent form above the kernel and thereby managed without any kernel support. On the opposite hand, the operating system directly manages the kernel-level threads. Nevertheless, there must be a form of relationship between user-level and kernel-level threads.

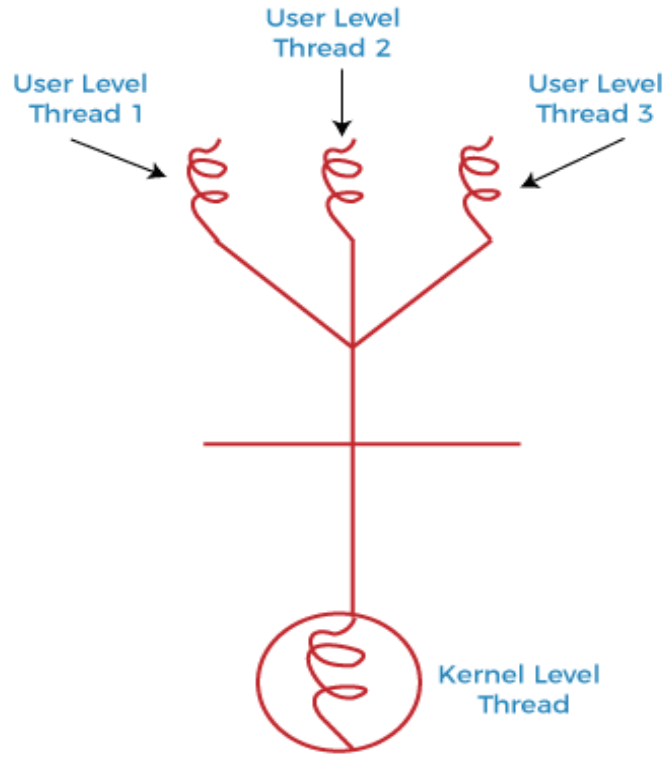
There exists three established multithreading models classifying these relationships are:

- Many to one multithreading model
- One to one multithreading model
- Many to Many multithreading models

Many to one multithreading model:

The many to one model maps many user levels threads to one kernel thread. This type of relationship facilitates an effective context-switching environment, easily implemented even on the simple kernel with no thread support.

The disadvantage of this model is that since there is only one kernel-level thread schedule at any given time, this model cannot take advantage of the hardware acceleration offered by multithreaded processes or multi-processor systems. In this, all the thread management is done in the userspace. If blocking comes, this model blocks the whole system.

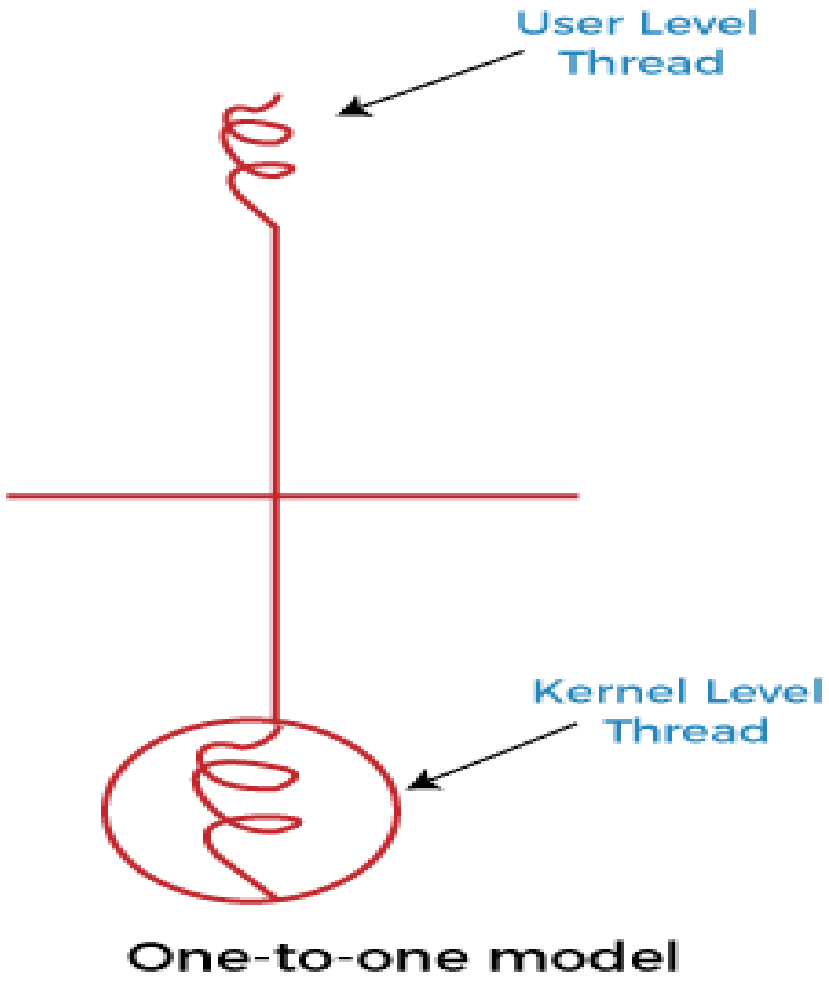


Many-to-one model

In the above figure, the many to one model associates all user-level threads to single kernel-level threads.

One to one multithreading model

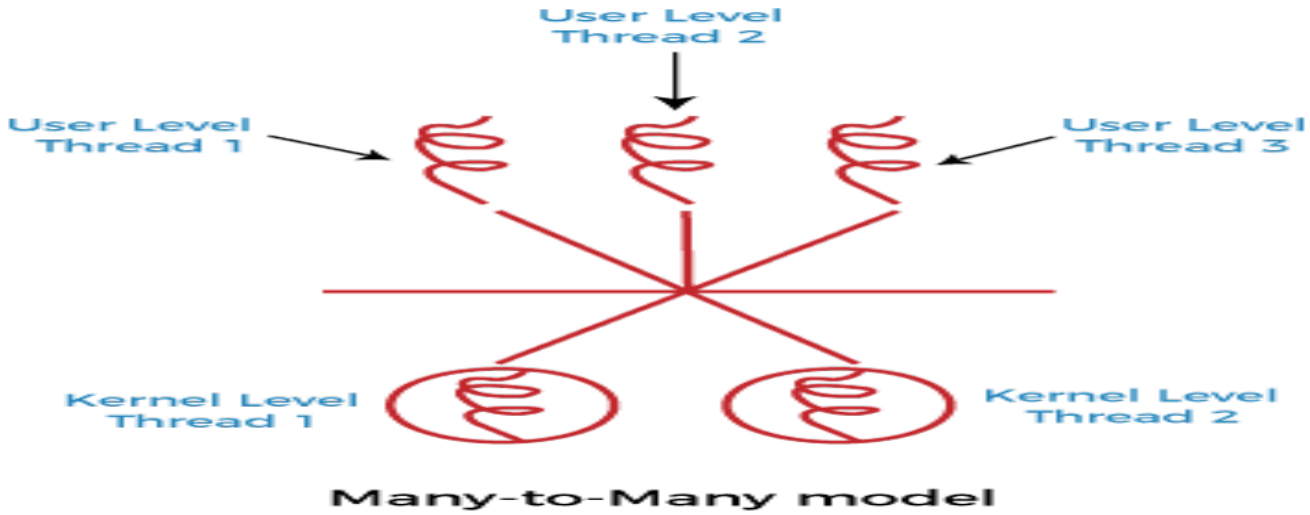
The one-to-one model maps a single user-level thread to a single kernel-level thread. This type of relationship facilitates the running of multiple threads in parallel. However, this benefit comes with its drawback. The generation of every new user thread must include creating a corresponding kernel thread causing an overhead, which can hinder the performance of the parent process. Windows series and Linux operating systems try to tackle this problem by limiting the growth of the thread count.



In the above figure, one model associates that one user-level thread to a single kernel-level thread.

Many to Many Model multithreading model

In this type of model, there are several user-level threads and several kernel-level threads. The number of kernel threads created depends upon a particular application. The developer can create as many threads at both levels but may not be the same. The many to many model is a compromise between the other two models. In this model, if any thread makes a blocking system call, the kernel can schedule another thread for execution. Also, with the introduction of multiple threads, complexity is not present as in the previous models. Though this model allows the creation of multiple kernel threads, true concurrency cannot be achieved by this model. This is because the kernel can schedule only one process at a time.

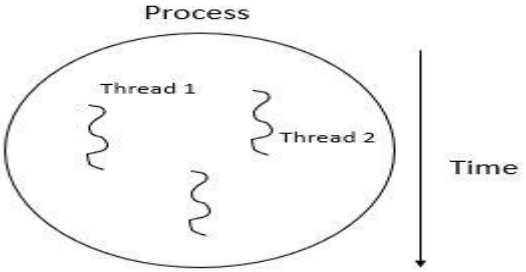


Many to many versions of the multithreading model associate several user-level threads to the same or much less variety of kernel-level threads in the above figure.

Thread Libraries

A thread is a lightweight of process and is a basic unit of CPU utilization which consists of a program counter, a stack, and a set of registers.

Given below is the structure of thread in a process −



A process has a single thread of control where one program can counter and one sequence of instructions is carried out at any given time. Dividing an application or a program into multiple sequential threads that run in quasi-parallel, the programming model becomes simpler.

Thread has the ability to share an address space and all of its data among themselves. This ability is essential for some specific applications.

Threads are lighter weight than processes, but they are faster to create and destroy than processes.

Thread Library

A thread library provides the programmer with an Application program interface for creating and managing thread.

Ways of implementing thread library

There are two primary ways of implementing thread library, which are as follows −

- The first approach is to provide a library entirely in user space with kernel support. All code and data structures for the library exist in a local function call in user space and not in a system call.
- The second approach is to implement a kernel level library supported directly by the operating system. In this case the code and data structures for the library exist in kernel space.

Invoking a function in the application program interface for the library typically results in a system call to the kernel.

The main thread libraries which are used are given below −

- **POSIX threads** − Pthreads, the threads extension of the POSIX standard, may be provided as either a user level or a kernel level library.
- **WIN 32 thread** − The windows thread library is a kernel level library available on windows systems.
- **JAVA thread** − The JAVA thread API allows threads to be created and managed directly as JAVA programs.

Implicit Threading

One way to address the difficulties and better support the design of multithreaded applications is to transfer the creation and management of threading from application developers to compilers and run-time libraries. This, termed implicit threading, is a popular trend today.

Implicit threading is mainly the use of libraries or other language support to hide the management of threads. The most common implicit threading library is OpenMP, in context of C.

OpenMP is a set of compiler directives as well as an API for programs written in C, C++, or FORTRAN that provides support for parallel programming in shared-memory environments. OpenMP identifies parallel regions as blocks of code that may run in parallel. Application developers insert compiler directives into their code at parallel regions, and these directives instruct the OpenMP run-time library to execute the region in parallel. The following C program illustrates a compiler directive above the parallel region containing the printf() statement:

Threading Issues

We can discuss some of the issues to consider in designing multithreaded programs. These issued are as follows −

The fork() and exec() system calls

The fork() is used to create a duplicate process. The meaning of the fork() and exec() system calls change in a multithreaded program.

If one thread in a program which calls fork(), does the new process duplicate all threads, or is the new process single-threaded? If we take, some UNIX systems have chosen to have two versions of fork(), one that duplicates all threads and another that duplicates only the thread that invoked the fork() system call.

If a thread calls the exec() system call, the program specified in the parameter to exec() will replace the entire process which includes all threads.

Signal Handling

Generally, signal is used in UNIX systems to notify a process that a particular event has occurred. A signal received either synchronously or asynchronously, based on the source of and the reason for the event being signalled.

All signals, whether synchronous or asynchronous, follow the same pattern as given below −

- A signal is generated by the occurrence of a particular event.

- The signal is delivered to a process.
- Once delivered, the signal must be handled.

Cancellation

Thread cancellation is the task of terminating a thread before it has completed.

For example − If multiple database threads are concurrently searching through a database and one thread returns the result the remaining threads might be cancelled.

Process Synchronization:

Process Synchronization is the coordination of execution of multiple processes in a multi-process system to ensure that they access shared resources in a controlled and predictable manner. It aims to resolve the problem of race conditions and other synchronization issues in a concurrent system.

The main objective of process synchronization is to ensure that multiple processes access shared resources without interfering with each other, and to prevent the possibility of inconsistent data due to concurrent access. To achieve this, various synchronization techniques such as semaphores, monitors, and critical sections are used.

In a multi-process system, synchronization is necessary to ensure data consistency and integrity, and to avoid the risk of deadlocks and other synchronization problems. Process synchronization is an important aspect of modern operating systems, and it plays a crucial role in ensuring the correct and efficient functioning of multi-process systems.

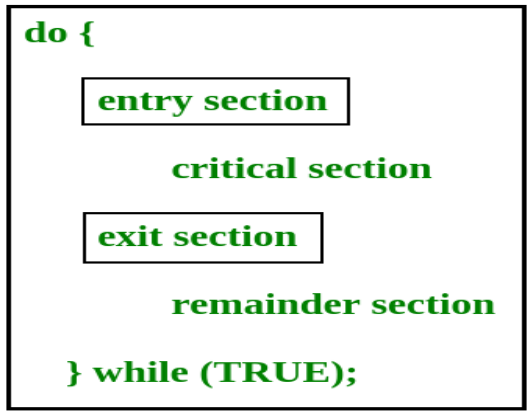
On the basis of synchronization, processes are categorized as one of the following two types:

- **Independent Process**: The execution of one process does not affect the execution of other processes.
- **Cooperative Process**: A process that can affect or be affected by other processes executing in the system.

Process synchronization problem arises in the case of Cooperative process also because resources are shared in Cooperative processes.

The Critical-Section Problem

A critical section is a code segment that can be accessed by only one process at a time. The critical section contains shared variables that need to be synchronized to maintain the consistency of data variables. So the critical section problem means designing a way for cooperative processes to access shared resources without creating data inconsistencies.



In the entry section, the process requests for entry in the **Critical Section.**
Any solution to the critical section problem must satisfy three requirements:

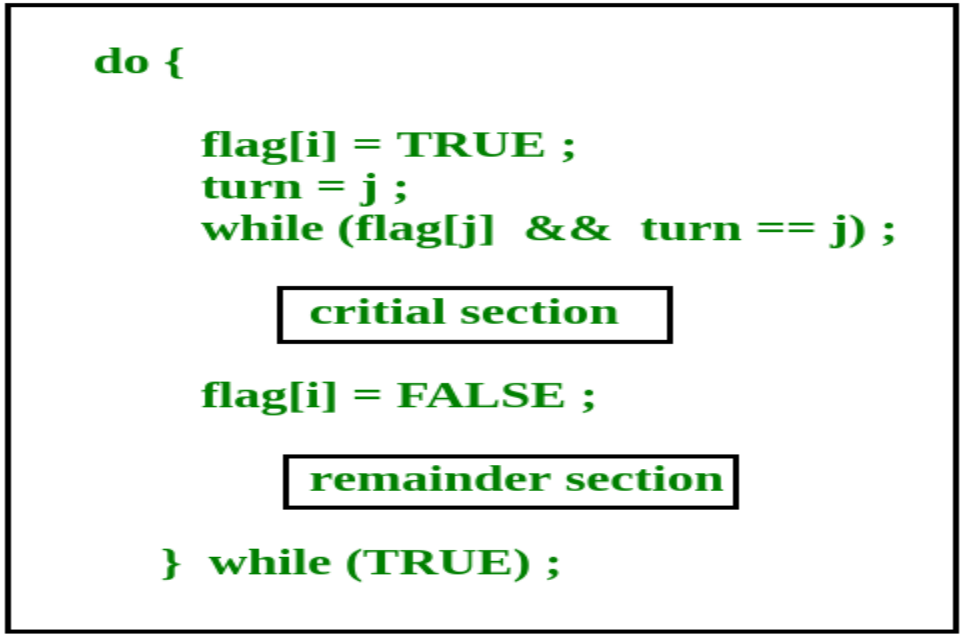
- **Mutual Exclusion**: If a process is executing in its critical section, then no other process is allowed to execute in the critical section.

- **Progress**: If no process is executing in the critical section and other processes are waiting outside the critical section, then only those processes that are not executing in their remainder section can participate in deciding which will enter in the critical section next, and the selection can not be postponed indefinitely.
- **Bounded Waiting**: A bound must exist 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.

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.



Peterson's Solution preserves all three conditions:

- Mutual Exclusion is assured as only one process can access the critical section at any time.
- Progress is also assured, as a process outside the critical section does not block other processes from entering the critical section.
- Bounded Waiting is preserved as every process gets a fair chance.

Disadvantages of Peterson's solution:

- It involves busy waiting.(In the Peterson's solution, the code statement- "while(flag[j] && turn == j);" is responsible for this. Busy waiting is not favored because it wastes CPU cycles that could be used to perform other tasks.)
- It is limited to 2 processes.
- Peterson's solution cannot be used in modern CPU architectures.

Semaphores:

A semaphore is a signaling mechanism and a thread that is waiting on a semaphore can be signaled by another thread. This is different than a mutex as the mutex can be signaled only by the thread that is called the wait function.

A semaphore uses two atomic operations, wait and signal for process synchronization.
A Semaphore is an integer variable, which can be accessed only through two operations wait() and signal().
There are two types of semaphores: Binary Semaphores and Counting Semaphores.

- **Binary Semaphores:** They can only be either 0 or 1. They are also known as mutex locks, as the locks can provide mutual exclusion. All the processes can share the same mutex semaphore that is initialized to 1. Then, a process has to wait until the lock becomes 0. Then, the process can make the mutex semaphore 1 and start its critical section. When it completes its critical section, it can reset the value of the mutex semaphore to 0 and some other process can enter its critical section.
- **Counting Semaphores:** They can have any value and are not restricted over a certain domain. They can be used to control access to a resource that has a limitation on the number of simultaneous accesses. The semaphore can be initialized to the number of instances of the resource. Whenever a process wants to use that resource, it checks if the number of remaining instances is more than zero, i.e., the process has an instance available. Then, the process can enter its critical section thereby decreasing the value of the counting semaphore by 1. After the process is over with the use of the instance of the resource, it can leave the critical section thereby adding 1 to the number of available instances of the resource.

Advantages and Disadvantages:
Advantages of Process Synchronization:

- Ensures data consistency and integrity
- Avoids race conditions
- Prevents inconsistent data due to concurrent access
- Supports efficient and effective use of shared resources

Disadvantages of Process Synchronization:

- Adds overhead to the system
- Can lead to performance degradation
- Increases the complexity of the system
- Can cause deadlocks if not implemented properly

Synchronization Hardware
In Synchronization hardware, we explore several more solutions to the critical-section problem using techniques ranging from hardware to software based APIs available to application programmers. These solutions are based on the premise of locking; however, the design of such locks can be quite sophisticated.

These Hardware features can make any programming task easier and improve system efficiency. Here, we present some simple hardware instructions that are available on many systems and show how they can be used effectively in solving the critical-section problem. If we could prevent interrupts from occurring while a shared variable was being modified. The critical-section problem could be solved simply in a uniprocessor environment. In this manner, we would be assuring that the current sequence of instructions would be allowed to execute in order without preemption. No other instructions would be run, so no unexpected modifications could be made to the shared variable. This is the approach taken by non-preemptive kernels. But unfortunately, this solution is not as feasible in a multiprocessor environment. Since the message is passed to all the processors, disabling interrupts on a multiprocessor can be time consuming.

System efficiency decreases when this massage passing delays entry into each critical section. Also the effect on a system's clock is considered if the clock is kept updated by interrupts. So many modern computer systems therefore provide special hardware instructions that allow us that we can test and modify the content of a word or to swap the contents of two words atomically—that is, as one uninterruptible unit. We may use these special instructions to solve the critical-section problem in a relatively simple manner. Now we abstract the main concepts behind these types of instructions. The TestAndSet() instruction can be defined as shown in below code.

```
boolean test and set(boolean *target){
  boolean rv = *target;
```

```
  *target = true;
  return rv;
}
```

Definition of the test and set() instruction.

The essential characteristic is that this instruction is executed atomically. So, if two TestAndSet C) instructions are executed simultaneously (each on a different CPU), they will be executed sequentially in some arbitrary order. we can implement mutual exclusion by declaring a Boolean variable lock, initialized to false, if the machine supports the TestAndSet () instruction. The structure of process P, is shown in below.

Example

```
do {
  while (test and set(&lock)) ;
  /* do nothing */
  /* critical section */
  lock = false;
  /* remainder section */
}
while (true);
```

Mutual-exclusion implementation with test and set().

The SwapO instruction, in contrast to the TestAndSet0 instruction, operates on the contents of two words; it is executed atomically. mutual exclusion can be provided as follows if the machine supports the SwapO instruction. Here, a global Boolean variable lock is declared and is initialized to false. Additionally, each process has a local Boolean variable key. The structure of process P, is shown in figure below.

```
int compare_and_swap(int *val, int expected, int new val){
  int temp = *val;
  if (*val == expected)
  *val = new val;
  return temp;
}
```

Definition of the compare and swap() instruction.

```
do{
  while (compare_and_swap(&lock, 0, 1) != 0) ;
  /* do nothing */
  /* critical section */
  lock = 0;
```

```
  /* remainder section */
}
while (true);
```

Mutual-exclusion implementation with the compare and swap() instruction.

Since these algorithms satisfy the mutual-exclusion requirement, they do not satisfy the bounded-waiting requirement. In below code, we present another algorithm using the TestAndSet() instruction that satisfies all the critical-section requirements.

```
do{
  waiting[i] = true;
  key = true;
  while (waiting[i] && key)
    key = test and set(&lock);
  waiting[i] = false;
  /* critical section */
  j = (i + 1) % n;
  while ((j != i) && !waiting[j])
    j = (j + 1) % n;
  if (j == i)
    lock = false;
  else
    waiting[j] = false;
  /* remainder section */
}
while (true);
```

Bounded-waiting mutual exclusion with test and set().

The same data structures are boolean waiting[n]; boolean lock; These data structures are initialized to false. To prove the point that the mutual exclusion requirement is met, we note that process P; can enter its critical section only if either waiting[i] == false or key -- false. The value of key can become false only if the TestAndSet() is executed. The first process to execute the TestAndSet() will find key == false; all others must wait. The variable waiting[i] may become false only if another process leaves its critical section; only one waiting [i] is set to false, maintaining the mutual-exclusion requirement.

To prove the point that the progress requirement is met, we note that the arguments presented for mutual exclusion also apply here, since a process exiting the critical section either set lock to false or sets waiting[j] to false. Both of them allow a process that is waiting to enter its critical section to proceed. To prove the point that the bounded-waiting requirement is met, we note that, when a process leaves its critical section, it scans the array waiting in the cyclic ordering (z' + 1, i + 2,..., n — 1, 0, ..., i — 1). It designates the first process in this ordering that is in the entry section (waiting [j] =- true) as the next one to enter the critical section.

Any process that waiting to enter its critical section will thus do so within n — 1 turns. Unfortunately for hardware designers, implementing atomic TestAndSet() instructions on multiprocessors is not a trivial task.

Mutex Locks

Mutex

Mutex is a mutual exclusion object that synchronizes access to a resource. It is created with a unique name at the start of a program. The Mutex is a locking mechanism that makes sure only one thread can acquire the Mutex at a time and enter the critical section. This thread only releases the Mutex when it exits the critical section.

This is shown with the help of the following example −

```
wait (mutex);
…..
Critical Section
…..
signal (mutex);
```

A Mutex is different than a semaphore as it is a locking mechanism while a semaphore is a signalling mechanism. A binary semaphore can be used as a Mutex but a Mutex can never be used as a semaphore.

semaphore is a signalling mechanism and a thread that is waiting on a semaphore can be signaled by another thread. This is different than a mutex as the mutex can be signaled only by the thread that called the wait function.

A semaphore uses two atomic operations, wait and signal for process synchronization.

The wait operation decrements the value of its argument S, if it is positive. If S is negative or zero, then no operation is performed.

```
wait(S)
{
   while (S<=0);
   S--;
}
```

The signal operation increments the value of its argument S.

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

SEMAPHORE

There are mainly two types of semaphores i.e. counting semaphores and binary semaphores.

Counting Semaphores are integer value semaphores and have an unrestricted value domain. These semaphores are used to coordinate the resource access, where the semaphore count is the number of available resources.

The binary semaphores are like counting semaphores but their value is restricted to 0 and 1. The wait operation only works when the semaphore is 1 and the signal operation succeeds when semaphore is 0

Classic Problems of Synchronization
The classical problems of synchronization are as follows:

1. Bound-Buffer problem
2. Sleeping barber problem
3. Dining Philosophers problem
4. Readers and writers problem

Bound-Buffer problem
Also known as the **Producer-Consumer problem**. In this problem, there is a buffer of n slots, and each buffer is capable of storing one unit of data. There are two processes that are operating on the buffer – Producer and Consumer. The producer tries to insert data and the consumer tries to remove data.
If the processes are run simultaneously they will not yield the expected output.
The solution to this problem is creating two semaphores, one full and the other empty to keep a track of the concurrent processes.

Sleeping Barber Problem
This problem is based on a hypothetical barbershop with one barber.
When there are no customers the barber sleeps in his chair. If any customer enters he will wake up the barber and sit in the customer chair. If there are no chairs empty they wait in the waiting queue.

Dining Philosopher's problem
This problem states that there are K number of philosophers sitting around a circular table with one chopstick placed between each pair of philosophers. The philosopher will be able to eat if he can pick up two chopsticks that are adjacent to the philosopher.
This problem deals with the allocation of limited resources.

Readers and Writers Problem
This problem occurs when many threads of execution try to access the same shared resources at a time. Some threads may read, and some may write. In this scenario, we may get faulty outputs.

Monitors

Monitors

Monitors are a synchronization construct that were created to overcome the problems caused by semaphores such as timing errors.

Monitors are abstract data types and contain shared data variables and procedures. The shared data variables cannot be directly accessed by a process and procedures are required to allow a single process to access the shared data variables at a time.

This is demonstrated as follows:

```
monitor monitorName
{
```

```
  data variables;

  Procedure P1(....)
  {

  }

  Procedure P2(....)
  {

  }

  Procedure Pn(....)
  {

  }

  Initialization Code(....)
  {

  }
}
```

Only one process can be active in a monitor at a time. Other processes that need to access the shared variables in a monitor have to line up in a queue and are only provided access when the previous process release the shared variables.