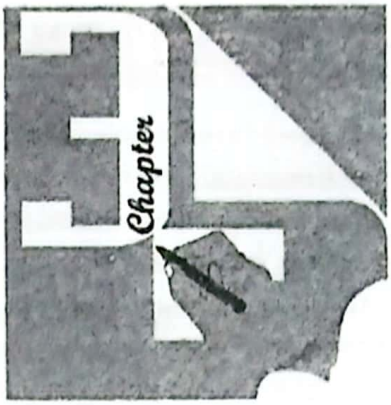

PROCESS MANAGEMENT

CHAPTER OUTLINE

After comprehensive study of this chapter, you will be able to:

- Definitions of Process, The process Model, Process States, Process State Transition, The process Control Block, Operations on Process (Creation, Termination, Hierarchies, Implementation), Cooperating Processes, System Calls (Process Management, File Management, Directory Management).
- Definitions of Threads, types of Thread Process (Single and Multithreaded process), Benefits of Multithread, Multithreading Models (Many-to-One Model, One-to-One Model, Many- to- Many Model).
- Introduction, Race Condition, Critical Regions, Avoiding Critical Region: Mutual Exclusion and serializability; Mutual Exclusion Conditions, proposals for Achieving Mutual Exclusion: Disabling Interrupts, Lock Variable, Strict Alteration (Peterson's Solution), The TSL Instruction, Sleep and Wakeup, Types of Mutual Exclusion (Semaphore, Monitors, Mutexes, Message Passing, Bounded Buffer), Serializability: Locking Protocols and Time Stamp Protocols: Classical IPC Problems (Dining Philosophers Problems, The Readers and Writers Problem, The Sleeping Barber's Problem)
- Basic Concept, Types of Scheduling (Preemptive Scheduling, Non-Preemptive Scheduling, Batch, Interactive, Real Time Scheduling), Scheduling Criteria or Performance Analysis, Scheduling Algorithm (Round-Robin, First Come First Served, Shortest job first, Shortest Process Next, Shortest Remaining time Next, Real Time, Priority Fair share, Guaranteed, Lottery Scheduling, HRN, Multiple Queue, Multilevel Feedback Queue); Some Numerical Examples on Scheduling.

INTRODUCTION TO PROCESS

A process is an instance of a program running in a computer. It is close in meaning to task, a term used in some operating systems. In UNIX and some other operating systems, a process is started when a program is initiated (either by a user entering a shell command or by another program). Like a task, a process is a running program with which a particular set of data is associated so that the process can be kept track of. An application that is being shared by multiple users will generally have one process at some stage of execution for each user. A process is basically a program in execution. In computing, a process is the instance of a computer program that is being executed. It contains the program code and its activity. Further A process is defined as an entity which represents the basic unit of work to be implemented in the system.A process can initiate a sub-process, which is a called a child process (and the initiating process is sometimes referred to as its parent). A child process is a replica of the parent process and shares some of its resources, but cannot exist if the parent is terminated.Processes can exchange information or synchronize their operation through several methods of inter process communication (IPC will be covered later).

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.

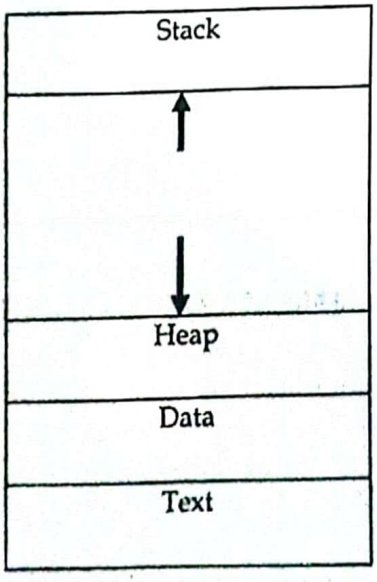

Fig 3.1: layout of a process inside main memory

- **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

Program is an executable file containing the set of instructions written to perform a specific job on your computer. For example, chrome.exe is an executable file containing the set of instructions written so that we can view web pages. **notepad.exe** is an executable file containing the set of instructions which help us to edit and print the text files. Programs are not stored on the primary memory in your computer. They are stored on a disk or a secondary memory on your computer. They are read into the primary memory and executed by the kernel. A program is sometimes referred as passive entity as it resides on a secondary memory.

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

```
#include <stdio.h>
int main()
{
        printf("Hello, World! \n");
        return 0;
}
```

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.

Some examples of computer programs:

- Operating system
- A web browser like Mozilla Firefox and Apple Safari can be used to view web pages on the Internet.
- An office suite can be used to write documents or spreadsheets.
- Video games are computer programs.

A computer program is written by a programmer. It is very difficult to write in the ones and zeroes of machine code, which is what the computer can read, so computer programmers write in a programming language, such as BASIC, C, or Java. Once it is written, the programmer uses a compiler to turn it into a language that the computer can understand.

There are also bad programs, called malware, written by people who want to do bad things to a computer. Some are spyware, trying to steal information from the computer. Some try to damage the data stored on the hard drive. Some others send users to web sites that offer to sell them things. Some are computer viruses or ransomware.

Differences between program and process

a. A program is a definite group of ordered operations that are to be performed. On the other hand, an instance of a program being executed is a process.

b. The nature of the program is passive as it does nothing until it gets executed whereas a process is dynamic or active in nature as it is an instance of executing program and performs the specific action.

c. A program has a longer lifespan because it is stored in the memory until it is not manually deleted while a process has a shorter and limited lifespan because it gets terminated after the completion of the task.

d. The resource requirement is much higher in case of a process; it could need processing, memory, I/O resources for the successful execution. In contrast, a program just requires memory for storage.

PROCESS MODEL

In process model, all the runnable software on the computer is organized into a number of sequential processes. Each process has its own virtual Central Processing Unit (CPU).The real Central Processing Unit (CPU) switches back and forth from process to process. This work of switching back and forth is called multi-programming. A process is basically an activity. It has a program, input, output, and a state. The operating system must need a way to make sure that all the essential processes exist. There are the following four principal events that cause the processes to be created.

- System initialization
- . Execution of a process creation system call by a running process
- A user request to create a new process
- Initiation of a batch work

Generally, there are some processes that are created whenever an operating system is booted. Some of those are foreground processes and others are background processes.

- Foreground process is the process that interacts with the computer users or computer programmers.
- Background processes have some specific functions.

In UNIX system, the ps program can be used to list all the running processes and in windows, the task manager is used to see what programs are currently running into the system. In addition to the processes that are created at the boot time, new processes can also be created. Sometime a running process will issue the system calls just to create one or more than one new processes to help it to do its work.

User can start a program just by typing the command of the program on the command prompt (CMD) or just by doing the double click on the icon of that program. When a process has been created, it starts running and does its work. The new process will terminate generally due to one of the following conditions, described in the table given below.

Condition	Description
Normal Exit	In Normal exit, process terminates because they have done their work successfully
Error Exit	In error exit, the termination of a process is done because of an error caused by the process, sometimes due to the program bug
Fatal Exit	In fatal exit, process terminates because it discovers a fatal error
Killed by other process	In this reason or condition, a process might also terminate due to that it executes a system call that tells the operating system (OS) just to kill some other process

In some computer systems when a process creates another process, then the parent process and child process continue to be associated in certain ways. The child process can itself creates more processes that form a process hierarchy.

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. The operating system maintains management information about a process in a process control block (PCB). Modern operating systems allow a process to be divided into multiple threads of execution, which share all process management information except for information directly related to execution. This information is held in a thread control block (TCB). Threads in a process can execute different parts of the program code at the same time. They can also execute the same parts of the code at the same time, but with different execution state:

- They have independent current instructions; that is, they have (or appear to have) independent program counters.
- They are working with different data; that is, they are (or appear to be) working with independent registers.

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

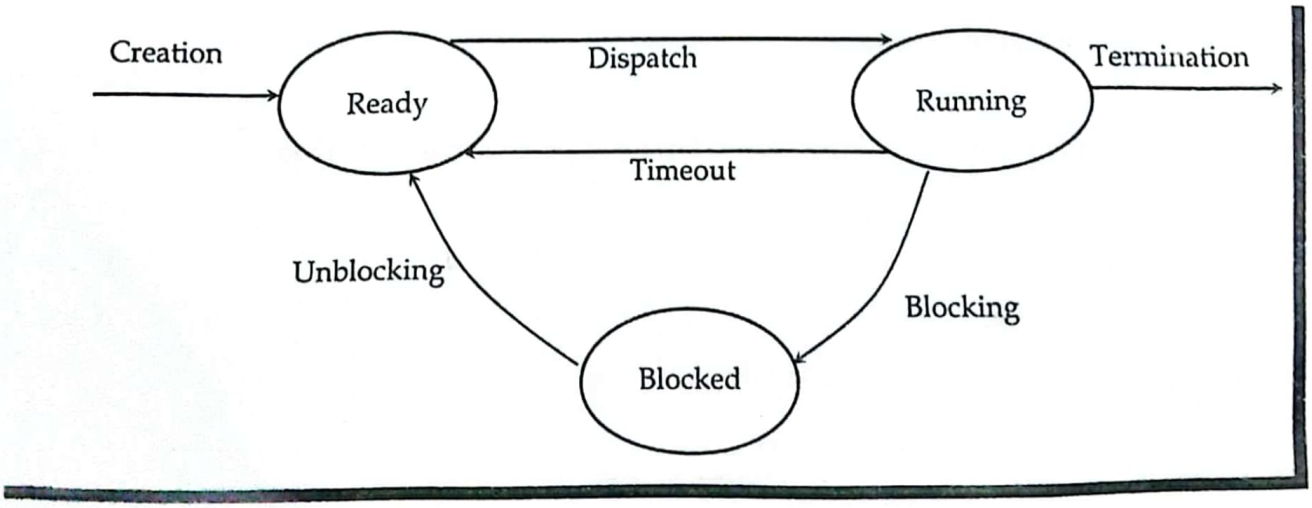

Fig 3.2: Process life cycle

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.

Suspended Processes

Characteristics of suspend process

- Suspended process is not immediately available for execution.
- The process may or may not be waiting on an event.
- For preventing the execution, process is suspended by OS, parent process, process itself and an agent.
- Process may not be removed from the suspended state until the agent orders the removal.

Note: Swapping is used to move all of a process from main memory to disk. When all the process by putting it in the suspended state and transferring it to disk.

Reasons for process suspension

- Swapping
- Timing
- Interactive user request
- Parent process request

Swapping

OS needs to release required main memory to bring in a process that is ready to execute.

Timing

Process may be suspended while waiting for the next time interval.

Interactive user request

Process may be suspended for debugging purpose by user.

Parent process request

To modify the suspended process or to coordinate the activity of various descendants

PROCESS CONTROL BLOCK (PCB)

While creating a process the operating system performs several operations. To identify these processes, it must identify each process; hence it assigns a process identification number (PID) to each process. As the operating system supports multi-programming, it needs to keep track of all the processes. For this task, the process control block (PCB) is used to track the process's execution status. Each block of memory contains information about the process state, program counter, stack pointer, status of opened files, scheduling algorithms, etc. All these information is required and must be saved when the process is switched from one state to another. When the process made transitions from one state to another, the operating system must update information in the process's PCB.

Role of Process Control Block

The role or work of process control block (PCB) in process management is that it can access or modified by most OS utilities including those are involved with memory, scheduling, and input/output resource access. It can be said that the set of the process control blocks give the information of the current state of the operating system. Data structuring for processes is often done in terms of process control blocks. For example, pointers to other process control blocks inside any process control block allows the creation of those queues of processes in various scheduling states.The various information that is contained by process control block is listed below:

- Naming the process
- State of the process
- Resources allocated to the process
- Memory allocated to the process
- Scheduling information
- Input / output devices associated with process

COMPONENTS OF 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:

a. **Process State:** As we know that the process state of any process can be New, running, waiting, executing, blocked, suspended, terminated. For more details regarding process states you can refer process management of an Operating System. Process control block is used to define the process state of any process. In other words, process control block refers the states of the processes.

b. **Process privileges:** This is required to allow/disallow access to system resources.

c. **Process ID:** In computer system there are various processes running simultaneously and each process has its unique ID. This Id helps system in scheduling the processes. This Id is provided by the process control block. In other words, it is an identification number that uniquely identifies the processes of computer system.

d. **Pointer:** A pointer to parent process.

e. **Program Counter:** Program Counter is a pointer to the address of the next instruction to be executed for this process.

f. **CPU registers:** This information is comprising with the various registers, such as index and stack that are associated with the process. This information is also managed by the process control block.

g. **CPU Scheduling Information:** Scheduling information is used to set the priority of different processes. This is very useful information which is set by the process control block. In computer system there were many processes running simultaneously and each process have its priority. The priority of primary feature of RAM is higher than other secondary features. Scheduling information is very useful in managing any computer system.

h. **Memory management information:** This includes the information of page table, memory limits, Segment table depending on memory used by the operating system.

i. **Accounting information:** This includes the amount of CPU used for process execution, time limits, execution ID etc.

j. **IO status information:** This includes a list of I/O devices allocated to the process.

Since PCB contains the critical information for the process, it must be kept in an area of memory protected from normal user access. In some operating systems the PCB is placed in the beginning of the kernel stack of the process as it is a convenient protected location. The architecture of a PCB is completely dependent on Operating System and may contain different information in different operating systems. The PCB is maintained for a process throughout its lifetime, and is deleted once the process terminates. Here is a simplified diagram of a PCB;

Process ID
State
Pointer
Priority
Program Counter
CPU register
I/O Information
Account Information
Etc.....

Fig 3.3: PCB diagram

OPERATIONS ON PROCESS

There are many operations that can be performed on processes. Some of these are process creation, process preemption, process blocking, and process termination. These are given in detail as follows:

Process Creation

Processes need to be created in the system for different operations. This can be done by the following events:

- User request for process creation
- System initialization
- Execution of a process creation system call by a running process
- Batch job initialization

A process may be created by another process using fork(). The creating process is called the parent process and the created process is the child process. A child process can have only one parent but a parent process may have many children. Both the parent and child processes have the same memory image, open files, and environment strings. However, they have distinct address spaces.

A diagram that demonstrates process creation using fork() is as follows:

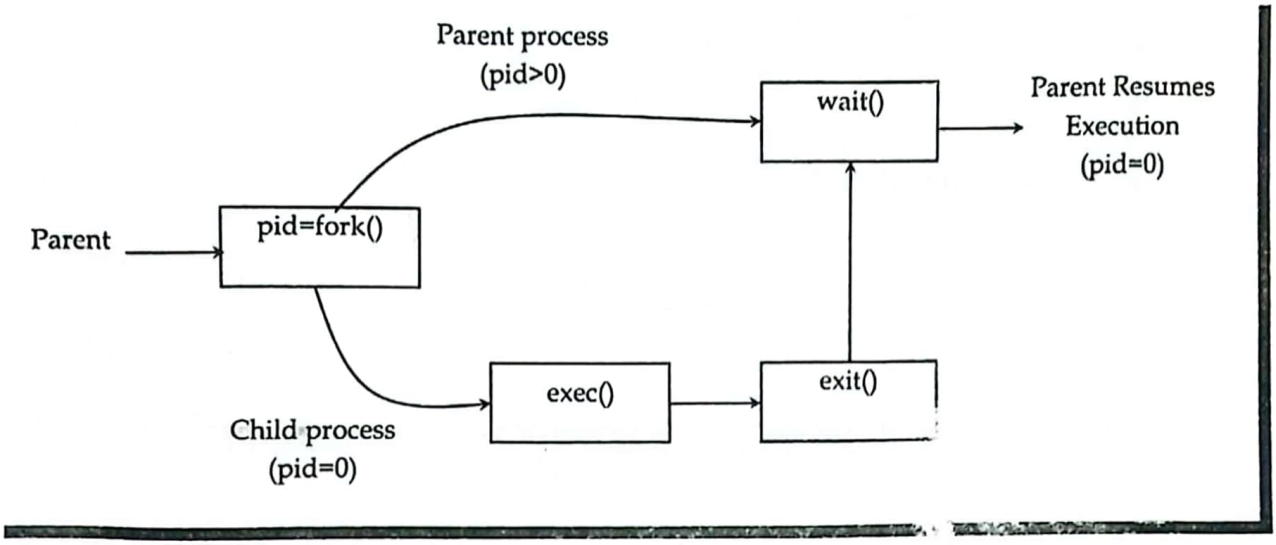

Fig 3.4 Process creation using fork()

Process Preemption

An interrupt mechanism is used in preemption that suspends the process executing currently and the next process to execute is determined by the short-term scheduler. Preemption makes sure that all processes get some CPU time for execution. A diagram that demonstrates process preemption is as follows:

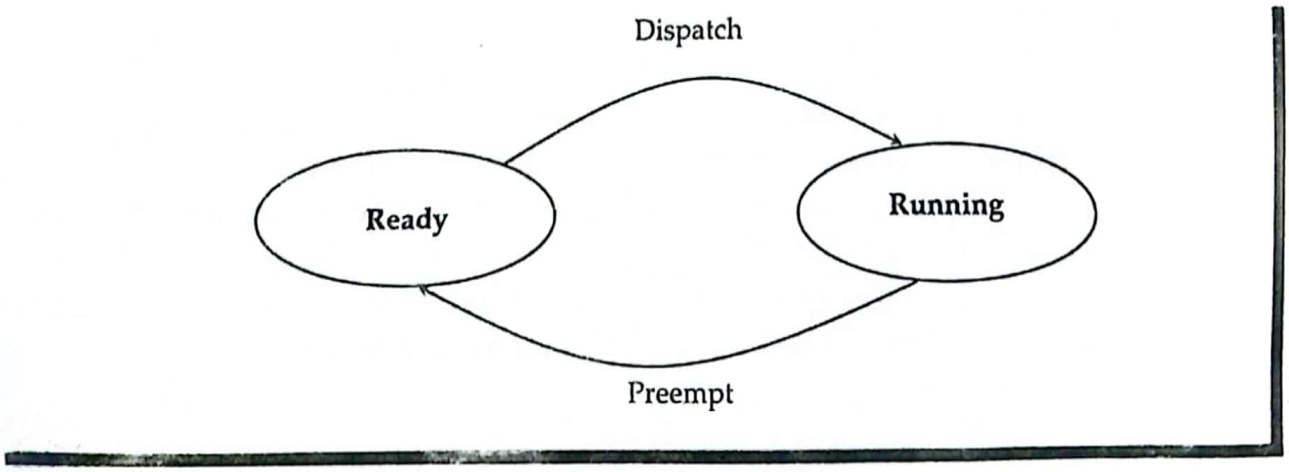

Fig 3.5: Process Preemption

Process Blocking

The process is blocked if it is waiting for some event to occur. This event may be I/O as the I/O events are executed in the main memory and don't require the processor. After the event is complete, the process again goes to the ready state. A diagram that demonstrates process blocking is as follows:

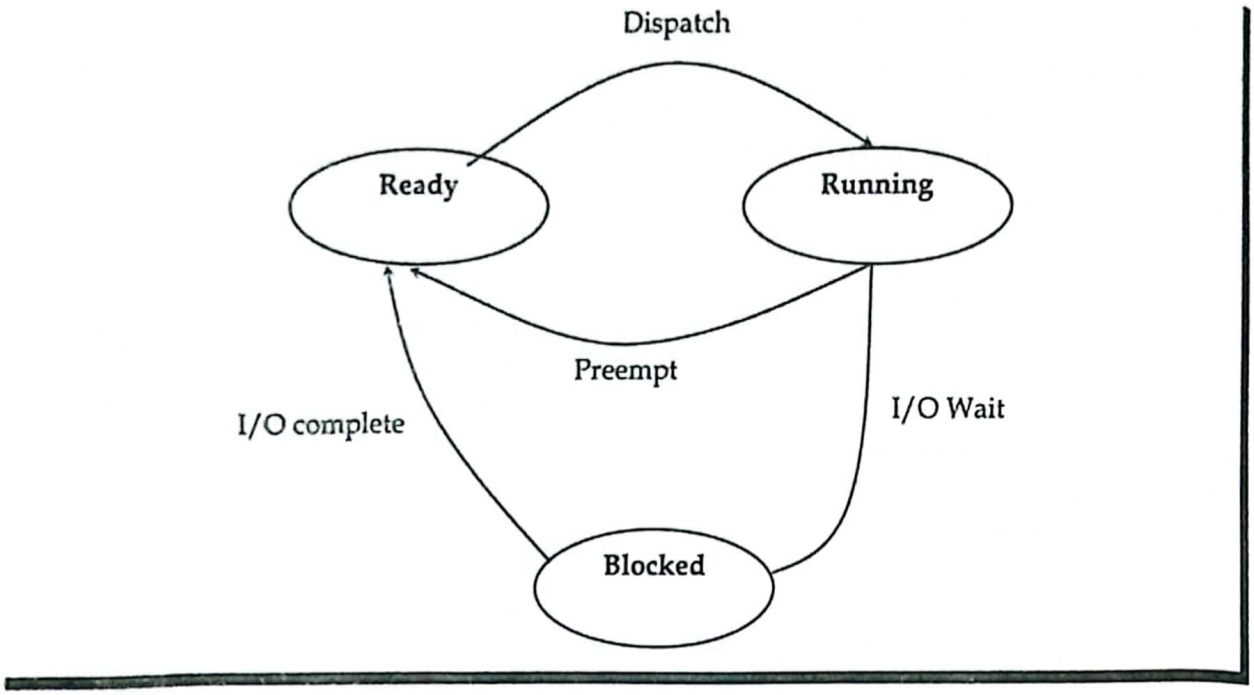

Fig 3.6: Process Blocking

Process Termination

After the process has completed the execution of its last instruction, it is terminated. The resources held by a process are released after it is terminated. A child process can be terminated by its parent process if its task is no longer relevant. The child process sends its status information to the parent process before it terminates. Also, when a parent process is terminated, its child processes are terminated as well as the child processes cannot run if the parent processes are terminated. Some of the causes of process termination are as follows:

- A process may be terminated after its execution is naturally completed. This process leaves the processor and releases all its resources.
- A child process may be terminated if its parent process requests for its termination.
- A process can be terminated if it tries to use a resource that it is not allowed to. For example - A process can be terminated for trying to write into a read only file.
- If an I/O failure occurs for a process, it can be terminated. For example - If a process requires the printer and it is not working, then the process will be terminated.
- In most cases, if a parent process is terminated then its child processes are also terminated. This is done because the child process cannot exist without the parent process.
- If a process requires more memory than is currently available in the system, then it is terminated because of memory scarcity.

PROCESS HIERARCHIES

The process of creating new process form their parent process and again creating new process from previous newly created process in tree like structure is called process hierarchy. Windows has no concept of process hierarchy.

Modern general purpose operating systems permit a user to create and destroy processes. In UNIX this is done by the fork system call, which creates a child process, and the exit system call, which terminates the current process. After a fork both parent and child keep running (indeed they have the same program text) and each can fork off other processes. The root of the tree is a special process created by the OS during startup.

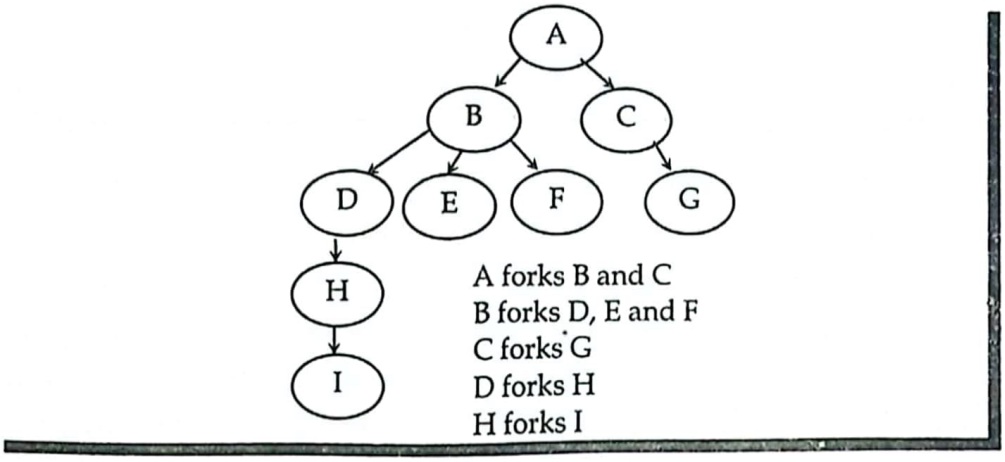

Fig 3.7: Process Hierarchy

PROCESS IMPLEMENTATION

Process Model is implemented by Process Table and Process Control Block which keep track all information of process. At the time of creation of a new process, operating system allocates a memory for it loads a process code in the allocated memory and setup data space for it. The state of process is stored as ' new ' in its PCB and when this process move to ready state its state is also changes in PCB.When a running process needs to wait for an input output devices, its state is changed to 'blocked'. The various queues used for this which is implemented as linked list.

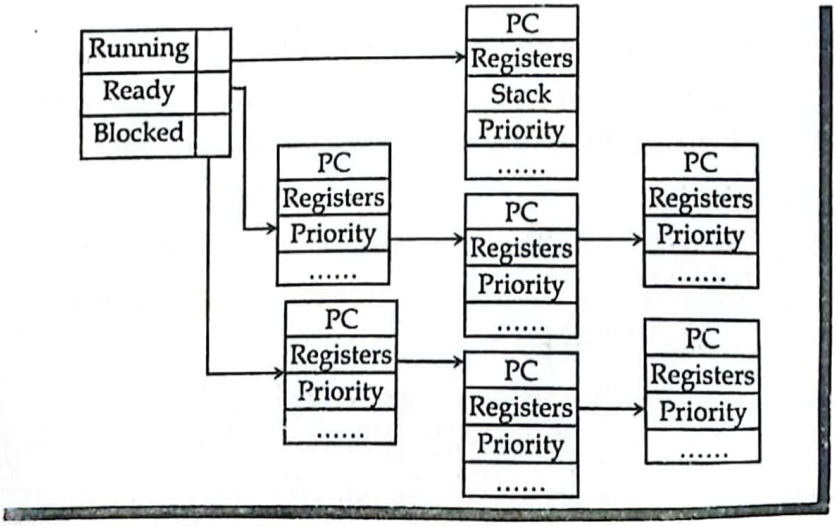

Fig. 3.8: Process Implementation

SYSTEM CALLS

The interface between a process and an operating system is provided by system calls. In general, system calls are available as assembly language instructions. They are also included in the manuals used by the assembly level programmers. System calls are usually made when a process in user mode requires access to a resource. Then it requests the kernel to provide the resource via a system call. A figure representing the execution of the system call is given as follows:

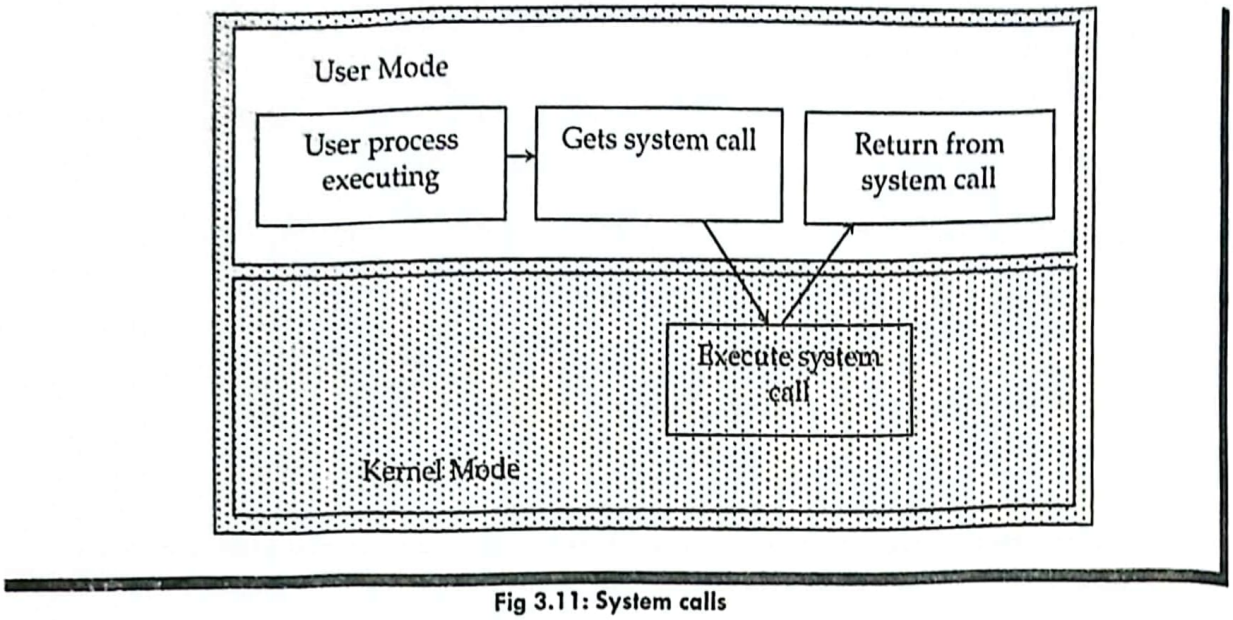

Fig 3.11: System calls

As can be seen from this diagram, the processes execute normally in the user mode until a system call interrupts this. Then the system call is executed on a priority basis in the kernel mode. After the execution of the system call, the control returns to the user mode and execution of user processes can be resumed. In general, system calls are required in the following situations:

- If a file system requires the creation or deletion of files. Reading and writing from files also require a system call.
- Creation and management of new processes.
- Network connections also require system calls. This includes sending and receiving packets.
- Access to a hardware device such as a printer, scanner etc. requires a system call.

Types of System Calls

There are mainly five types of system calls. These are explained in detail as follows:

- **Process Control:** These system calls deal with processes such as process creation, process termination etc.
- **File Management:** These system calls are responsible for file manipulation such as creating a file, reading a file, writing into a file etc.
- **Device Management:** These system calls are responsible for device manipulation such as reading from device buffers, writing into device buffers etc.

- **Information Maintenance:** These system calls handle information and its transfer between the operating system and the user program.
- **Communication:** These system calls are useful for inter process communication. They also deal with creating and deleting a communication connection.

Examples of Windows and UNIX System Calls

	Windows	Unix
Process Control	CreateProcess(),ExitProcess() WaitForSingleObject()	fork() exit(),wait()
File Manipulation	CreateFile(),ReadFile() WriteFile(),CloseHandle()	open(),read() write(),close()
Device Manipulation	SetConsoleMode(),ReadConsole() WriteConsole()	ioctl() read(),write()
Information Maintenance	GetCurrentProcessID(),SetTimer() Sleep()	getpid() alarm(),sleep()
Communication	CreatePipe() CreateFileMapping() MapViewOfFile()	pipe() shmget() mmap()
Protection	SetFileSecurity() InitlializeSecurityDescriptor() SetSecurityDescriptorGroup()	chmod() umask() chown()

DEFINITIONS OF THREADS

Despite of the fact that a thread must execute in process, the process and its associated threads are different concept. Processes are used to group resources together and threads are the entities scheduled for execution on the CPU.

A thread is a single sequence stream within in a process. Because threads have some of the properties of processes, they are sometimes called lightweight processes. In a process, threads allow multiple executions of streams. In many respect, threads are popular way to improve application through parallelism. The CPU switches rapidly back and forth among the threads giving illusion that the threads are running in parallel. Like a traditional process i.e., process with one thread, a thread can be in any of several states (Running, Blocked, Ready or terminated). Each thread has its own stack. Since thread will generally call different procedures and thus a different execution history. This is why thread needs its own stack. An operating system that has thread facility, the basic unit of CPU utilization is a thread. A thread has or consists of a program counter (PC), a register set, and a stack space. Threads are not independent of one other like processes as a result threads shares with other threads their code section, data section, OS resources also known as task, such as open files and signals.

Traditional (heavyweight) processes have a single thread of control - There is one program counter, and one sequence of instructions that can be carried out at any given time, as shown in figure below multi-threaded applications have multiple threads within a single process, each having their own

program counter, stack and set of registers, but sharing common code, data, and certain structures such as open files.

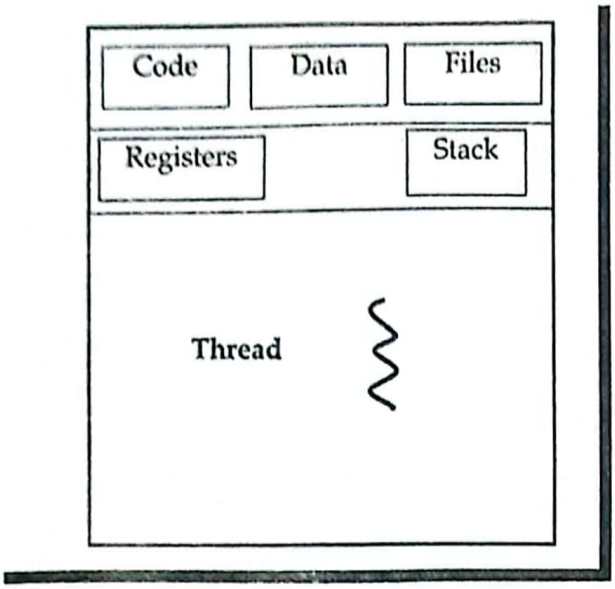

Fig 3.12: Single threaded process

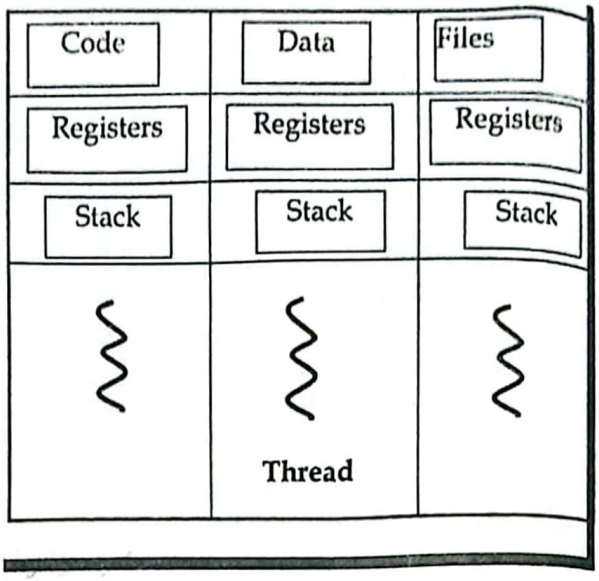

Fig 3.13: Multi threaded process

Threads are very useful in modern programming whenever a process has multiple tasks to perform independently of the others. This is particularly true when one of the tasks may block, and it is desired to allow the other tasks to proceed without blocking. For example, in a word processor, a background thread may check spelling and grammar while a foreground thread processes user input (keystrokes), while yet a third thread loads images from the hard drive, and a fourth does periodic automatic backups of the file being edited.

Another example is a web server - Multiple threads allow for multiple requests to be satisfied simultaneously, without having to service requests sequentially or to fork off separate processes for every incoming request. (The latter is how this sort of thing was done before the concept of threads was developed. A daemon would listen at a port, fork off a child for every incoming request to be processed, and then go back to listening to the port). There are four major benefits to multi-threading:

- **Responsiveness** - One thread may provide rapid response while other threads are blocked or slowed down doing intensive calculations.
- **Resources haring** - By default threads share common code, data, and other resources, which allows multiple tasks to be performed simultaneously in a single address space.
- **Economy** - Creating and managing threads (and context switches between them) is much faster than performing the same tasks for processes.
- **Scalability, i.e. Utilization of multiprocessor architectures** - A single threaded process can only run on one CPU, no matter how many may be available, whereas the execution of a multi-threaded application may be split amongst available processors. (Note that single threaded processes can still benefit from multi-processor architectures when there are multiple processes contending for the CPU, i.e. when the load average is above some certain threshold.)

Properties of a Thread

- Only one system call can create more than one thread (Lightweight process).
- Threads share data and information.
- Threads shares instruction, global and heap regions but have its own individual stack and registers.
- Thread management consumes no or fewer system calls as the communication between threads can be achieved using shared memory.
- The isolation property of the process increases its overhead in terms of resource consumption.

THE THREAD MODEL

There are two types of threads to be managed in a modern system: User threads and kernel threads. User threads are supported above the kernel, without kernel support. These are the threads that application programmers would put into their programs. Kernel threads are supported within the kernel of the OS itself. All modern operating systems support kernel level threads, allowing the kernel to perform multiple simultaneous tasks and/or to service multiple kernel system calls simultaneously. In a specific implementation, the user threads must be mapped to kernel threads, using one of the following strategies.

- **Many-To-One Model:** This model maps many user level threads to one kernel level thread. Thread management is done by thread library in user space, so it is efficient. However, if a blocking system call is made, then the entire process blocks, even if the other user threads would otherwise be able to continue. Because a single kernel thread can operate only on a single CPU, the many-to-one model does not allow individual processes to be split across multiple CPUs. Green threads for Solaris and GNU Portable Threads implement the many-to-one model in the past, but few systems continue to do so today.

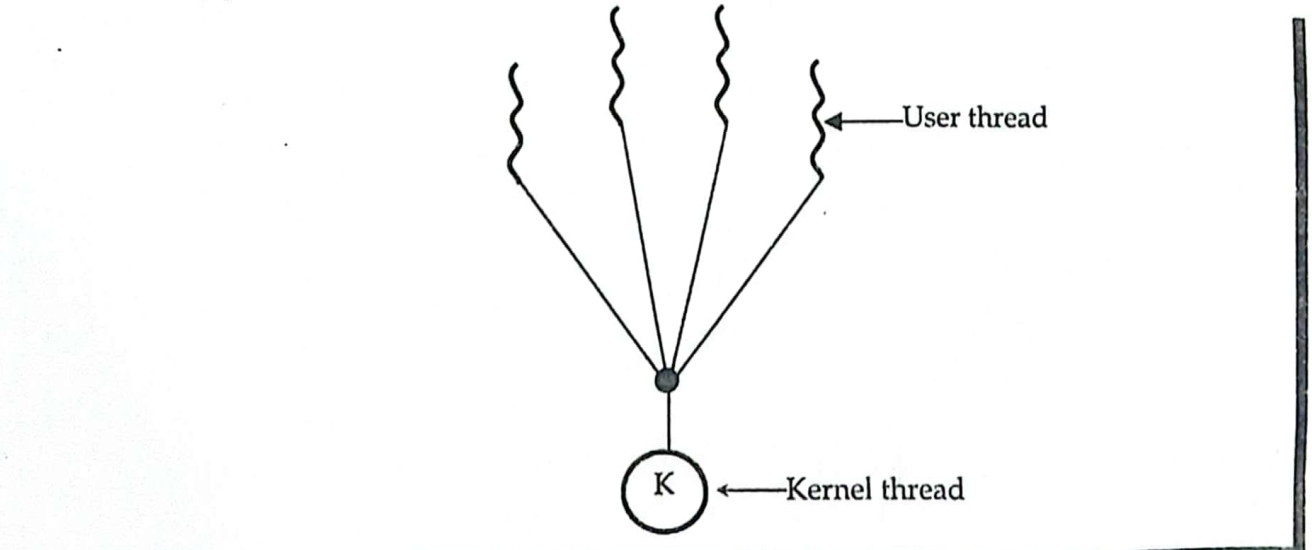

Fig 3.14: many to one thread model

- **One-To-One Model:** One user thread is mapped to one kernel thread. It provides more concurrency than previous model by allowing another thread to run during blocking. It also allows parallelism. The only overhead is for each threads corresponding kernel thread should be created. Most implementations of this model place a limit on how many threads can be created. Linux and Windows from 95 to XP implement the one-to-one model for threads.

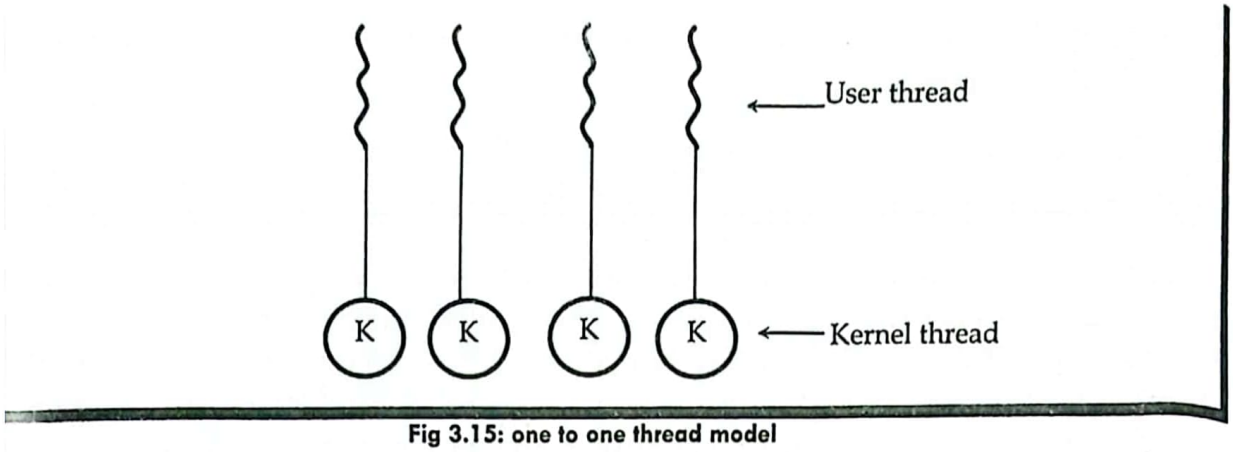

Fig 3.15: one to one thread model

- **Many-To-Many Model:** In this model, many user level threads multiplex to the Kernel thread of smaller or equal numbers. The number of Kernel threads may be specific to either a particular application or a particular machine. Users have no restrictions on the number of threads created. Blocking kernel system calls do not block the entire process. Processes can be split across multiple processors. Individual processes may be allocated variable numbers of kernel threads, depending on the number of CPUs present and other factors.

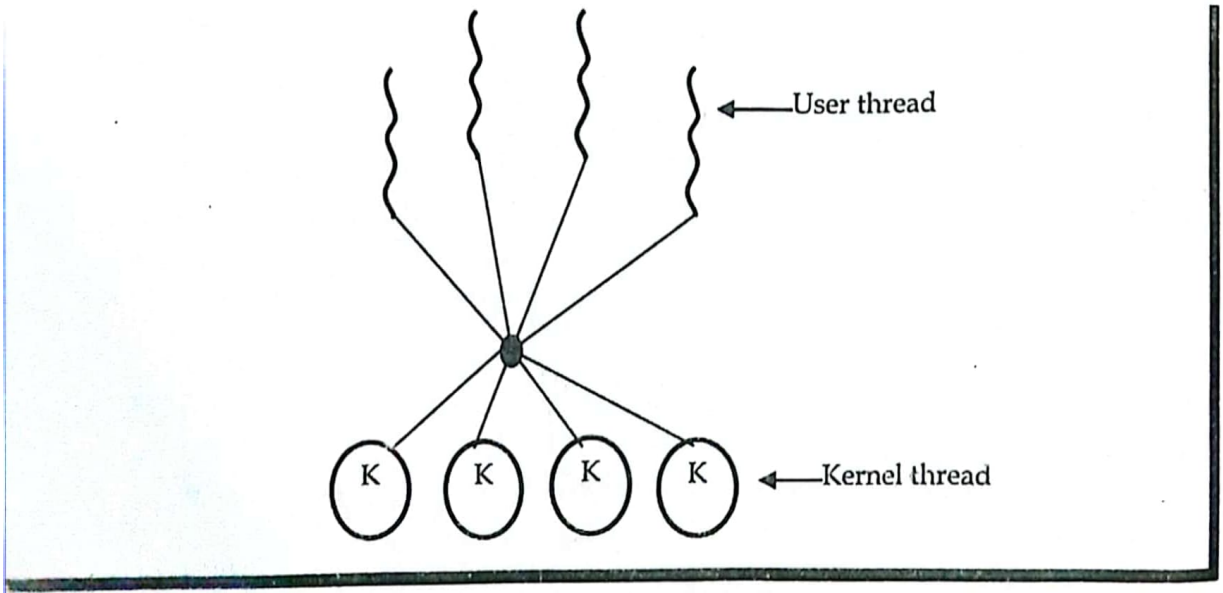

Fig 3.16: Many-to-many thread model

IMPLEMENTING THREADS IN USER SPACE

The first method is to put the threads package entirely in user space. The kernel knows nothing about them. As far as the kernel is concerned, it is managing ordinary, single-threaded processes. The first, and most obvious, advantage is that a user-level threads package can be implemented on an operating system that does not support threads. All operating systems used to fall into this category, and even now some still do.

The threads run on top of a run-time system, which is a collection of procedures that manage threads. When threads are managed in user space, each process needs its own private thread table. It is analogous to the kernel's process table, except that it keeps track only of the per-thread properties such each thread's program counter stack pointer, registers, state, etc. The thread table is managed by the runtime system. When a thread is moved to ready state or blocked state, the information needed to restart it is stored in the thread table, exactly the same way as the kernel stores information about processes in the process table.

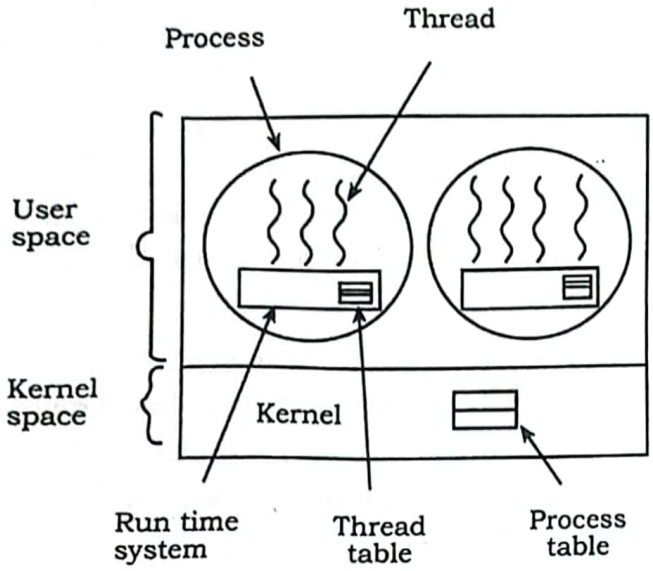

Fig 3.17: A user-level threads package.

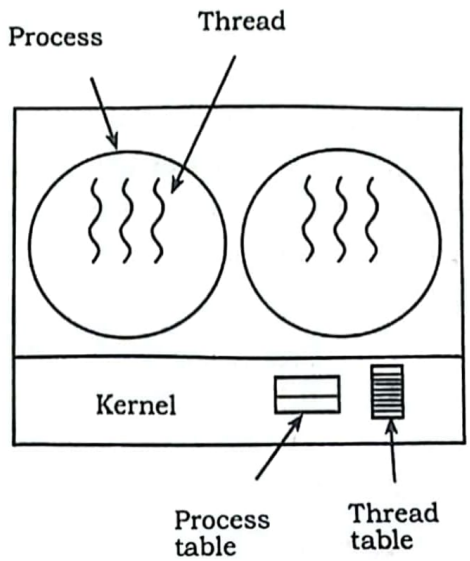

Fig 3.18: A threads package managed by thekernel.

THREAD VS. PROCESS

As we mentioned earlier that in many respect threads operate in the same way as that of processes. Some of the similarities and differences are:

Similarities

- Like processes threads share CPU and only one thread active (running) at a time.
- Like processes, threads within a process, threads within a process execute sequentially.
- Like processes, thread can create children.
- And like process, if one thread is blocked, another thread can run.

Differences

- All threads of a program are logically contained within a process.
- A process is heavy weighted, but a thread is light weighted.
- A program is an isolated execution unit whereas thread is not isolated and shares memory.
- A thread cannot have an individual existence; it is attached to a process. On the other hand, a process can exist individually.
- At the time of expiration of a thread, its associated stack could be recovered as every thread has its own stack. In contrast, if a process dies, all threads die including the process.

KERNEL-LEVEL THREADS

To make concurrency cheaper, the execution aspect of process is separated out into threads. As such, the OS now manages threads and processes. All thread operations are implemented in the kernel and the OS schedules all threads in the system. OS managed threads are called kernel-level threads or light weight processes.

In this method, the kernel knows about and manages the threads. No runtime system is needed in this case. Instead of thread table in each process, the kernel has a thread table that keeps track of all threads in the system. In addition, the kernel also maintains the traditional process table to keep track of processes. Operating Systems kernel provides system call to create and manage threads.

Advantages

- Because kernel has full knowledge of all threads, Scheduler may decide to give more time to a process having large number of threads than process having small number of threads.
- Kernel-level threads are especially good for applications that frequently block.

Disadvantages

- The kernel-level threads are slow and inefficient. For instance, threads operations are hundreds of times slower than that of user-level threads.
- Since kernel must manage and schedule threads as well as processes. It requires a full thread control block (TCB) for each thread to maintain information about threads. As a result, there is significant overhead and increased in kernel complexity.

USER-LEVEL THREADS

Kernel-Level threads make concurrency much cheaper than process because, much less state to allocate and initialize. However, for fine-grained concurrency, kernel-level threads still suffer from too much overhead. Thread operations still require system calls. Ideally, we require thread operations to be as fast as a procedure call. Kernel-Level threads have to be general to support the

needs of all programmers, languages, runtimes, etc. For such fine grained concurrency, we need still cheaper threads.

To make threads cheap and fast, they need to be implemented at user level. User-Level threads are managed entirely by the run-time system (user-level library). The kernel knows nothing about user-level threads and manages them as if they were single-threaded processes. User-Level threads are small and fast, each thread is represented by a PC, register, stack, and small thread control block. Creating a new thread, switching between threads, and synchronizing threads are done via procedure call i.e. no kernel involvement. User-Level threads are hundred times faster than Kernel-Level threads.

Advantages

The most obvious advantage of this technique is that a user-level threads package can be implemented on an Operating System that does not support threads. Some other advantages are

- User-level threads do not require modification to operating systems.
- Simple Representation: Each thread is represented simply by a PC, registers, stack and a small control block, all stored in the user process address space.
- Simple Management: This simply means that creating a thread, switching between threads and synchronization between threads can all be done without intervention of the kernel.
- Fast and Efficient: Thread switching is not much more expensive than a procedure call.

Disadvantages

- There is a lack of coordination between threads and operating system kernel. Therefore, process as whole gets one time slice irrespective of whether process has one thread or 1000 threads within. It is up to each thread to relinquish control to other threads.
- User-level threads require non-blocking systems call i.e., a multithreaded kernel. Otherwise, entire process will have blocked in the kernel, even if there are runnable threads left in the processes. For example, if one thread causes a page fault, the process blocks.

INTER PROCESS COMMUNICATION

Inter-process communication (IPC) is a mechanism that allows the exchange of data between processes. By providing a user with a set of programming interfaces, IPC helps a programmer organize the activities among different processes. IPC allows one application to control another application, thereby enabling data sharing without interference. IPC enables data communication by allowing processes to use segments, semaphores, and other methods to share memory and information. IPC facilitates efficient message transfer between processes. The idea of IPC is based on Task Control Architecture (TCA). It is a flexible technique that can send and receive variable length arrays, data structures, and lists. It has the capability of using publish/subscribe and client/server data-transfer paradigms while supporting a wide range of operating systems and languages.

Working together with multiple processes, require an inter-process communication (IPC) method which will allow them to exchange data along with various information. There are two primary models of inter-process communication:

- shared memory and
- Message passing.

In the shared-memory model, a region of memory which is shared by cooperating processes gets established. Processes can be then able to exchange information by reading and writing all the data to the shared region. In the message-passing form, communication takes place by way of messages exchanged among the cooperating processes. The two communications models are contrasted in the figure below:

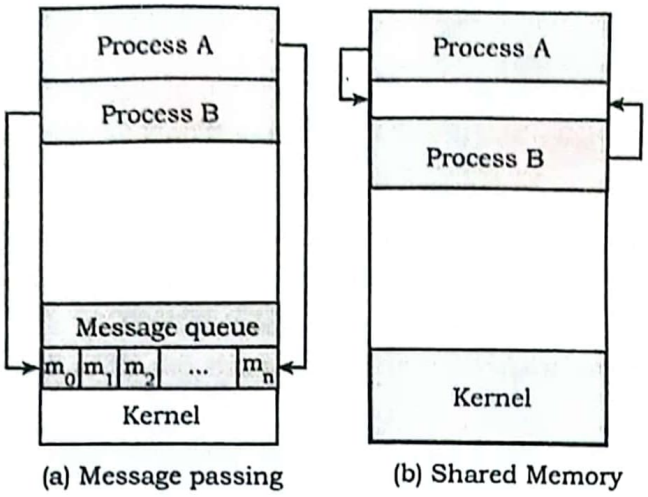

Fig 3.19: Inter process communication

RACE CONDITION

A race condition occurs when two or more threads can access shared data and they try to change it at the same time. Because the thread scheduling algorithm can swap between threads at any time, you don't know the order in which the threads will attempt to access the shared data. Therefore, the result of the change in data is dependent on the thread scheduling algorithm, i.e. both threads are racing to access/change the data.

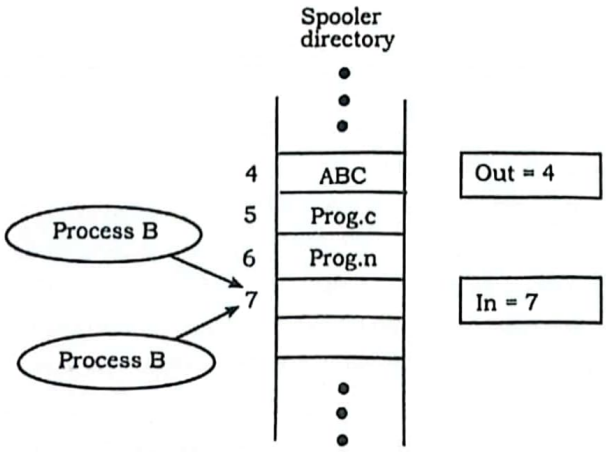

Fig 3.20: IPC with race condition

A print spooler: When a process wants to print a file it enters the filename in a special spooler directly. Another process, the Printer Daemon, periodically checks to see if there are any files to be printed, and if there are, it prints them and removes their name from the directory. Imagine that our spooler directory has a large number of slots, numbered 0, 1, 2 ... each one capable of holding a filename. Also imagine that there are two shared variables,

- Out: points to next file to printed.
- In: points to next free slot in the directory.

Slots 0 to 3 files already printed. Slots 4 to 6 files names which has to be printed.

Now the main issue comes:

Process A reads in and store the value, 7, in a local variable called next-free-slot. Just then a clock interrupt occurs and the CPU decides that process A has run long enough, it switches to process B.

Process B also reads in, and also gets a 7, so it stores the name of its in slot 7 and update into 8. Then it goes off and does other things.

Eventually, process A once again, starting from the place at left off last time. It looks next free slot, finds a7 there, and writes its file name 7 in slot 7, erasing the name that process B just put there. Then it computes next-free-slot+1, which is 8, and sets in to 8.

The spooler directory is now internally consistent, so the printer daemon will not notice anything wrong, but process B will never receive any output.

CRITICAL SECTION

How do we avoid race conditions? One way to prevent two or more process, using the shared data is mutual exclusion i.e. some way of making sure that if one process is using a shared variable or file, the process will be excluded from doing same thing. Sometimes a process has to access shared memory or files that can lead to races. That part of the program where the shared memory is accessed is called the critical region or critical section. If we could arrange matters such that no two processes were ever in their critical regions at the same time, we could avoid races. The critical section is given as follows:

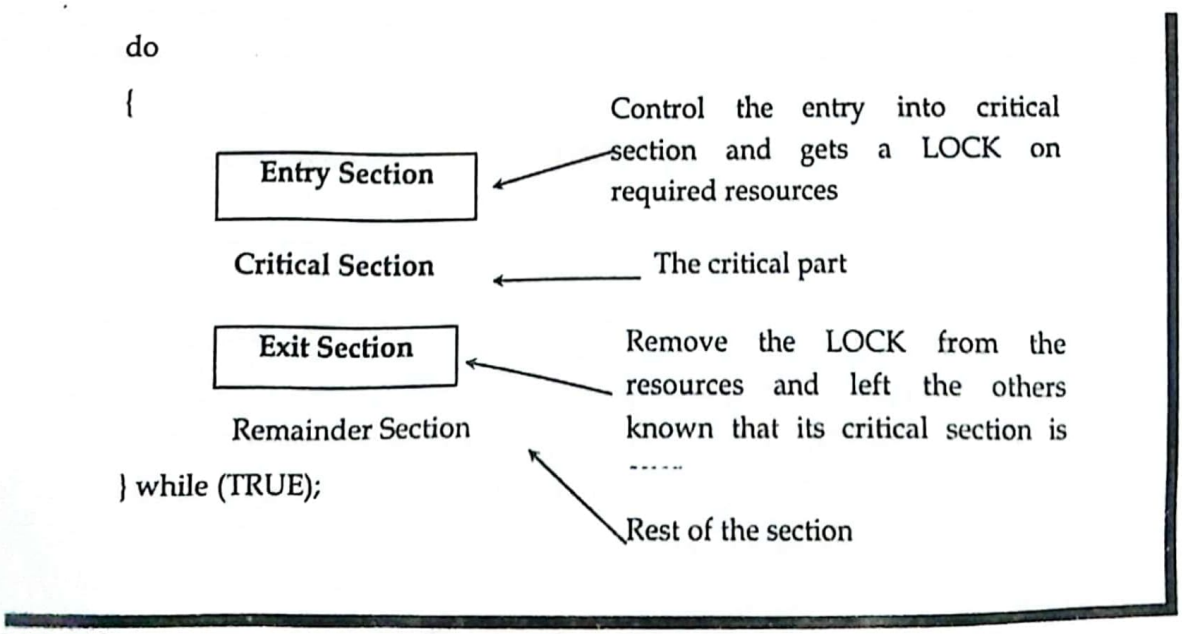

Fig 3.21: Critical section

In the above diagram, the entry sections handle the entry into the critical section. It acquires the resources needed for execution by the process. The exit section handles the exit from the critical section. It releases the resources and also informs the other processes that critical section is free.

The critical section problem needs a solution to synchronize the different processes. The solution to the critical section problem must satisfy the following conditions:

a. **Mutual Exclusion:** Mutual exclusion implies that only one process can be inside the critical section at any time. If any other processes require the critical section, they must wait until it is free.

b. **Progress:** Progress means that if a process is not using the critical section, then it should not stop any other process from accessing it. In other words, any process can enter a critical section if it is free.

c. **Bounded Waiting:** Bounded waiting means that each process must have a limited waiting time. It should not wait endlessly to access the critical section.

AVOIDING CRITICAL REGION

To avoiding critical region we need process synchronization. Process Synchronization is the task of coordinating the execution of processes in a way that no two processes can have access to the same shared data and resources. It is specially needed in a multi-process system when multiple processes are running together, and more than one process try to gain access to the same shared resource or data at the same time.

This can lead to the inconsistency of shared data. So the change made by one process not necessarily reflected when other processes accessed the same shared data. To avoid this type of inconsistency of data, the processes need to be synchronized with each other. Mutual exclusion and serializability is the best way of avoiding critical regions.

Mutual Exclusion and Serializability

Mutual exclusion is a concurrency control property which is introduced to prevent race conditions. It is the requirement that a process cannot enter its critical section while another concurrent process is currently present or executing in its critical section i.e. only one process is allowed to execute the critical section at any given instance of time.

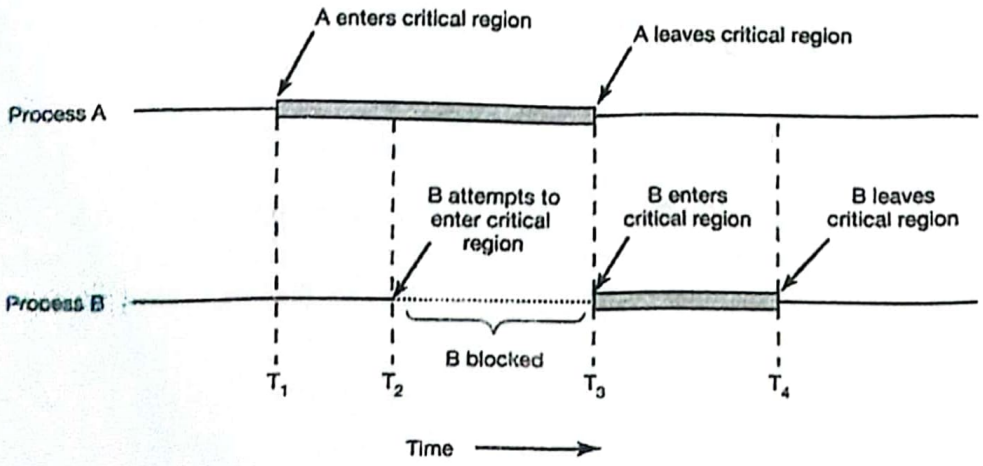

Fig 3.22: Mutual exclusion

At time T1 process A enters its critical region. At T2 process B attempts to enter its critical region but fails. Until T3, process B is temporarily suspended. At time T3, B enters its critical region. At T4, B leaves its critical region.

MUTUAL EXCLUSION CONDITIONS

If we could arrange matters such that no two processes were ever in their critical sections simultaneously, we could avoid race conditions. We need four conditions to hold to have a good solution for the critical section problem (mutual exclusion).

- No two processes may at the same moment inside their critical sections.
- No assumptions are made about relative speeds of processes or number of CPUs.
- No process should outside its critical section should block other processes.
- No process should wait arbitrary long to enter its critical section.

Proposals for Achieving Mutual Exclusion

In this section we will examine various proposals for achieving mutual exclusion, so that while one process is busy updating shared memory in its critical region, no other process will enter its critical region and cause trouble. Some major approaches for achieving mutual exclusion are listed below:

- Disabling Interrupts
- Lock Variable
- Strict Alteration
- Peterson's Solution
- The TSL Instruction
- Sleep and Wakeup

Disabling Interrupts

It is also called hardware solution for critical section problem. It is the simplest solution to have each process disable all interrupts just after entering its critical region and re-enable them just before leaving critical regions. With interrupts disabled, no clock interrupts can occur. The CPU is only switched from process to process as a result of clock or other interrupts, after all, and with interrupts turned off the CPU will not be switched to another process. Hence, no other process will enter its critical and mutual exclusion achieved.

Disabling interrupts is sometimes a useful interrupts is sometimes a useful technique within the kernel of an operating system, but it is not appropriate as a general mutual exclusion mechanism for user's process. The reason is that it is unwise to give user process the power to turn off interrupts. Furthermore if the system is a multiprocessor, with two or more CPUs, disabling interrupts affects only the CPU that executed the disable instruction. The other ones will continue running and can access the shared memory.

Solution:

Whenever someone is about to sleep then a bit is maintained to tell do not sleep. But when there are N producer and consumer then we have to record N wake up calls. So Dijkstra introduced something called as Semaphores which will tell how many wake up calls happened. However Semaphores need support from Operating System. So in the next section we will discuss about SEMAPHORS.

TYPES OF MUTUAL EXCLUSION

Mutual exclusion is a property of concurrency control, which is instituted for the purpose of preventing race conditions. The major types of mutual exclusion arelisted below:

- Semaphore
- Monitors
- Mutexes
- Message Passing
- Bounded Buffer

Semaphore

In 1965, Dijkstra proposed a new and very significant technique for managing concurrent processes by using the value of a simple integer variable to synchronize the progress of interacting processes. A semaphore is a variable or abstract data type used to control access to a common resource by multiple processes in a concurrent system such as a multitasking operating system. A semaphore is simply a variable. This variable is used to solve critical section problems and to achieve process synchronization in the multi processing environment. A semaphore S is an integer variable that can be accessed only through two standard operations: wait() and signal().

The wait() operation reduces the value of semaphore by 1 and the signal() operation increases its value by 1.

```
wait(S)
{
        while(S<=0);  // busy waiting
        S--;
}
signal(S)
{
        S++;
}
```

There are mainly two types of semaphore:

- Binary semaphore and
- Counting semaphore

a. **Binary Semaphore**

It is a special form of semaphore used for implementing mutual exclusion; hence it is often called a Mutex. The binary semaphores are quite similar to counting semaphores, but their value is restricted to 0 and 1. In this type of semaphore, the wait operation works only if semaphore = 1, and the signal operation succeeds when semaphore= 0. It is easy to implement than counting semaphores.

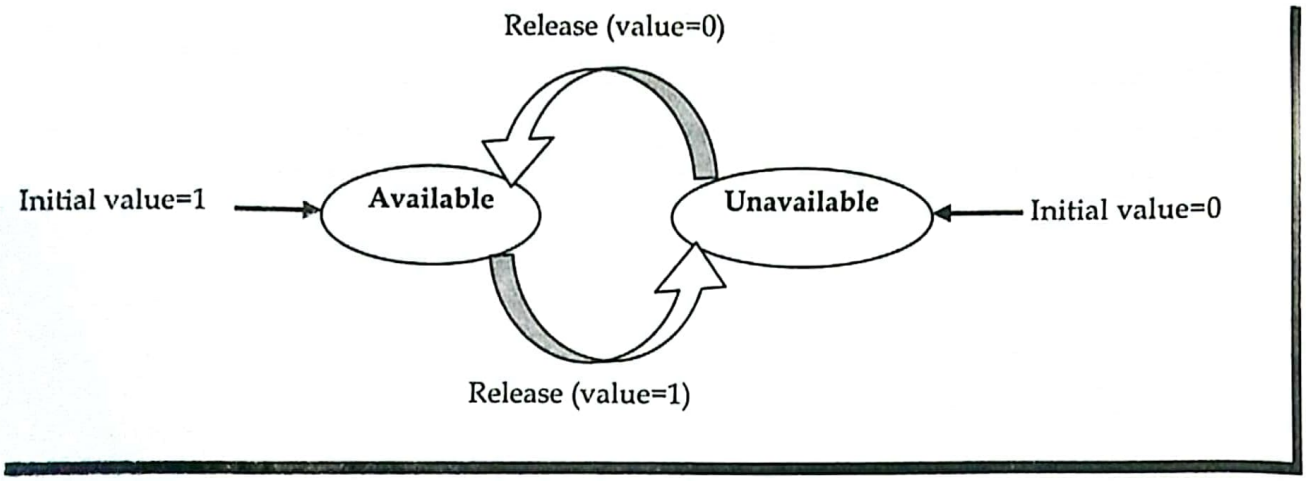

Fig 3.23: Binary Semaphore

b. **Counting Semaphores**

These are used to implement bounded concurrency. This type of Semaphore uses a count that helps task to be acquired or released numerous times. If the initial count = 0, the counting semaphore should be created in the unavailable state. However, if the count is > 0, the semaphore is created in the available state, and the number of tokens it has equals to its count.

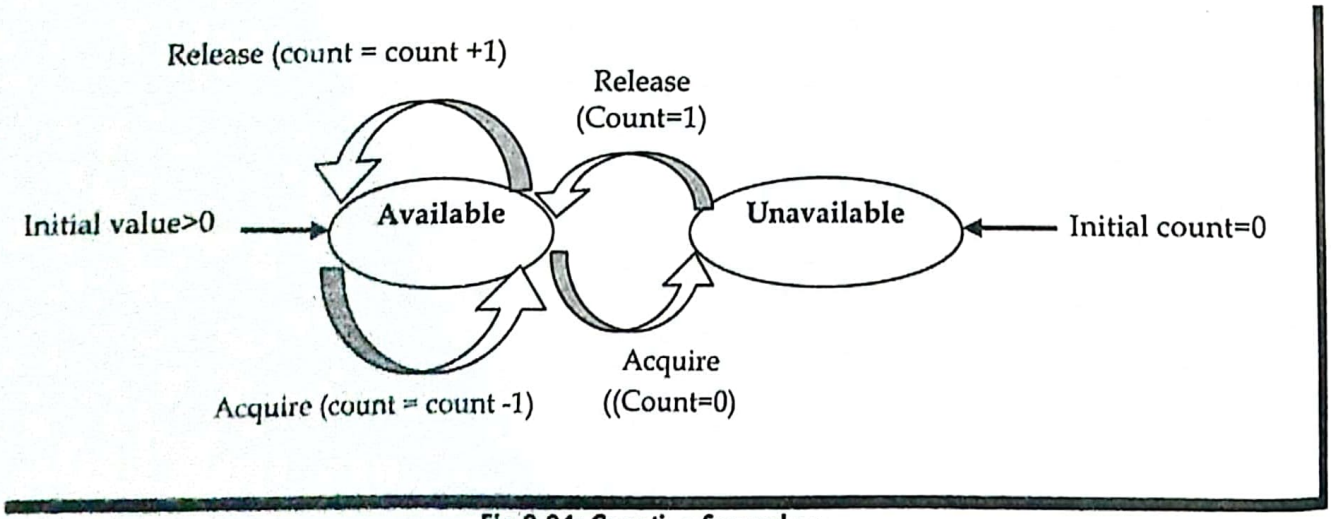

Fig 3.24: Counting Semaphore

Problem Statement: We have a buffer of fixed size. A producer can produce an item and can place in the buffer. A consumer can pick items and can consume them. We need to ensure that when a producer is placing an item in the buffer, then at the same time consumer should not consume any item. In this problem, buffer is the critical section.

To solve this problem, we need two counting semaphores – Full and Empty. "Full" keeps track of number of items in the buffer at any given time and "Empty" keeps track of number of unoccupied slots.

Initialization of semaphores:

```
Mutex = 1
Full = 0          // initially, all slots are empty. Thus full slots are 0
Empty = n         // All slots are empty initially
```

Solution for Producer

```
do
{
    //produce an item
    wait(empty);
    wait(mutex);
    //place in buffer
    signal(mutex);
    signal(full);
}while(true)
```

When producer produces an item then the value of "empty" is reduced by 1 because one slot will be filled now. The value of mutex is also reduced to prevent consumer to access the buffer. Now, the producer has placed the item and thus the value of "full" is increased by 1. The value of mutex is also increased by 1 because the task of producer has been completed and consumer can access the buffer.

Solution for Consumer:

```
do
{
    wait(full);
    wait(mutex);
    // remove item from buffer
    signal(mutex);
    signal(empty);
    // consumes item
}while(true)
```

As the consumer is removing an item from buffer, therefore the value of "full" is reduced by 1 and the value is mutex is also reduced so that the producer cannot access the buffer at this moment. Now, the consumer has consumed the item, thus increasing the value of "empty" by 1. The value of mutex is also increased so that producer can access the buffer now.

Properties of Semaphores

- It's simple and always has a non-negative Integer value.
- Semaphores are machine independent.
- Semaphores are simple to implement.

- Works with many processes.
- Can have many different critical sections with different semaphores.
- Each critical section has unique access semaphores.
- Can permit multiple processes into the critical section at once, if desirable.

Use of Semaphores

- For achieving mutual exclusion
- To solve the synchronization problems

Advantages of Semaphores

The pros/benefits of using semaphore are listed below:

- It allows more than one thread to access the critical section
- Semaphores are machine-independent.
- Semaphores are implemented in the machine-independent code of the microkernel.
- They do not allow multiple processes to enter the critical section.
- As there is busy waiting in semaphore, there is never wastage of process time and resources.
- They are machine-independent, which should be run in the machine-independent code of the microkernel.
- They allow flexible management of resources.

Disadvantage of semaphores

The cons/drawbacks of semaphore are listed below:

- One of the biggest limitations of a semaphore is priority inversion.
- The operating system has to keep track of all calls to wait and signal semaphore.
- Their use is never enforced, but it is by convention only.
- In order to avoid deadlocks in semaphore, the Wait and Signal operations require to be executed in the correct order.
- Semaphore programming is a complicated, so there are chances of not achieving mutual exclusion.
- It is also not a practical method for large scale use as their use leads to loss of modularity.
- Semaphore is more prone to programmer error.
- It may cause deadlock or violation of mutual exclusion due to programmer error.

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 Monitor_name
{
```

CLASSICAL IPC PROBLEMS

The operating systems literature is full of interesting problems that have been widely discussed and analyzed using a variety of synchronization methods. In the following sections we will examine three of the better-known problems.

- Dining Philosophers Problems
- The Readers and Writers Problem
- The Sleeping Barber's Problem

Dining Philosopher Problem

In 1965, Dijkstra posed and solved a synchronization problem he called the dining philosophers problem. Since that time, everyone inventing yet another synchronization primitive has felt obligated to demonstrate how wonderful the new primitive is by showing how elegantly it solves the dining philosophers' problem.

Fig: 3.27: Dining philosopher problem

There are N philosophers sitting around a circular table eating spaghetti and discussing philosophy. The problem is that each philosopher needs 2 forks to eat, and there are only N forks, one between each 2 philosophers. Design an algorithm that the philosophers can follow that insures that none starves as long as each philosopher eventually stops eating, and such that the maximum numbers of philosopher scan eat at once.

- *Philosophers eat/think*
- *Eating needs 2 forks*
- *Pick one fork at a time*
- *How to prevent deadlock*

The problem was designed to illustrate the problem of avoiding deadlock, a system state in which no progress is possible. One idea is to instruct each philosopher to behave as follows:

- *think until the left fork is available; when it is, pick it up*
- *think until the right fork is available; when it is, pick it up*
- *eat*

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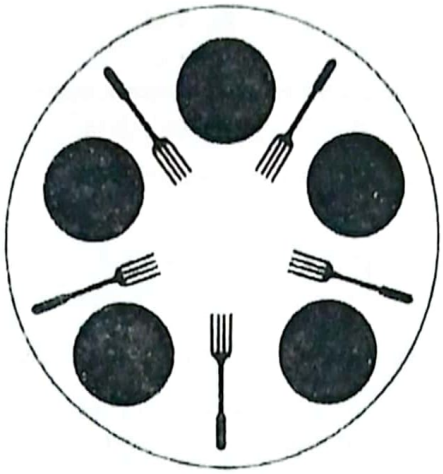

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- think until the left fork is available; when it is, pick it up
- think until the right fork is available; when it is, pick it up
- eat

- put the left fork down
- put the right fork down
- repeat from the start

This solution is incorrect: it allows the system to reach deadlock. Suppose that all five philosophers take their left forks simultaneously. None will be able to take their right forks, and there will be a deadlock. We could modify the program so that after taking the left fork, the program checks to see if the right fork is available. If it is not, the philosopher puts down the left one, waits for some time, and then repeats the whole process. This proposal too, fails, although for a different reason. With a little bit of bad luck, all the philosophers could start the algorithm simultaneously, picking up their left forks, seeing that their right forks were not available, putting down their left forks, waiting, and picking up their left forks again simultaneously, and so on, forever. A situation like this, in which all the programs continue to run indefinitely but fail to make any progress is called starvation.

The solution presented below is deadlock-free and allows the maximum parallelism for an arbitrary number of philosophers. It uses an array, state, to keep track of whether a philosopher is eating, thinking, or hungry (trying to acquire forks). A philosopher may move into eating state only if neither neighbor is eating. Philosopher is neighbors are defined by the macros LEFT and RIGHT. In other words, if i is 2, LEFT is 1 and RIGHT is 3.

```
#define N 5                         /* number of philosophers */
#define LEFT (i+N−1)%N              /* number of i's left neighbor */
#define RIGHT (i+1)%N               /* number of i's right neighbor */
#define THINKING 0                  /* philosopher is thinking */
#define HUNGRY 1                    /* philosopher is trying to get forks */
#define EATING 2                    /* philosopher is eating */
Typedefint semaphore;               /* semaphores are a special kind of int */
int state[N];                       /* array to keep track of everyone's state */
semaphoremutex = 1;                 /* mutual exclusion for critical regions */
semaphore s[N];                     /* one semaphore per philosopher */
void philosopher (inti)             /* i: philosopher number, from 0 to N−1 */
{
        while (TRUE)
        {                           /* repeat forever */
                think();            /* philosopher is thinking */
                take_forks(i);      /* acquire two forks or block */
                eat();              /* yum-yum, spaghetti */
                put_forks(i);       /* put both forks back on table */
        }
}
voidtake_forks(inti)                /* i: philosopher number, from 0 to N−1 */
{
        down(&mutex);               /* enter critical region */
        state[i] = HUNGRY;          /* record fact that philosopher i is hungry */
        test(i);                    /* try to acquire 2 forks */
        up(&mutex);                 /* exit critical region */
        down(&s[i]);                /* block if forks were not acquired */
```

```
}
voidput_forks(i)                    /* i: philosopher number, from 0 to N-1 */
{
        down(&mutex);               /* enter critical region */
        state[i] = THINKING;        /* philosopher has finished eating */
        test(LEFT);                 /* see if left neighbor can now eat */
        test(RIGHT);                /* see if right neighbor can now eat */
        up(&mutex);                 /* exit critical region */
}
void test(i)                        /* i: philosopher number, from 0 to N-1 */
{
        if (state[i] == HUNGRY && state[LEFT] != EATING && state[RIGHT] != EATING)
        {
                state[i] = EATING;
                up(&s[i]);
        }
}
```

The Readers and Writers 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 is non-zero number of readers accessing the resource at that time.

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.

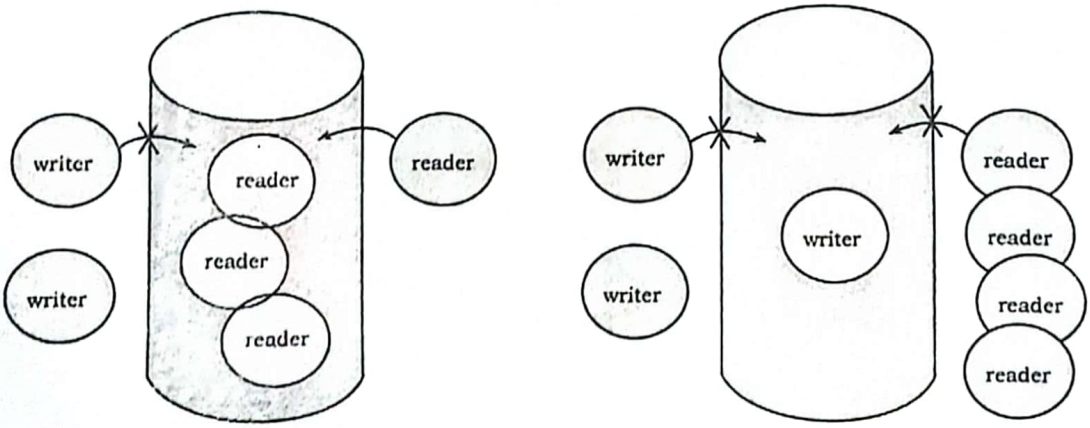


Fig 3.28: Readers and Writers Problem

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

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.

The Sleeping BarberProblem

Problem Statement: The analogy is based upon a hypothetical barber shop with one barber. There is a barber shop which has one barber, one barber chair, and n chairs for waiting for customers if there are any to sit on the chair.

- If there is no customer, then the barber sleeps in his own chair.
- When a customer arrives, he has to wake up the barber.
- If there are many customers and the barber is cutting a customer's hair, then the remaining customers either wait if there are empty chairs in the waiting room or they leave if no chairs are empty.

Fig 3.29: Sleeping barber problem

Each customer, when he arrives, looks to see what the barber is doing. If the barber is sleeping, then the customer wakes him up and sits in the chair. If the barber is cutting hair, then the customer goes to the waiting room. If there is a free chair in the waiting room, the customer sits in it and waits his turn. If there is no free chair, then the customer leaves. Based on a naive analysis, the above description should ensure that the shop functions correctly, with the barber cutting the hair of anyone who arrives until there are no more customers, and then sleeping until the next customer arrives. In practice, there are a number of problems that can occur that are illustrative of general scheduling problems.

The problems are all related to the fact that the actions by both the barber and the customer (checking the waiting room, entering the shop, taking a waiting room chair, etc.) all take an unknown amount of time. For example, a customer may arrive and observe that the barber is cutting hair, so he goes to the waiting room. While he is on his way, the barber finishes the haircut he is doing and goes to check the waiting room. Since there is no one there (the customer not having arrived yet), he goes back to his chair and sleeps. The barber is now waiting for a customer and the customer is waiting for the barber.

In another example, two customers may arrive at the same time when there happens to be a single seat in the waiting room. They observe that the barber is cutting hair, go to the waiting room, and both attempt to occupy the single chair.

Solution: The solution to this problem includes three semaphores. First is for the customer which counts the number of customers present in the waiting room (customer in the barber chair is not included because he is not waiting). Second, the barber 0 or 1 is used to tell whether the barber is idle or is working, and the third mutex is used to provide the mutual exclusion which is required for the process to execute. In the solution, the customer has the record of the number of customers waiting in the waiting room if the number of customers is equal to the number of chairs in the waiting room then the upcoming customer leaves the barbershop.

When the barber shows up in the morning, he executes the procedure barber, causing him to block on the semaphore customers because it is initially 0. Then the barber goes to sleep until the first customer comes up.

When a customer arrives, he executes customer procedure the customer acquires the mutex for entering the critical region, if another customer enters thereafter, the second one will not be able to anything until the first one has released the mutex. The customer then checks the chairs in the waiting room if waiting customers are less than the number of chairs then he sits otherwise he leaves and releases the mutex.

If the chair is available then customer sits in the waiting room and increments the variable waiting value and also increases the customer's semaphore this wakes up the barber if he is sleeping.At this point, customer and barber are both awake and the barber is ready to give that person a haircut. When the haircut is over, the customer exits the procedure and if there are no customers in waiting room barber sleeps.

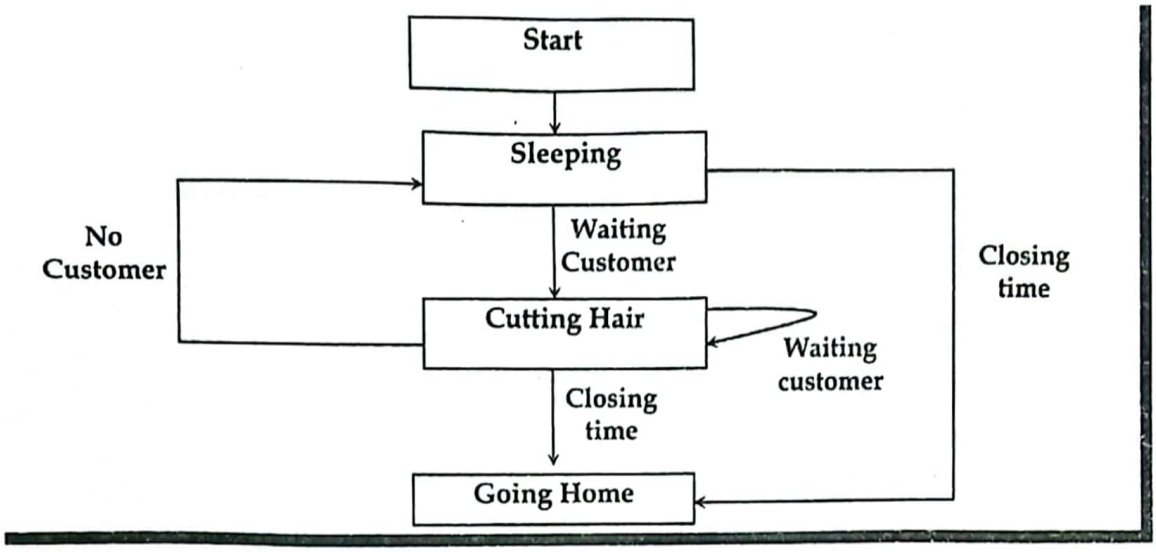


Fig 3.30: flow chart for implementation of Sleeping barber problem

Algorithm for Sleeping Barber problem

```
Semaphore Customers = 0;
Semaphore Barber = 0;
Mutex Seats = 1;
intFreeSeats = N;
Barber
{
while(true)
{
        /* waits for a customer (sleeps). */
down(Customers);
        /* mutex to protect the number of available seats.*/
down(Seats);
        /* a chair gets free.*/
FreeSeats++;
        /* bring customer for haircut.*/
up(Barber);
        /* release the mutex on the chair.*/
up(Seats);
        /* barber is cutting hair.*/
```

```
    }
}
Customer
{
while(true)
{
        /* protects seats so only 1 customer tries to sit in a chair if that's the case.*/
down(Seats); //This line should not be here.
if(FreeSeats> 0)
        {
FreeSeats--;
        /* notify the barber. */
up(Customers);
        /* release the lock */
up(Seats);
        /* wait in the waiting room if barber is busy. */
down(Barber);
        // customer is having hair cut
      }
        else
        {
        /* release the lock */
up(Seats);
        // customer leaves
      }
  }
}
```

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 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.

Process Scheduling Queues

The OS maintains all 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.

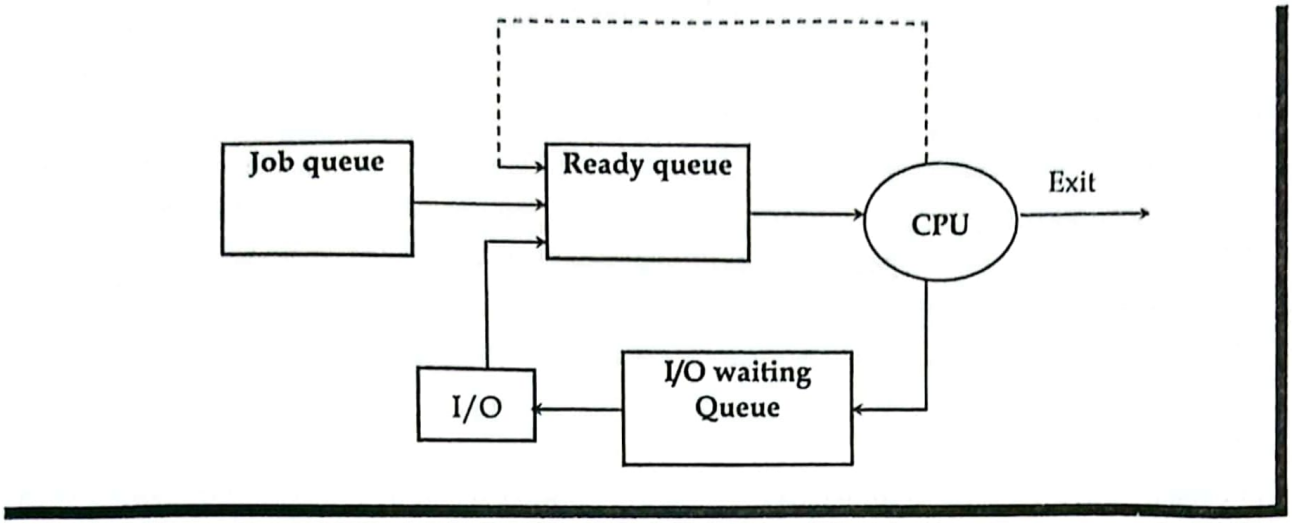


Fig 3.31: Process scheduling queue

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 handles 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

a. **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.

b. **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.

c. **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 process 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.

Dispatcher

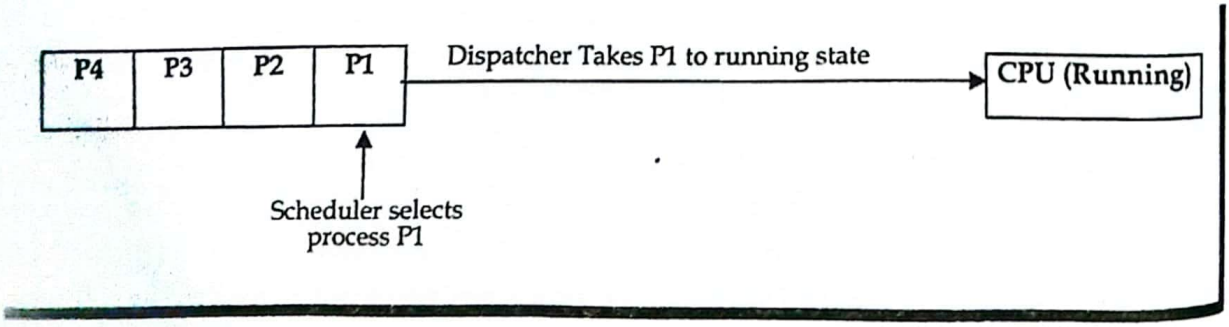
Dispatcher is a special program which comes into play after scheduler. When scheduler completed its job of selecting a process, then after it is the dispatcher which takes that process to the desired state/queue. The dispatcher is the module that gives control of the CPU to the process selected by the short-term scheduler. This function involves the following:

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

Difference between the Scheduler and Dispatcher

Consider a situation, where various process residing in ready queue and waiting for execution. But CPU can't execute all the process of ready queue simultaneously, operating system have to choose a particular process on the basis of scheduling algorithm used. So, this procedure of selecting a process among various processes is done by scheduler. Now here the task of scheduler completed. Now dispatcher comes into picture as scheduler have decide a process for execution, it is dispatcher who takes that process from ready queue to the running status, or you can say that providing CPU to that process is the task of dispatcher.

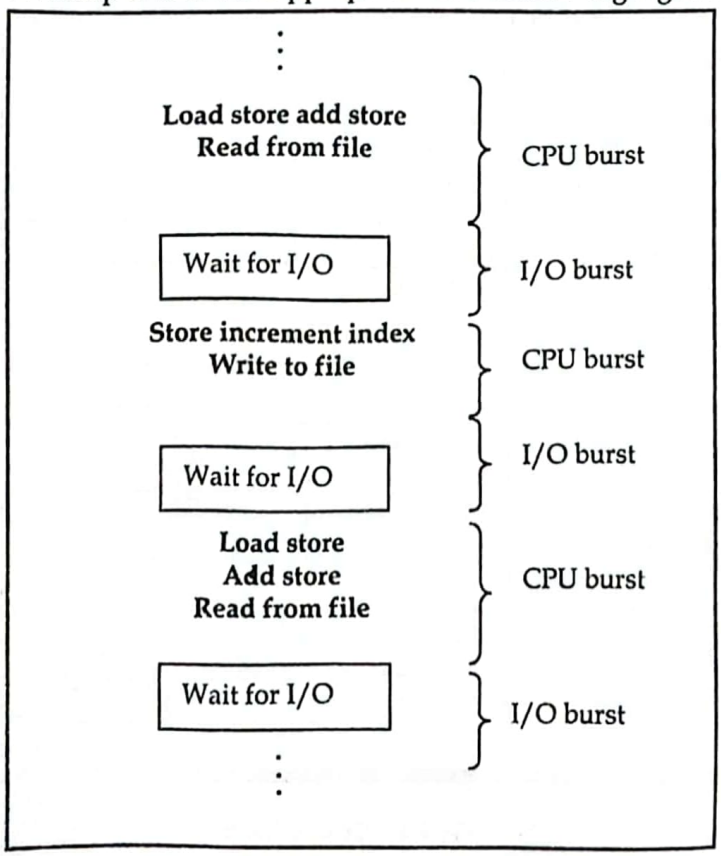
Example: There are 4 processes in ready queue, i.e., P1, P2, P3, P4; they all are arrived at t0, t1, t2, t3 respectively. First in First out scheduling algorithm is used. So, scheduler decided that first of all P1 has came, so this is to be executed first. Now dispatcher takes P1 to the running state.



Dispatcher	Scheduler
Dispatcher is a module that gives control of CPU to the process selected by short term scheduler.	Scheduler is something which selects a process among various processes.
There are no different types in dispatcher. It is just a code segment.	There are 3 types of scheduler i.e. Long-term, Short-term, Medium-term.
Working of dispatcher is dependent on scheduler. Means dispatchers have to wait until scheduler selects a process.	Scheduler works independently. It works immediately when needed.
Dispatcher has no specific algorithm for its implementation	Scheduler works on various algorithm such as FCFS, SJF, RR etc.
The time taken by dispatcher is called dispatch latency.	Time taken by scheduler is usually negligible. Hence we neglect it.
Dispatcher is also responsible for: Context Switching, Switch to user mode, Jumping to proper location when process again restarted	The only work of scheduler is selection of processes.

CPU - I/O Burst Cycle

The success of CPU scheduling depends on the following observed property of processes: Process execution consists of a cycle of CPU execution and I/O wait. Processes alternate back and forth between these two states. The execution begins with CPU burst, followed by I/O burst, then another CPU burst and so on. The last CPU burst will end with a system request to terminate execution rather than with another I/O burst.An I/O bound program would typically have many short CPU bursts; a CPU bound program might have a few very long CPU bursts. The duration of these CPU bursts are measured, which help to select an appropriate CPU scheduling algorithm.



Context Switch

A context switch 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

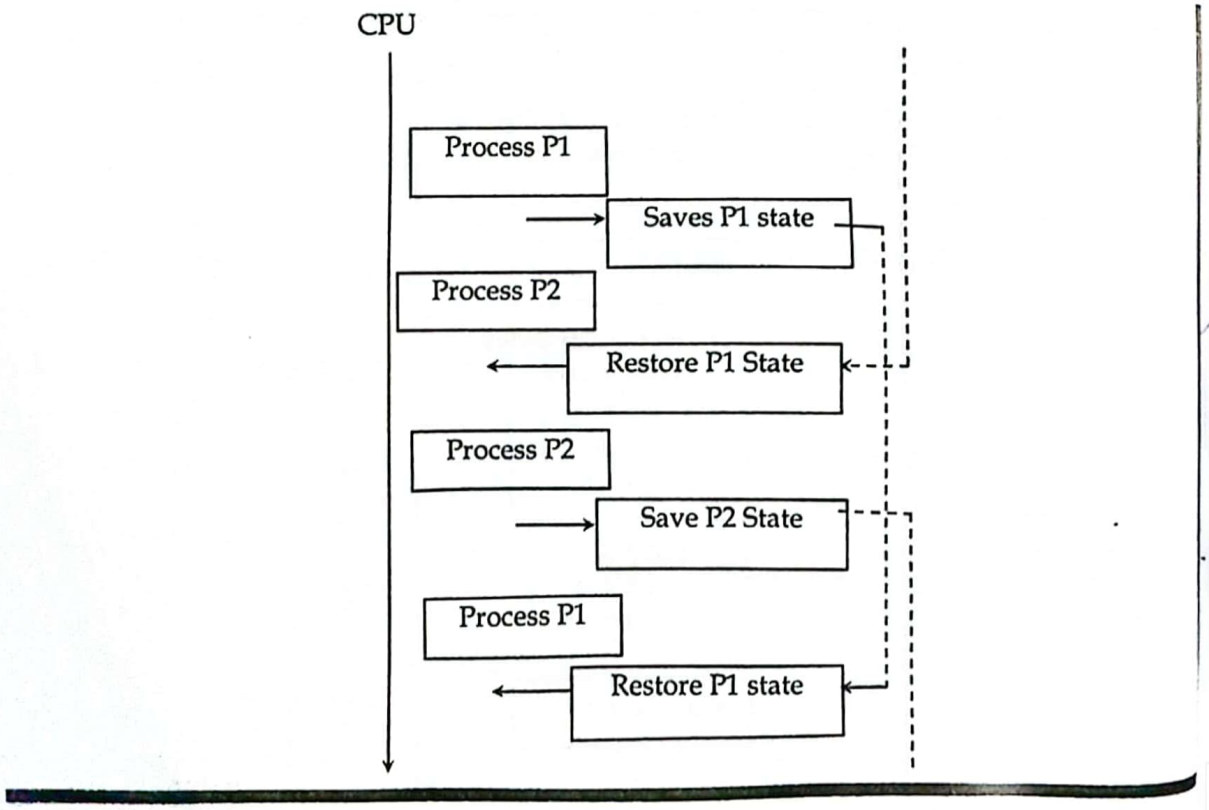


Fig 3.32: Context switching

TYPES OF SCHEDULING

An operating system uses two types of scheduling processes execution, preemptive and non - preemptive. CPU scheduling decisions may take place under the following four circumstances:

1. When a process switches from the running state to the waiting state (for I/O request or invocation of wait for the termination of one of the child processes).
2. When a process switches from the running state to the ready state (for example, when an interrupt occurs).
3. When a process switches from the waiting state to the ready state(for example, completion of I/O).
4. When a process terminates.

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

When Scheduling takes place only under circumstances 1 and 4, we say the scheduling scheme is non-preemptive; otherwise the scheduling scheme is preemptive.

Preemptive Scheduling

In this type of Scheduling, the tasks are usually assigned with priorities. At times it is necessary to run a certain task that has a higher priority before another task although it is running. Therefore, the running task is interrupted for some time and resumed later when the priority task has finished its execution.

Preemptive scheduling is one which can be done in the circumstances when a process switches from running state to ready state or from waiting state to ready state. Here, the resources (CPU cycles) are allocated to the process for the limited amount of time and then is taken away, and the process is placed back in the ready queue again if it still has CPU burst time remaining. The process stays in ready queue till it gets next chance to execute.

If a process with high priority arrives in the ready queue, it does not have to wait for the current process to complete its burst time. Instead, the current process is interrupted in the middle of execution and is placed in the ready queue till the process with high priority is utilizing the CPU cycles. In this way, each process in the ready queue gets some time to run CPU. It makes the preemptive scheduling flexible but, increases the overhead of switching the process from running state to ready state and vise-verse. Algorithms that work on preemptive scheduling are Round Robin. Shortest Job First (SJF) and Priority scheduling may or may not come under preemptive scheduling.

Characteristics of Preemptive Scheduling

- Picks a process and let it run for a maximum of fixed time and releases the CPU after that quantum, whether it finishes or not.
- Processes are allowed to run for a maximum of some fixed time.
- Useful in systems in which high-priority processes requires rapid attention.
- In time sharing systems, preemptive scheduling is important in guaranteeing acceptable response times.
- High overhead.

Ready → Running,

Non-preemptive Scheduling

Under non-preemptive scheduling, once the CPU has been allocated to a process, the process keeps the CPU until it releases the CPU either by terminating or by switching to the waiting state.

Non-preemptive Scheduling is one which can be applied in the circumstances when a process terminates, or a process switches from running to waiting state. In Non-Preemptive Scheduling, once the resources (CPU) are allocated to a process, the process holds the CPU till it gets terminated or it reaches a waiting state.Unlike preemptive scheduling, non-preemptive scheduling does not interrupt a process running CPU in middle of the execution. Instead, it waits for the process to complete its CPU burst time and then it can allocate the CPU to another process. In Non-preemptive scheduling, if a process with long CPU burst time is executing then the other process will have to wait for a long time which increases the average waiting time of the processes in the ready queue. However, the non-preemptive scheduling does not have any overhead of switching the processes from ready queue to CPU but it makes the scheduling rigid as the process in execution is not even preempted for a process with higher priority.

Characteristics of Non-Preemptive Scheduling

- Picks a process to run until it releases the CPU
- Once a process has been given the CPU, it runs until blocks for I/O or termination
- Treatment of all processes is fair
- Response times are more predictable
- Useful in real-time system
- Shorts jobs are made to wait by longer jobs -no priority

Comparisons of preemptive and non-preemptive scheduling

Preemptive scheduling	Non preemptive scheduling
The resources are allocated to a process for a limited time.	Once resources are allocated to a process, the process holds it till it completes its burst time or switches to waiting state.
Process can be interrupted in between.	Process cannot be interrupted till it terminates or switches to waiting state.
If a high priority process frequently arrives in the ready queue, low priority process may starve.	If a process with long burst time is running CPU, then another process with less CPU burst time may starve.
Preemptive scheduling has overheads of scheduling the processes.	Non-preemptive scheduling does not have overheads.
Preemptive scheduling is flexible.	Non-preemptive scheduling is rigid.
Preemptive scheduling is cost associated.	Non-preemptive scheduling is not cost associative.

SCHEDULING CRITERIA

Different CPU scheduling algorithms have different properties and may favor one class of processes over another. In choosing which algorithm to use in a particular situation, we must consider the properties of the various algorithms. Many criteria have been suggested for comparing CPU scheduling algorithms. Criteria that are used include the following:

1. **CPU utilization** – keep the CPU as busy as possible
2. **Throughput** – number of processes that complete their execution per time unit
3. **Turnaround time** – amount of time to execute a particular process
4. **Waiting time** – amount of time a process has been waiting in the ready queue
5. **Response time** – amount of time it takes from when a request was submitted until the first response is produced, not output (for time-sharing environment)

The goals of scheduling are as follows:

- **Fairness:** Each process gets fair share of the CPU.
- **Efficiency:** When CPU is 100% busy then efficiency is increased.
- **Response Time:** Minimize the response time for interactive user.
- **Throughput:** Maximizes jobs per given time period.
- **Waiting Time:** Minimizes total time spent waiting in the ready queue.
- **Turnaround Time:** Minimizes the time between submission and termination.

SCHEDULING ALGORITHM

Scheduling algorithms mainly divided into following three categories

- Batch system scheduling
- Interactive system scheduling and
- Real Time Scheduling

Batch System Scheduling

Batch processing is a technique in which an Operating System collects the programs and data together in a batch before processing starts. An operating system does the following activities related to batch processing:

- The OS defines a job which has predefined sequence of commands, programs and data as a single unit.
- The OS keeps a number a job in memory and executes them without any manual information.
- Jobs are processed in the order of submission, i.e., first come first served fashion.
- When a job completes its execution, its memory is released and the output for the job gets copied into an output spool for later printing or processing.

The some major terminologies used in various scheduling algorithms are:

- **Arrival Time:** Time at which the process arrives in the ready queue.
- **Completion Time:** Time at which process completes its execution.
- **Burst Time:** Time required by a process for CPU execution.
- **Turn Around Time:** Time Difference between completion time and arrival time.

Turn Around Time = Completion Time – Arrival Time

- **Waiting Time (W.T):** Time Difference between turnaround time and burst time.

Waiting Time = Turn Around Time – Burst Time

The major process scheduling algorithms based on batch system scheduling are described as below;

a. **First come first served**

FCFS provides an efficient, simple and error-free process scheduling algorithm that saves valuable CPU resources. It uses non-preemptive scheduling in which a process is automatically queued and processing occurs according to an incoming request or process order. FCFS derives its concept from real-life customer service.

Let's take a look at how FCFS process scheduling works. Suppose there are three processes in a queue: P1, P2 and P3. P1 is placed in the processing register with a waiting time of zero seconds and 10 seconds for complete processing. The next process, P2, must wait 10 seconds and is placed in the processing cycle until P1 is processed. Assuming that P2 will take 15 seconds to complete, the final process, P3, must wait 25 seconds to be processed. FCFS may not be the fastest process scheduling algorithm, as it does not check for priorities associated with processes. These priorities may depend on the processes' individual execution times.

Characteristics

- Processes are scheduled in the order they are received.
- Once the process has the CPU, it runs to completion
- Easily implemented, by managing a simple queue or by storing time the process was received.
- Fair to all processes.

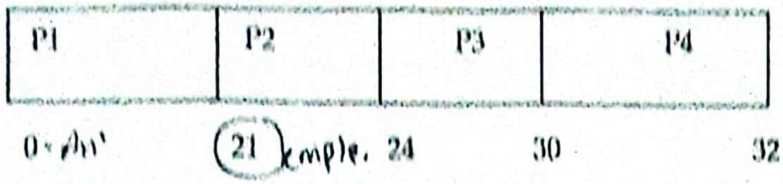
Problems

- No guarantee of good response time.
- Large average waiting time.

Example 1: Consider the processes P1, P2, P3, P4 given in the below table, arrives for execution in the order, with zero Arrival Time and given Burst Time, let's find the average waiting time and Average turnaround time using the FCFS scheduling algorithm.

Process	Burst Time
P1	21
P2	3
P3	6
P4	2

The Gnatt chart is as follows,



In the above example, we can see that we have four processes P1, P2, P3 and P4 and they are coming in the ready state at 0 ms. So the process P1 will be executed for the first 21 ms. After that, the process P2 will be executed for 3 ms and then process P3 will be executed for 6 ms and finally, the process P4 will be executed for 2 ms. One thing to be noted here is that if the arrival time of the processes is the same, then the CPU can select any process.

Process	Turnaround time = Completion Time – Arrival Time	Waiting Time = Turn Around Time – Burst Time
P1	21 - 0=21 ms	21-21=0
P2	24 ms	24-3=21
P3	30 ms	30-6=24
P4	32 ms	32-2=30

Total waiting time: (0 + 21 + 24 + 30) = 75 ms

Average waiting time: (75/4) = 18.75 ms

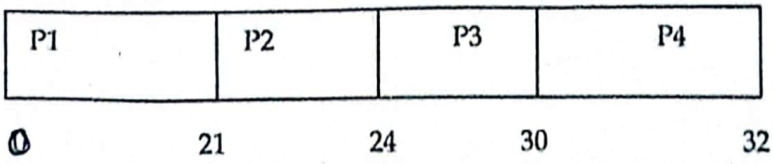
Total turnaround time: (21 + 24 + 30 + 32) = 107 ms

Average turnaround time: (107/4) = 26.75 ms

Example 2: Consider the processes P1, P2, P3, P4 given in the below table, arrives for execution in the order, with Arrival Time 0, 2, 2 and 3 respectively and given Burst Time, let's find the average waiting time and Average turnaround time using the FCFS scheduling algorithm.

Process	Arrival time	Burst Time
P1	0 ms	21
P2	2 ms	3
P3	2 ms	6
P4	3 ms	2

The Gnatt chart is as follows,



In the above example, we can see that we have four processes P1, P2, P3 and P4 and they are coming in the ready state at 0 ms, 2 ms, 2 ms and 3 ms respectively. So, based on the arrival time, the process P1 will be executed for the first 21 ms. After that, the process P2 will be executed for 3 ms and then process P3 will be executed for 6 ms and finally, the process P4 will be executed for 2 ms. One thing

to be noted here is that if the arrival time of the processes is the same, then the CPU can select any process.

Process	Turnaround time = Completion Time – Arrival Time	Waiting Time = Turn Around Time – Burst Time
P1	21 - 0=21 ms	21-21=0
P2	24-2=22 ms	22-3=19
P3	30-2=28 ms	28-6=22
P4	32-3=29 ms	29-2=27

Total waiting time: (0 + 19 + 22 + 27) = 68 ms

Average waiting time: (68/4) = 17 ms

Total turnaround time: (21 + 22 + 28 + 29) = 100 ms

Average turnaround time: (100/4) = 25 ms

b. Shortest job first

In the FCFS, we saw if a process is having a very high burst time and it comes first then the other process with a very low burst time have to wait for its turn. So, to remove this problem, we come with a new approach i.e. Shortest Job First or SJF.

In this technique, the process having the minimum burst time at a particular instant of time will be executed first. If the subsequent CPU bursts of two processes become the same, then FCFS scheduling is used to break the tie. It is a non-preemptive approach i.e. if the process starts its execution then it will be fully executed and then some other process will come. Shortest job first (SJF) or shortest job next, is a scheduling policy that selects the waiting process with the smallest execution time to execute next. Shortest Job first has the advantage of having minimum average waiting time among all scheduling algorithms.

Characteristics

- The processing times are known in advanced.
- SJF selects the process with shortest expected processing time. In case of the tie FCFS scheduling is used.
- The decision policies are based on the CPU burst time. Advantages:
- Reduces the average waiting time over FCFS.
- Favors shorts jobs at the cost of long jobs.

Problems

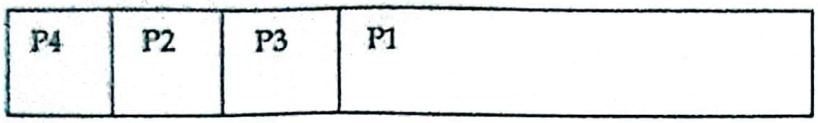
- It may lead to starvation if only short burst time processes are coming in the ready state.
- Estimation of run time to completion.
- Accuracy
- Not applicable in timesharing system.

Example 1: Consider the processes P1, P2, P3, P4 given in the below table, arrives for execution in the same order, with Arrival Time 0, and given Burst Time, let's find the average waiting time and Average turnaround time using the SJF scheduling algorithm.

Process	Burst Time
P1	21
P2	3
P3	6
P4	2

Solution: In shortest Job First Scheduling, the shortest Process is executed first.

Hence the Gantt chart will be as follow



As in the Gantt chart above, the process P4 will be picked up first as it has the shortest burst time, then P2, followed by P3 and at last P1.

Process	Turnaround time = Completion Time – Arrival Time	Waiting Time = Turn Around Time - Burst Time
P4	2- 0=2 ms	2-2=0
P2	5 ms	5-3=2
P3	11 ms	11-6=5
P1	32 ms	32-21=11

Total waiting time: (0 + 2 + 5 + 11) = 18 ms

Average waiting time: (18/4) = 4.50 ms

Total turnaround time: (2 + 5 + 11 + 32) = 50 ms

Average turnaround time: (50/4) = 12.50 ms

We scheduled the same set of processes using the First come first serve algorithm, and got average waiting time to be 18.75 ms, whereas with SJF, the average waiting time comes out 4.5 ms.

c. **Shortest remaining time next**

It is a preemptive version of shortest job next scheduling. In this scheduling algorithm, the process with the smallest amount of time remaining until completion is selected to execute. Since the currently executing process is the one with the shortest amount of time remaining by definition, and since that time should only reduce as execution progresses, processes will always run until they complete or a new process is added that requires a smaller amount of time.

Shortest remaining time is advantageous because short processes are handled very quickly. The system also requires very little overhead since it only makes a decision when a process completes or a new process is added, and when a new process is added the algorithm only needs to compare the currently executing process with the new process, ignoring all other processes currently waiting to execute.

Characteristics

- Low average waiting time than SJF
- Useful in timesharing

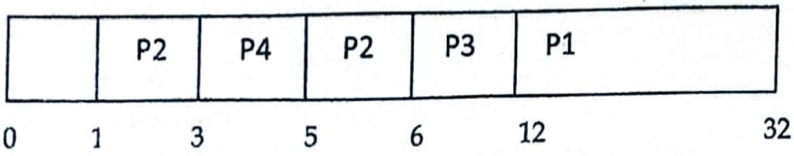
Demerits

- Very high overhead than SJF
- Requires additional computation.
- Favors short jobs, longs jobs can be victims of starvation.

Example: Consider the processes P1, P2, P3, P4 given in the below table, arrives for execution in the same order, with Arrival Time 0, 1, 2, and 3 respectively and given Burst Time, let's find the average waiting time and average turnaround time using the **Shortest remaining time next** scheduling algorithm.

Process	Burst Time	Arrival Time
P1	21	0
P2	3	1
P3	6	2
P4	2	3

The Gantt chart for Preemptive Shortest remaining time next Scheduling will be



As it is seen in the GANTT chart above, as P1 arrives first, hence it's execution starts immediately, but just after 1 ms, process P2 arrives with a burst time of 3 ms which is less than the burst time of P1, hence the process P1(1 ms done, 20 ms left) is preempted and process P2 is executed.

As P2 is getting executed, after 1 ms, P3 arrives, but it has a burst time greater than that of P2, hence execution of P2 continues. But after another millisecond, P4 arrives with a burst time of 2 ms, as a result P2 (2 ms done, 1 ms left) is preempted and P4 is executed.

After the completion of P4, process P2 is picked up and finishes, then P3 will get executed and at last P1.

Process	Burst Time	Arrival Time	Turnaround time = Completion Time – Arrival Time	Waiting Time = Turn Around Time – Burst Time
P1	21	0	32- 0=32 ms	32-21=11
P2	3	1	6-1=5 ms	5-3=2
P3	6	2	12-2=10 ms	10-6=4
P4	2	3	5-3=2 ms	2-2=0

Total waiting time: (11 + 2 + 4 + 0) = 17 ms

Average waiting time: (17/4) = 4.25 ms

Total turnaround time: (32 + 5 + 10 + 2) = 49 ms

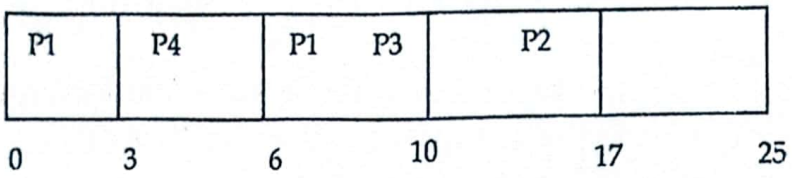
Average turnaround time: (49/4) = 12.25 ms

Example 2: Find average waiting time and average Turnaround time of following four processes with their arrival time and burst time as below,

Process	Burst Time	Arrival Time
P1	6 ms	1 ms
P2	8 ms	1 ms
P3	7 ms	2 ms
P4	3 ms	3 ms

Solution:

Gantt chart



In the above example, at time 1ms, there are two processes i.e. P1 and P2. Process P1 is having burst time as 6ms and the process P2 is having 8ms. So, P1 will be executed first. Since it is a preemptive approach, so we have to check at every time quantum. At 2ms, we have three processes i.e. P1(5ms remaining), P2(8ms), and P3(7ms). Out of these three, P1 is having the least burst time, so it will continue its execution. After 3ms, we have four processes i.e. P1(4ms remaining), P2(8ms), P3(7ms), and P4(3ms). Out of these four, P4 is having the least burst time, so it will be executed. The process P4 keeps on executing for the next three ms because it is having the shortest burst time. After 6ms, we have 3 processes i.e. P1(4ms remaining), P2(8ms), and P3(7ms). So, P1 will be selected and executed. This process of time comparison will continue until we have all the processes executed. So, waiting and turnaround time of the processes will be:

Process	Waiting Time	Turnaround Time
P1	3 ms	9 ms
P2	16 ms	24 ms
P3	8 ms	15ms
P4	0 ms	3 ms

Total waiting time: (3 + 16 + 8 + 0) = 27ms

Average waiting time: (27/4) = 6.75ms

Total turnaround time: (9 + 24 + 15 + 3) = 51ms

Average turnaround time: (51/4) = 12.75ms

Interactive System Scheduling

a. Round Robin scheduling

In this algorithm the process is allocated the CPU for the specific time period called time slice or quantum, which is normally of 10 to 100 milliseconds. If the process completes its execution within this time slice, then it is removed from the queue otherwise it has to wait for another time slice. Preempted process is placed at the back of the ready list.

In this approach of CPU scheduling, we have a fixed time quantum and the CPU will be allocated to a process for that amount of time only at a time. For example, if we are having three process P1, P2, and P3, and our time quantum is 2ms, then P1 will be given 2ms for its execution, then P2 will be given 2ms, then P3 will be given 2ms. After one cycle, again P1 will be given 2ms, and then P2 will be given 2ms and so on until the processes complete its execution.

Advantages

- Fair allocation of CPU across the process.
- Used in timesharing system.
- Low average waiting time when process lengths vary widely.
- Poor average waiting time when process lengths are identical.

Disadvantages

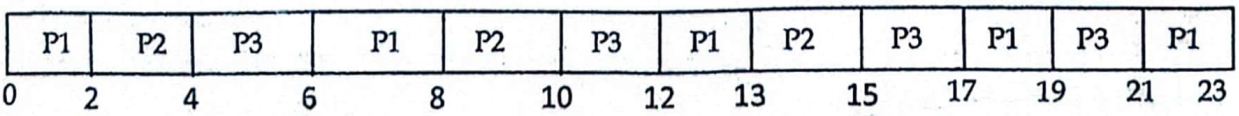
- We have to perform a lot of context switching here, which will keep the CPU idle

Quantum size: If the quantum is very large, each process is given as much time as needs for completion; RR degenerate to FCFS policy. If quantum is very small, system busy at just switching from one process to another process, the overhead of context-switching causes the system efficiency degrading.

Example: Consider the processes P1, P2, P3given in the below table, arrives for execution in the same order, with Arrival Time 0, and given Burst Time, let's find the average waiting time using and Average turnaround time by using the **Round Robin scheduling** algorithm.

Process	Burst Time
P1	10 ms
P2	5 ms
P3	8 ms

The Gantt chart for following processes based on Round robin scheduling with quantum size=2 will be



In the above example, every process will be given 2ms in one turn because we have taken the time quantum to be 2ms. So process P1 will be executed for 2ms, then process P2 will be executed for 2ms, then P3 will be executed for 2 ms. Again process P1 will be executed for 2ms, then P2, and so on. The waiting time and turnaround time of the processes will be:

Process	Turnaround Time = Completion Time – Arrival Time	Waiting Time = Turn Around Time – Burst Time
P1	23	13
P2	15	10
P3	21	13

Total waiting time: (13 + 10 + 13) = 36ms
Average waiting time: (36/3) = 12ms
Total turnaround time: (23 + 15 + 21) = 59ms
Average turnaround time: (59/3) = 19.66ms

b. Priority scheduling

In this scheduling algorithm the priority is assigned to all the processes and the process with highest priority executed first. Priority assignment of processes is done on the basis of internal factor such as CPU and memory requirements or external factor such as user's choice. It is just used to identify which process is having a higher priority and which process is having a lower priority. For example, we can denote 0 as the highest priority process and 100 as the lowest priority process. Also, the reverse can be true i.e. we can denote 100 as the highest priority and 0 as the lowest priority.

Advantages of priority scheduling (non-preemptive)

- Higher priority processes like system processes are executed first.

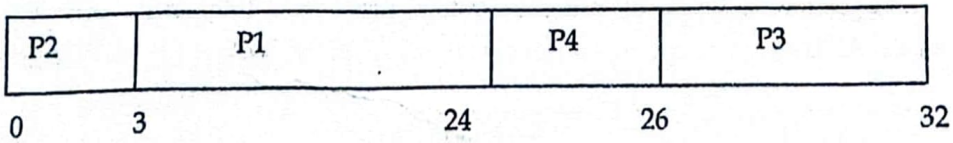
Disadvantages of priority scheduling (non-preemptive)

- It can lead to starvation if only higher priority process comes into the ready state. Low priority processes may never execute.
- If the priorities of more two processes are the same, then we have to use some other scheduling algorithm.

Example: Consider the processes P1, P2, P3, P4 given in the below table, arrives for execution in the same order, with Arrival Time 0, and given Burst Time, let's find the average waiting time using the **Priority scheduling** algorithm.

Process	Burst Time	Priority
P1	21	2
P2	3	1
P3	6	4
P4	2	3

The Gantt chart for following processes based on Priority scheduling will be



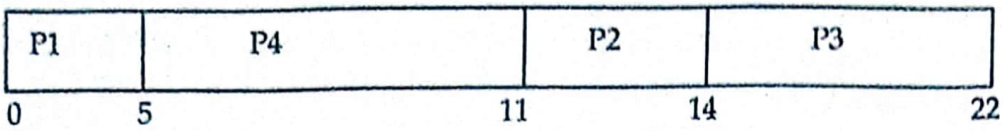
The average waiting time will be (0 + 3 + 24 + 26) / 4 = 13.25 ms

Example 2: Find average waiting time and average Turnaround time of following four processes with their arrival time, burst time and priority as below,

Process	Arrival time	Burst Time	Priority
P1	0 ms	5 ms	1
P2	1 ms	3 ms	2
P3	2 ms	8 ms	1
P4	3 ms	6 ms	3

Note: in this example we are taking higher priority number as higher priority.

Gantt chart



In the above example, at 0 ms, we have only one process P1. So P1 will execute for 5ms because we are using non-preemption technique here. After 5ms, there are three processes in the ready state i.e. process P2, process P3, and process P4. Out to these three processes, the process P4 is having the highest priority so it will be executed for 6ms and after that, process P2 will be executed for 3ms followed by the process P1. The waiting and turnaround time of processes will be:

Process	Arrival time	Burst Time	Priority	Turnaround Time = Completion Time – Arrival Time	Waiting Time = Turn Around Time - Burst Time
P1	0 ms	5 ms	1	5-0=5 ms	5-5=0 ms
P2	1 ms	3 ms	2	14-1=13 ms	13-3=10 ms
P3	2 ms	8 ms	1	22-2=20 ms	20-8=12 ms
P4	3 ms	6 ms	3	11-3=8 ms	8-6=2 ms

Total waiting time: (0 + 10 + 12 + 2) = 24 ms

Average waiting time: (24/4) = 6 ms

Total turnaround time: (5 + 13 + 20 + 8) = 46 ms

Average turnaround time: (46/4) = 11.5 ms

c. Multiple queues (Multilevel Queue Scheduling)

It may happen that processes in the ready queue can be divided into different classes where each class has its own scheduling needs. For example, a common division is a foreground (interactive) process and background (batch) processes. These two classes have different scheduling needs. For this kind of situation Multilevel Queue Scheduling is used. Now, let us see how it works.

Ready Queue is divided into separate queues for each class of processes. For example, let us take three different types of process System processes, Interactive processes and Batch Processes. All three processes have their own queue. Now, look at the below figure.

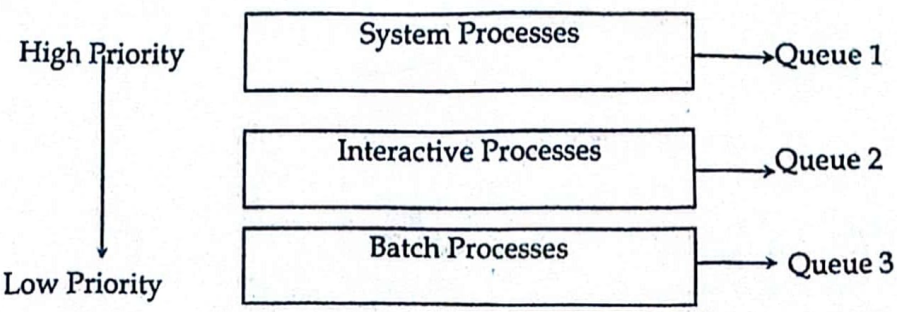


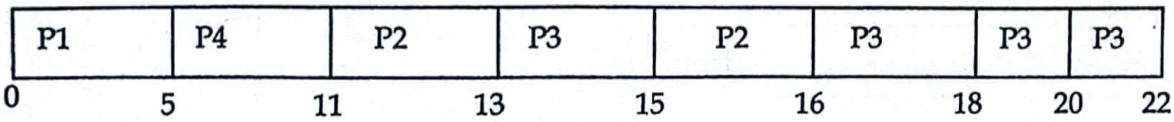
Fig 3.33: Multiple queue

All three different types of processes have their own queue. Each queue has its own Scheduling algorithm. For example, queue 1 and queue 2 uses Round Robin while queue 3 can use FCFS to schedule their processes.

Example: Consider below table of four processes under multilevel queue scheduling. Queue number denotes the queue of the process.

Process	Arrival Time	CPU Burst Time	Queue Number
P1	0	5	1
P2	0	3	2
P3	0	8	2
P4	0	6	1

In the above example, we have two queues i.e. queue1 and queue2. Queue1 is having higher priority and queue1 is using the FCFS approach and queue2 is using the round-robin approach (time quantum = 2ms). Below is the Gantt chart of the problem:



Since the priority of queue1 is higher, so queue1 will be executed first. In the queue1, we have two processes i.e. P1 and P4 and we are using FCFS. So, P1 will be executed followed by P4. Now, the job of the queue1 is finished. After this, the execution of the processes of queue2 will be started by using the round-robin approach.

d. Multilevel Feedback Queue Scheduling

It allows the process to move in between queues. The idea is to separate processes according to the characteristics of their CPU bursts. If a process uses too much CPU time, it is moved to a lower-priority queue. Similarly, a process that waits too long in a lower-priority queue may be moved to a higher-priority queue. This form of aging prevents starvation.

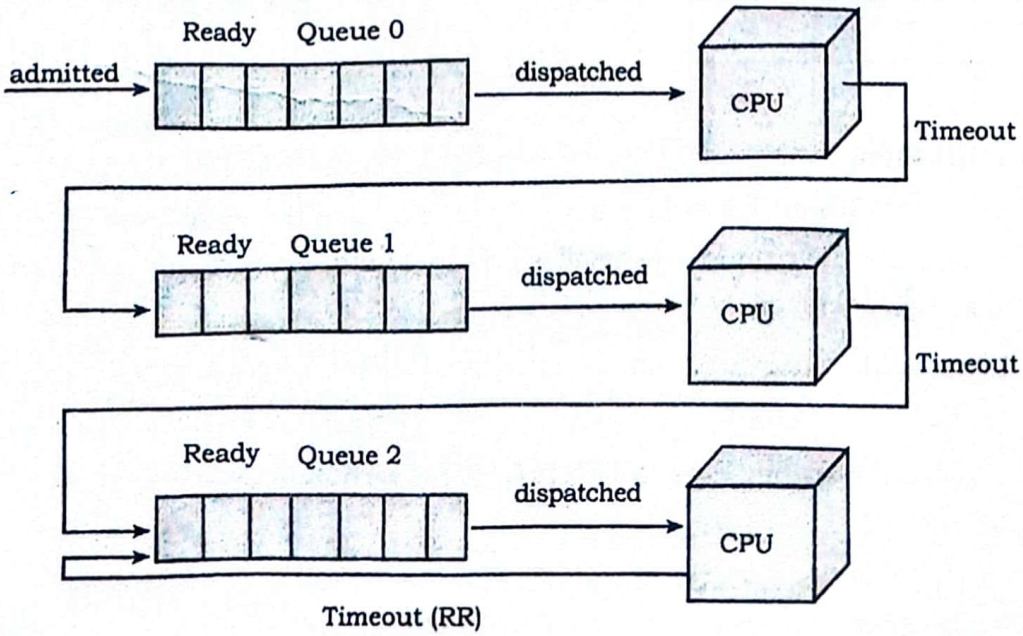
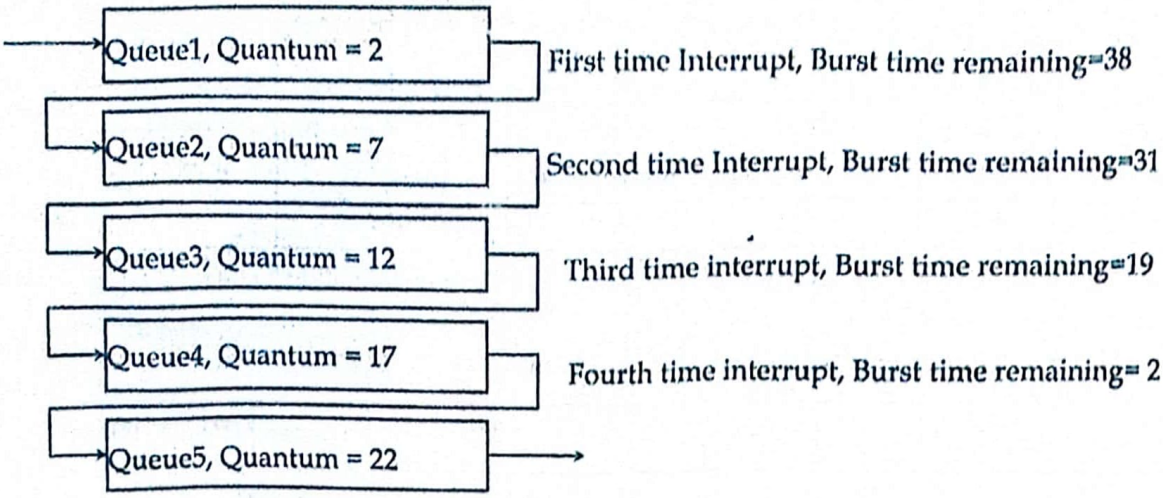


Fig 3.34: Multilevel feedback queue

Example: Consider a system which has CPU Bound process which requires burst time of 40 time units. Multilevel feedback queue scheduling is used. The time quantum is 2 units and it will be incremented by 5 units in each level. How many times the process will be interrupted and in which queue process will complete the execution?

Solution:



Hence from above figure process will be interrupted in 4 times and in 5th queue the process will complete the execution.

Practice Question 1: Consider the following set of processes, with the length of the CPU burst time given in milliseconds.

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

The processes are assumed to have arrived in the order P1, P2, P3, P4, P5, all at time 0.

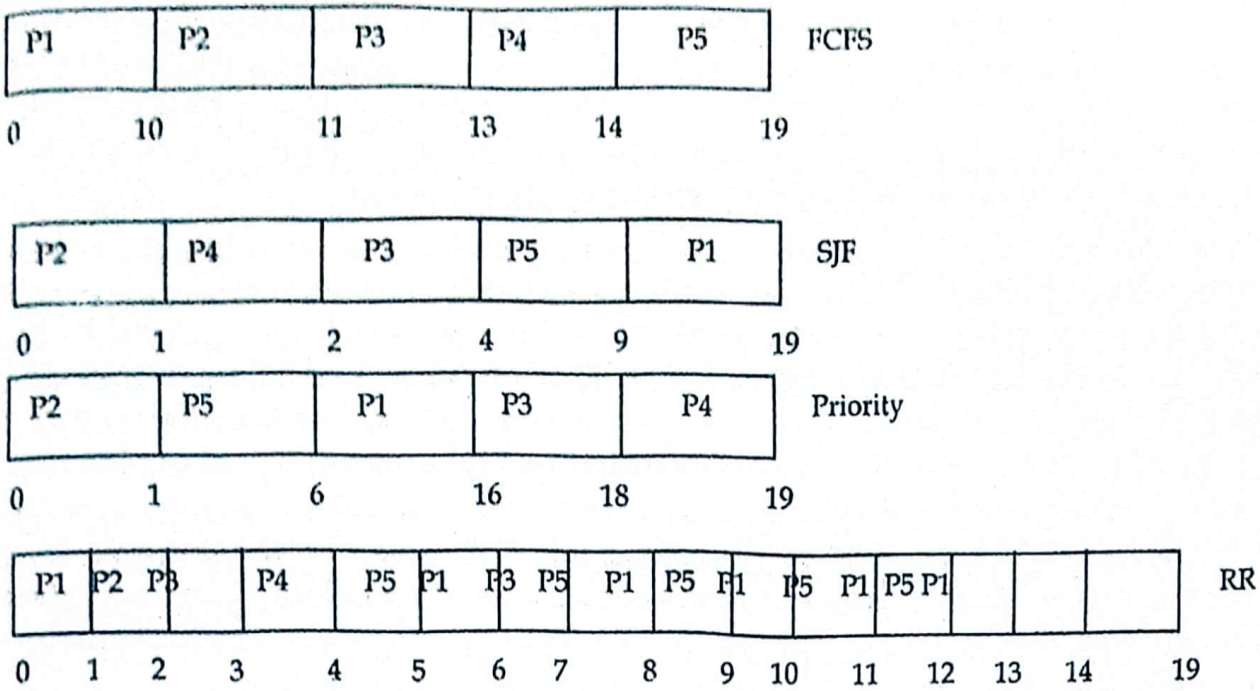
a. Draw four Gantt charts illustrating the execution of these processes using FCFS, SJF, a non- preemptive priority (a smaller priority number implies a higher priority) and RR scheduling with quantum=1.

b. What is the turnaround time of each process for each of the scheduling algorithms in part a?

c. What is the waiting time of each process for each of the scheduling algorithms in part a?

d. Which of the scheduling in part 'a' results in the minimal average time (over all processes)?

Solution: Gantt charts



b. Turnaround time

Process	FCFS	RR	SJF	Priority
P1	10	19	19	16
P2	11	2	1	1
P3	13	7	4	18
P4	14	4	2	19
P5	19	14	9	6

c. Waiting time (Turnaround time minus burst time)

Process	FCFS	RR	SJF	Priority
P1	0	9	9	6
P2	10	1	0	0
P3	11	5	2	16
P4	13	3	1	18
P5	14	9	4	1
Total waiting time	48	27	16	41
Average waiting time	9.6	5.4	3.2	8.2

d. Shortest job first (SJF) scheduling algorithm has minimal average time over all processes.

Overview of Real Time System Scheduling

A real-time scheduling System is composed of the scheduler, clock and the processing hardware elements. In a real-time system, a process or task has schedulability; tasks are accepted by a real-time system and completed as specified by the task deadline depending on the characteristic of the scheduling algorithm. Modeling and evaluation of a real-time scheduling system concern is on the

EXERCISE

Multiple Choice Questions

1. In operating system, each process has its own _____
   a) Address space and global variables b) open files
   c) Pending alarms, signals and signal handlers
   d) all of the mentioned
2. A process can be terminated due to _____
   a) Normal exit b) fatal error
   c) Killed by another process d) all of the mentioned
3. What is the ready state of a process?
   a) When process is scheduled to run after some execution
   b) When process is unable to run until some task has been completed
   c) When process is using the CPU
   d) none of the mentioned
4. What is inter-process communication?
   a) Communication within the process
   b) Communication between two process
   c) Communication between two threads of same process
   d) None of the mentioned
5. Which system call returns the process identifier of a terminated child?
   a) Wait b) exit
   c) Fork d) get
6. Semaphore is a/an _____ to solve the critical section problem.
   a) Hardware for a system b) special program for a system
   c) Integer variable d) none of the mentioned
7. If the semaphore value is negative _____
   a) its magnitude is the number of processes waiting on that semaphore
   b) it is invalid
   c) no operation can be further performed on it until the signal operation is performed on it
   d) none of the mentioned
8. An I/O bound program will typically have _____
   a) A few very short CPU bursts b) many very short I/O bursts
   c) Many very short CPU bursts d) a few very short I/O bursts
9. The switching of the CPU from one process or thread to another is called _____
   a) Process switch b) task switch
   c) Context switch d) all of the mentioned

10. A system is in the safe state if _____
    a) the system can allocate resources to each process in some order and still avoid a deadlock
    b) there exist a safe sequence
    c) all of the mentioned
    d) none of the mentioned

Subjective Questions

1. What are disadvantages of too much multiprogramming?
2. What is process? How it is differ from program? Explain.
3. What are different process models? Draw a state (block) diagram of process with different state and explain each briefly.
4. For each of the following transitions between the processes states, indicate whether the transition is possible. If it is possible, give an example of one thing that would cause it.
    a. Running -> Ready
    b. Running -> Blocked
    c. Blocked -> Running
3. Describe how multithreading improve performance over a singled-threaded solution.
4. What are the two differences between the kernel level threads and user level threads? Which one has a better performance?
5. What is multi threading? Explain
6. Describe differentiate between preemptive and non-preemptive scheduling with suitable example.
7. How processes and threads are created in compiler like gcc.
8. What resources are used when a thread is created? How do they differ from those used when a process is created?
9. What is the meaning of busy waiting? What others kinds of waiting are in OS? Compare each type on their applicability and relative merits.
10. Compare the use of monitor and semaphore operations.
11. What are CPU scheduling criteria in scheduling algorithm? Define each.
12. When a computer is being developed, it is usually first simulated by a program that runs one instruction at a time. Even multiprocessors are simulated strictly sequentially like this. Is it possible for a race condition to occur when there are no simultaneous events like this?
13. Does the busy waiting solution using the turn variable work when the two processes are running on a shared-memory multiprocessor, that is, two CPUs sharing a common memory?
14. What is process scheduling? Why it is used? Explain any two scheduling algorithms with suitable example.
15. What is semaphore? Explain their functions.

16. Does Peterson's solution to the mutual exclusion problem work when process scheduling is preemptive? How about when it is non-preemptive?

17. Round-robin schedulers normally maintain a list of all runnable processes, with each process occurring exactly once in the list. What would happen if a process occurred twice in the list? Can you think of any reason for allowing this?

18. Five jobs are waiting to be run. Their expected run times are 9, 6, 3, 5, and X. In what order should they be run to minimize average response time? (Your answer will depend on X.)

19. Five batch jobs A through E, arrive at a computer center at almost the same time. They have estimated running times of 10, 6, 2, 4, and 8 minutes. Their (externally determined) priorities are 3, 5, 2, 1, and 4, respectively, with 5 being the highest priority. For each of the following scheduling algorithms, determine the mean process turnaround time. Ignore process switching overhead.

    (a) Round robin.

    (b) Priority scheduling.

    (c) First-come, first-served (run in order 10, 6, 2, 4, and 8).

    (d) Shortest job first.

    For (a), assume that the system is multi-programmed, and that each job gets its fair share of the CPU. For (b) through (d) assume that only one job at a time runs, until it finishes. All jobs are completely CPU bound.

20. For the processes listed in following table, draw a Gantt chart illustrating their execution using:

    (a) First-Come-First-Serve

    (b) Short-Job-First

    (c) Shortest-Remaining-Time-Next

    (d) Round-Robin (quantum = 2)

    (e) Round-Robin (quantum = 1)

Processes	Arrival Time	Burst Time
A	0.00	4
B	2.01	7
C	3.01	2
D	3.02	2

ANSWERS KEY

1. (d)	2. (d)	3. (a)	4. (b)	5. (a)	6. (c)	7. (a)	8. (c)	9. (c)	10. (c)

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