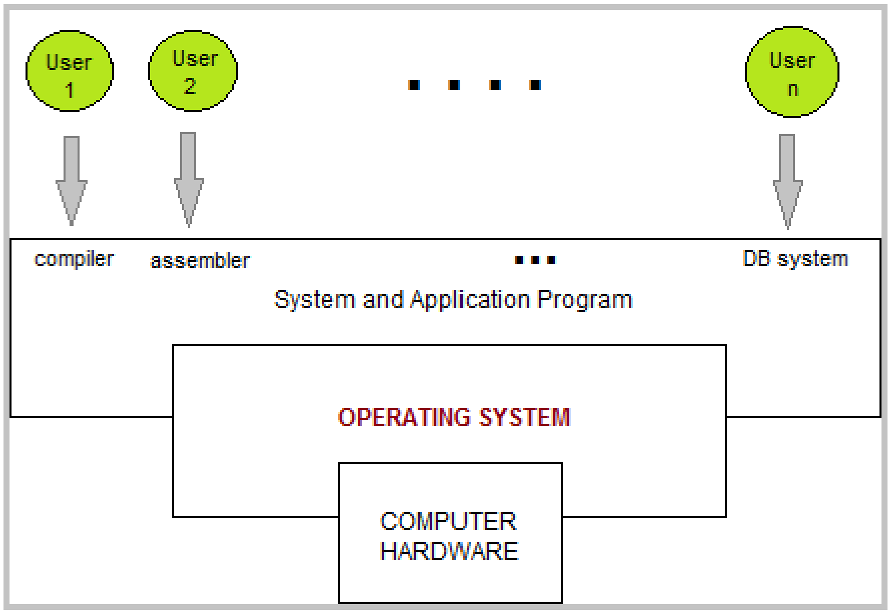
Operating System

BCA II Year

Introduction of Operating Systems

A computer system has many resources (hardware and software), which may be require to complete a task. The commonly required resources are input/output devices, memory, file storage space, CPU etc. The operating system acts as a manager of the above resources and allocates them to specific programs and users as necessary for their task. Therefore operating system is the resource manager i.e. it can manage the resource of a computer system internally. The resources are processor, memory, files, and I/O devices.

Four Components of a Computer System



Two Views of Operating System

1. User's View

2. System View

User View :

The user view of the computer refers to the interface being used. Such systems are designed for one user to monopolize its resources, to maximize the work that the user is performing. In these cases, the operating system is designed mostly for ease of use, with some attention paid to performance, and none paid to resource utilization.

System View :

Operating system can be viewed as a resource allocator also. A computer system consists of many resources like - hardware and software - that must be managed efficiently. The operating system acts as the manager of the resources, decides between conflicting requests, controls execution of programs etc.

Operating System Management Tasks

1. **Processor management** which involves putting the tasks into order and pairing them into manageable size before they go to the CPU.
2. **Memory management** which coordinates data to and from RAM (random-access memory) and determines the necessity for virtual memory.
3. **Device management** which provides interface between connected devices.
4. **Storage management** which directs permanent data storage.
5. **Application** which allows standard communication between software and your computer.
6. **User interface** which allows you to communicate with your computer.

Functions of Operating System

1. It boots the computer
2. It performs basic computer tasks e.g. managing the various peripheral devices e.g. mouse, keyboard

3. It provides a user interface, e.g. command line, graphical user interface (GUI)
4. It handles system resources such as computer's memory and sharing of the central processing unit(CPU) time by various applications or peripheral devices.
5. It provides file management which refers to the way that the operating system manipulates, stores, retrieves and saves data.
6. Error Handling is done by the operating system. It takes preventive measures whenever required to avoid errors.

Evolution of Operating Systems

The evolution of operating systems is directly dependent to the development of computer systems and how users use them. Here is a quick tour of computing systems through the past fifty years in the timeline.

Early Evolution

- 1945: ENIAC, Moore School of Engineering, University of Pennsylvania.
- 1949: EDSAC and EDVAC
- 1949 BINAC – a successor to the ENIAC
- 1951: UNIVAC by Remington
- 1952: IBM 701
- 1956: The interrupt
- 1954–1957: FORTRAN was developed

Operating Systems by the late 1950s

By the late 1950s Operating systems were well improved and started supporting following usages :

- It was able to Single stream batch processing
- It could use Common, standardized, input/output routines for device access
- Program transition capabilities to reduce the overhead of starting a new job was added
- Error recovery to clean up after a job terminated abnormally was added.

- Job control languages that allowed users to specify the job definition and resource requirements were made possible.

Operating Systems In 1960s

- 1961: The dawn of minicomputers
- 1962 Compatible Time-Sharing System (CTSS) from MIT
- 1963 Burroughs Master Control Program (MCP) for the B5000 system
- 1964: IBM System/360
- 1960s: Disks become mainstream
- 1966: Minicomputers get cheaper, more powerful, and really useful
- 1967–1968: The mouse
- 1964 and onward: Multics
- 1969: The UNIX Time-Sharing System from Bell Telephone Laboratories

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Supported OS Features by 1970s

- Multi User and Multi tasking was introduced.
- Dynamic address translation hardware and Virtual machines came into picture.
- Modular architectures came into existence.
- Personal, interactive systems came into existence.

Accomplishments after 1970

- 1971: Intel announces the microprocessor
- 1972: IBM comes out with VM: the Virtual Machine Operating System
- 1973: UNIX 4th Edition is published
- 1973: Ethernet
- 1974 The Personal Computer Age begins
- 1974: Gates and Allen wrote BASIC for the Altair
- 1976: Apple II
- August 12, 1981: IBM introduces the IBM PC
- 1983 Microsoft begins work on MS-Windows
- 1984 Apple Macintosh comes out

- 1990 Microsoft Windows 3.0 comes out
- 1991 GNU/Linux
- 1992 The first Windows virus comes out
- 1993 Windows NT
- 2007: iOS
- 2008: Android OS

And the research and development work still goes on, with new operating systems being developed and existing ones being improved to enhance the overall user experience while making operating systems fast and efficient like they have never been before.

Types of Operating Systems

Following are some of the most widely used types of Operating system.

1. Simple Batch System
2. Multiprogramming Batch System
3. Multiprocessor System
4. Distributed Operating System
5. Realtime Operating System

SIMPLE BATCH SYSTEMS

- In this type of system, there is no direct interaction between user and the computer.
- The user has to submit a job (written on cards or tape) to a computer operator.
- Then computer operator places a batch of several jobs on an input device.
- Jobs are batched together by type of languages and requirement.
- Then a special program, the monitor, manages the execution of each program in the batch.
- The monitor is always in the main memory and available for execution.

Following are some disadvantages of this type of system:

1. Zero interaction between user and computer.
2. No mechanism to prioritize processes.

MULTIPROGRAMMING BATCH SYSTEMS

- In this the operating system, picks and begins to execute one job from memory.
- Once this job needs an I/O operation operating system switches to another job (CPU and OS always busy).
- Jobs in the memory are always less than the number of jobs on disk(Job Pool).
- If several jobs are ready to run at the same time, then system chooses which one to run (CPU Scheduling).
- In Non-multiprogrammed system, there are moments when CPU sits idle and does not do any work.
- In Multiprogramming system, CPU will never be idle and keeps on processing.

Time-Sharing Systems are very similar to Multiprogramming batch systems. In fact time sharing systems are an extension of multiprogramming systems.

In time sharing systems the prime focus is on minimizing the response time, while in multiprogramming the prime focus is to maximize the CPU usage.

MULTIPROCESSOR SYSTEMS

A multiprocessor system consists of several processors that share a common physical memory. Multiprocessor system provides higher computing power and speed. In multiprocessor system all processors operate under single operating system. Multiplicity of the processors and how they do act together are transparent to the others.

Following are some advantages of this type of system.

1. Enhanced performance
2. Execution of several tasks by different processors concurrently, increases the system's throughput without speeding up the execution of a single task.
3. If possible, system divides task into many subtasks and then these subtasks can be executed in parallel in different processors. Thereby speeding up the execution of single tasks.

DISTRIBUTED OPERATING SYSTEMS

The motivation behind developing distributed operating systems is the availability of powerful and inexpensive microprocessors and advances in communication technology.

These advancements in technology have made it possible to design and develop distributed systems comprising of many computers that are inter connected by communication networks. The main benefit of distributed systems is its low price/performance ratio.

REAL-TIME OPERATING SYSTEM

It is defined as an operating system known to give maximum time for each of the critical operations that it performs, like OS calls and interrupt handling.

The Operating system which guarantees the maximum time for these operations are commonly referred to as **hard real-time**, while operating systems that can only guarantee a maximum of the time are referred to as **soft real-time**.

What is a Process?

A program in the execution is called a Process. Process is not the same as program. A process is more than a program code. A process is an 'active' entity as opposed to program which is considered to be a 'passive' entity. Attributes held by process include hardware state, memory, CPU etc.

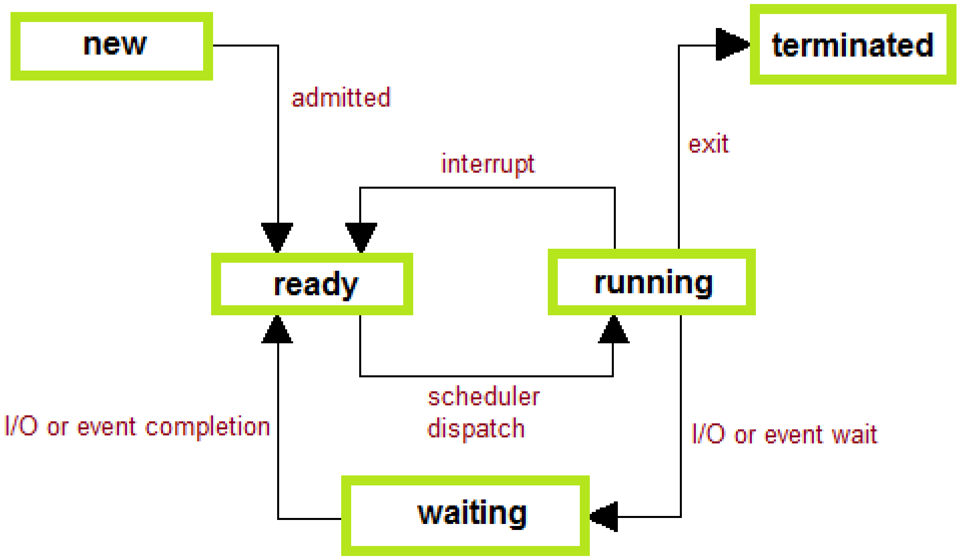
Process memory is divided into four sections for efficient working:

- The text section is made up of the compiled program code, read in from non-volatile storage when the program is launched.
- The data section is made up the global and static variables, allocated and initialized prior to executing the main.
- The heap is used for the dynamic memory allocation, and is managed via calls to new, delete, malloc, free, etc.
- The stack is used for local variables. Space on the stack is reserved for local variables when they are declared.

PROCESS STATE

Processes can be any of the following states :

- **New -** The process is in the stage of being created.
- **Ready -** The process has all the resources available that it needs to run, but the CPU is not currently working on this process's instructions.
- **Running -** The CPU is working on this process's instructions.
- **Waiting -** The process cannot run at the moment, because it is waiting for some resource to become available or for some event to occur.
- **Terminated -** The process has completed.

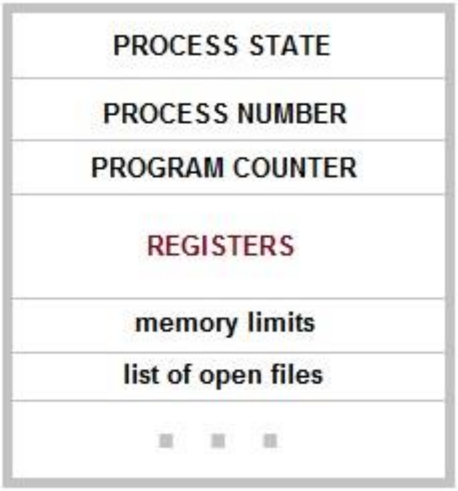


PROCESS CONTROL BLOCK

There is a Process Control Block for each process, enclosing all the information about the process. It is a data structure, which contains the following :

- Process State - It can be running, waiting etc.
- Process ID and parent process ID.
- CPU registers and Program Counter. **Program Counter** holds the address of the next instruction to be executed for that process.

- CPU Scheduling information - Such as priority information and pointers to scheduling queues.
- Memory Management information - Eg. page tables or segment tables.
- Accounting information - user and kernel CPU time consumed, account numbers, limits, etc.
- I/O Status information - Devices allocated, open file tables, etc.



PROCESS STATE

PROCESS NUMBER

PROGRAM COUNTER

REGISTERS

memory limits

list of open files

■ ■ ■

Process Scheduling

The act of determining which process in the ready state should be moved to the running state is known as Process Scheduling.

The prime aim of the process scheduling system is to keep the CPU busy all the time and to deliver minimum response time for all programs. For achieving this, the scheduler must apply appropriate rules for swapping processes IN and OUT of CPU.

Schedulers fell into one of the two general categories :

- **Non pre-emptive scheduling.** When the currently executing process gives up the CPU voluntarily.
- **Pre-emptive scheduling.** When the operating system decides to favour another process, pre-empting the currently executing process.

Scheduling Queues

- All processes when enters into the system are stored in the **job queue**.
- Processes in the Ready state are placed in the **ready queue**.
- Processes waiting for a device to become available are placed in **device queues**. There are unique device queues for each I/O device available.

Types of Schedulers

There are three types of schedulers available :

1. **Long Term Scheduler** :

   Long term scheduler runs less frequently. Long Term Schedulers decide which program must get into the job queue. From the job queue, the Job Processor, selects processes and loads them into the memory for execution. Primary aim of the Job Scheduler is to maintain a good degree of Multiprogramming. An optimal degree of Multiprogramming means the average rate of process creation is equal to the average departure rate of processes from the execution memory.

2. **Short Term Scheduler** :

   This is also known as CPU Scheduler and runs very frequently. The primary aim of this scheduler is to enhance CPU performance and increase process execution rate.

3. **Medium Term Scheduler** :

   During extra load, this scheduler picks out big processes from the ready queue for some time, to allow smaller processes to execute, thereby reducing the number of processes in the ready queue.

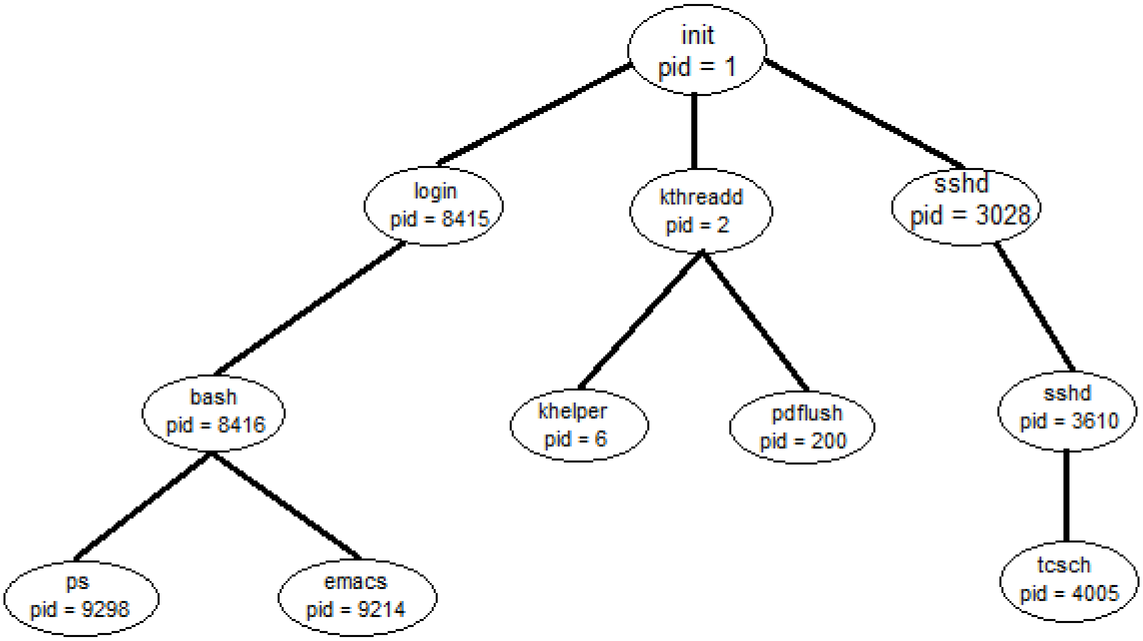
Operations on Process

Process Creation

Through appropriate system calls, such as fork or spawn, processes may create other processes. The process which creates other process, is termed the **parent** of the other process, while the created sub-process is termed its **child**.

Each process is given an integer identifier, termed as process identifier, or PID. The parent PID (PPID) is also stored for each process.

On a typical UNIX systems the process scheduler is termed as `sched`, and is given PID 0. The first thing done by it at system start-up time is to launch `init`, which gives that process PID 1. Further Init launches all the system daemons and user logins, and becomes the ultimate parent of all other processes.



A Tree of processes on a typical Linux system

A child process may receive some amount of shared resources with its parent depending on system implementation. To prevent runaway children from consuming all of a certain system resource, child processes may or may not be limited to a subset of the resources originally allocated to the parent.

There are two options for the parent process after creating the child:

- Wait for the child process to terminate before proceeding. Parent process makes a `wait ()` system call, for either a specific child process or for any particular child process, which causes the parent process to block until the

wait() returns. UNIX shells normally wait for their children to complete before issuing a new prompt.
- Run concurrently with the child, continuing to process without waiting. When a UNIX shell runs a process as a background task, this is the operation seen. It is also possible for the parent to run for a while, and then wait for the child later, which might occur in a sort of a parallel processing operation.

Process Termination

By making the `exit`(system call), typically returning an int, processes may request their own termination. This int is passed along to the parent if it is doing a `wait()`, and is typically zero on successful completion and some non-zero code in the event of any problem.

Processes may also be terminated by the system for a variety of reasons, including :

- The inability of the system to deliver the necessary system resources.
- In response to a KILL command or other unhandled process interrupts.
- A parent may kill its children if the task assigned to them is no longer needed i.e. if the need of having a child terminates.
- If the parent exits, the system may or may not allow the child to continue without a parent (In UNIX systems, orphaned processes are generally inherited by `init`, which then proceeds to kill them.)

When a process ends, all of its system resources are freed up, open files flushed and closed, etc. The process termination status and execution times are returned to the parent if the parent is waiting for the child to terminate, or eventually returned to init if the process already became an orphan.

The processes which are trying to terminate but cannot do so because their parent is not waiting for them are termed **zombies**. These are eventually inherited by init as orphans and killed off.

CPU Scheduling

CPU scheduling is a process which allows one process to use the CPU while the execution of another process is on hold(in waiting state) due to unavailability of any resource like I/O etc, thereby making full use of CPU. The aim of CPU scheduling is to make the system efficient, fast and fair.

Scheduling Criteria

There are many different criterias to check when considering the "best" scheduling algorithm :

- **CPU utilization**

  To make out the best use of CPU and not to waste any CPU cycle, CPU would be working most of the time(Ideally 100% of the time). Considering a real system, CPU usage should range from 40% (lightly loaded) to 90% (heavily loaded.)

- **Throughput**

  It is the total number of processes completed per unit time or rather say total amount of work done in a unit of time. This may range from 10/second to 1/hour depending on the specific processes.

- **Turnaround time**

  It is the amount of time taken to execute a particular process, i.e. The interval from time of submission of the process to the time of completion of the process(Wall clock time).

- **Waiting time**

  The sum of the periods spent waiting in the ready queue amount of time a process has been waiting in the ready queue to acquire get control on the CPU.

- **Load average**

  It is the average number of processes residing in the ready queue waiting for their turn to get into the CPU.

- **Response time**

Amount of time it takes from when a request was submitted until the first response is produced. Remember, it is the time till the first response and not the completion of process execution(final response).

In general CPU utilization and Throughput are maximized and other factors are reduced for proper optimization.

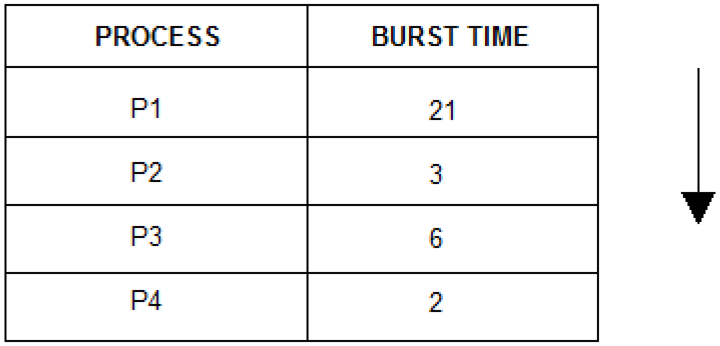
Scheduling Algorithms

We'll discuss four major scheduling algorithms here which are following :

1. First Come First Serve(FCFS) Scheduling
2. Shortest-Job-First(SJF) Scheduling
3. Priority Scheduling
4. Round Robin(RR) Scheduling
5. Multilevel Queue Scheduling

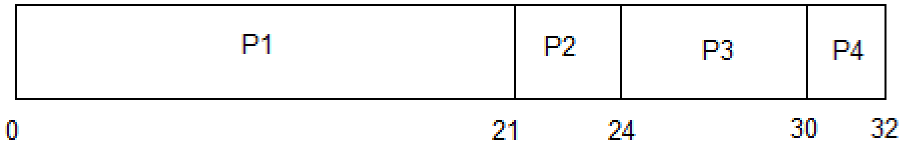
First Come First Serve(FCFS) Scheduling

- Jobs are executed on first come, first serve basis.
- Easy to understand and implement.
- Poor in performance as average wait time is high.



PROCESS	BURST TIME
P1	21
P2	3
P3	6
P4	2

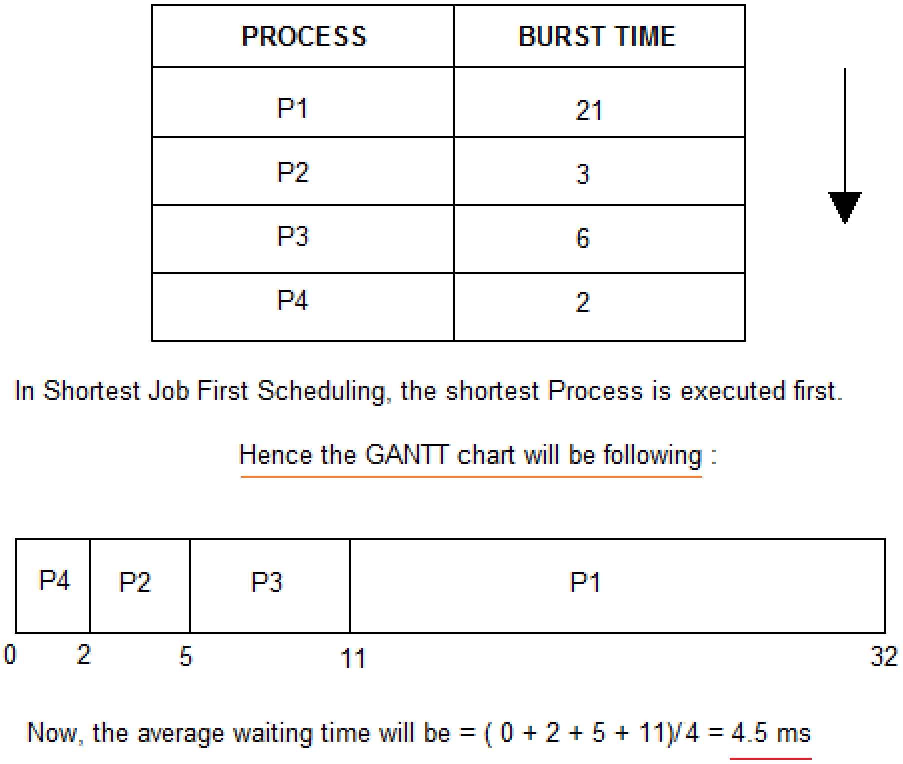
The average waiting time will be = (0 + 21 + 24 + 30)/4 = 18.75 ms



This is the GANTT chart for the above processes

Shortest-Job-First(SJF) Scheduling

- Best approach to minimize waiting time.
- Actual time taken by the process is already known to processor.
- Impossible to implement.



PROCESS	BURST TIME
P1	21
P2	3
P3	6
P4	2

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

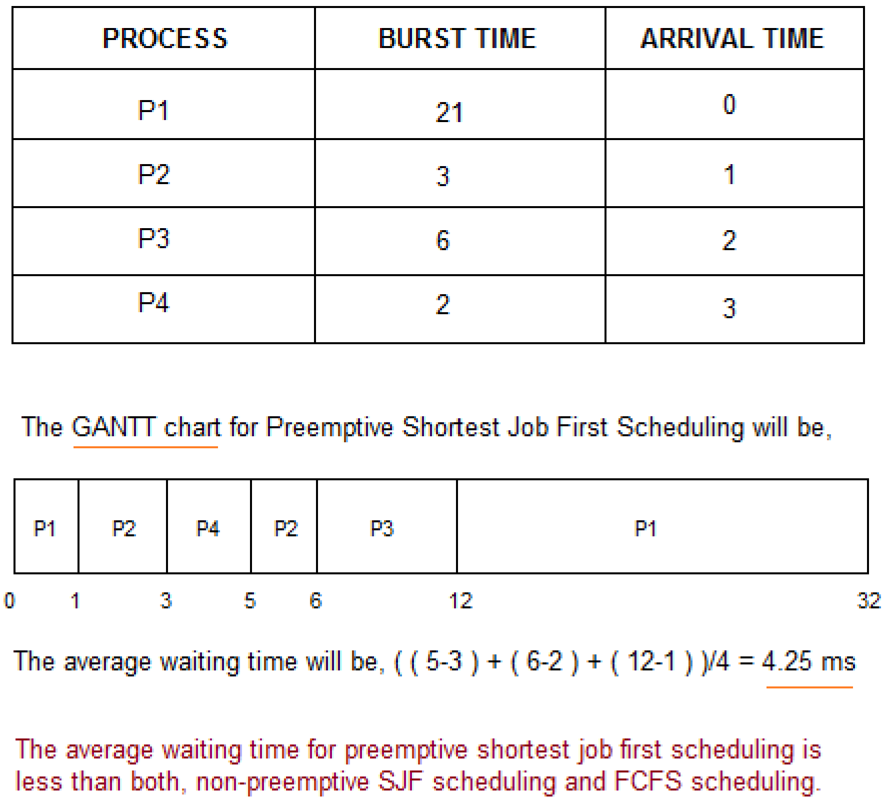
Hence the GANTT chart will be following :

P4	P2	P3	P1

0 2 5 11 32

Now, the average waiting time will be = (0 + 2 + 5 + 11)/4 = 4.5 ms

In Preemptive Shortest Job First Scheduling, jobs are put into ready queue as they arrive, but as a process with short burst time arrives, the existing process is preempted.



PROCESS	BURST TIME	ARRIVAL TIME
P1	21	0
P2	3	1
P3	6	2
P4	2	3

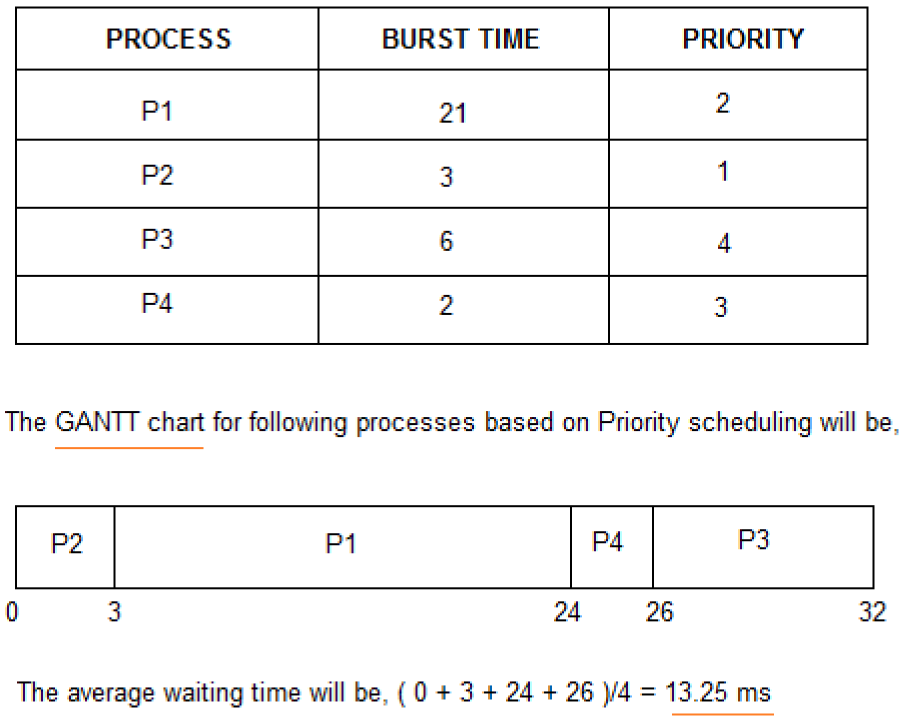
The GANTT chart for Preemptive Shortest Job First Scheduling will be,

The average waiting time will be, ((5-3) + (6-2) + (12-1))/4 = 4.25 ms

The average waiting time for preemptive shortest job first scheduling is less than both, non-preemptive SJF scheduling and FCFS scheduling.

Priority Scheduling

- Priority is assigned for each process.
- Process with highest priority is executed first and so on.
- Processes with same priority are executed in FCFS manner.
- Priority can be decided based on memory requirements, time requirements or any other resource requirement.



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,

P2	P1	P4	P3

0 3 24 26 32

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

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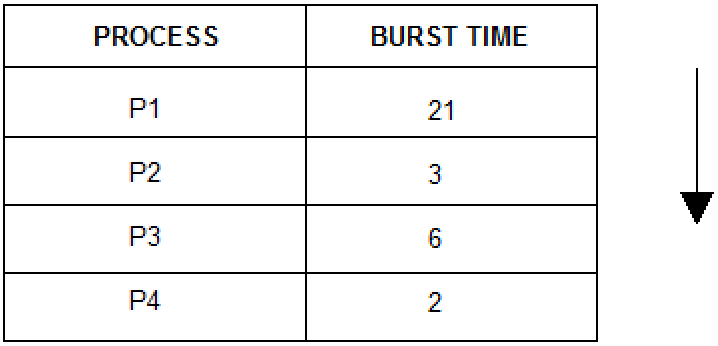
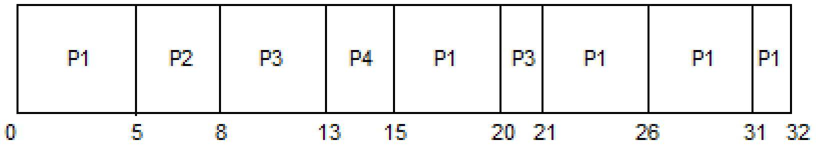
Round Robin(RR) Scheduling

- A fixed time is allotted to each process, called **quantum**, for execution.
- Once a process is executed for given time period that process is preempted and other process executes for given time period.
- Context switching is used to save states of preemptied processes.



PROCESS	BURST TIME
P1	21
P2	3
P3	6
P4	2

The GANTT chart for round robin scheduling will be,



The average waiting time will be, 11 ms.

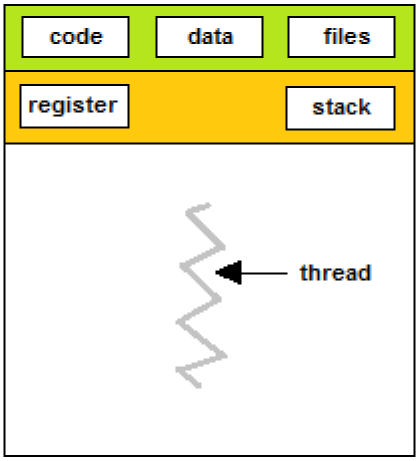
Multilevel Queue Scheduling

- Multiple queues are maintained for processes.
- Each queue can have its own scheduling algorithms.
- Priorities are assigned to each queue.

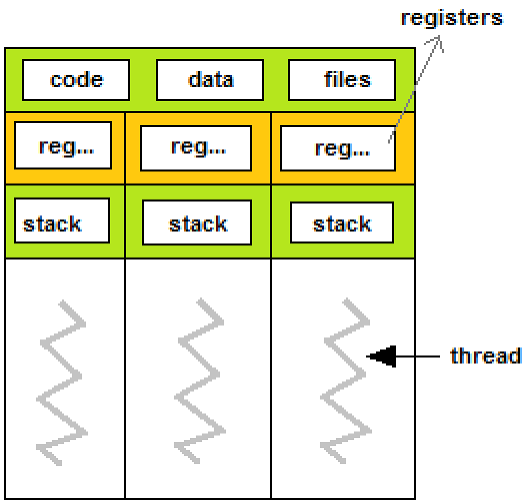
What are Threads?

Thread is an execution unit which consists of its own program counter, a stack, and a set of registers. Threads are also known as Lightweight processes. 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.

As each thread has its own independent resource for process execution, multpile processes can be executed parallely by increasing number of threads.



single-threaded process



multithreaded process

Types of Thread

There are two types of threads :

- User Threads
- Kernel Threads

User threads, are above the kernel and without kernel support. These are the threads that application programmers use in their programs.

Kernel threads are supported within the kernel of the OS itself. All modern OSs support kernel level threads, allowing the kernel to perform multiple simultaneous tasks and/or to service multiple kernel system calls simultaneously.

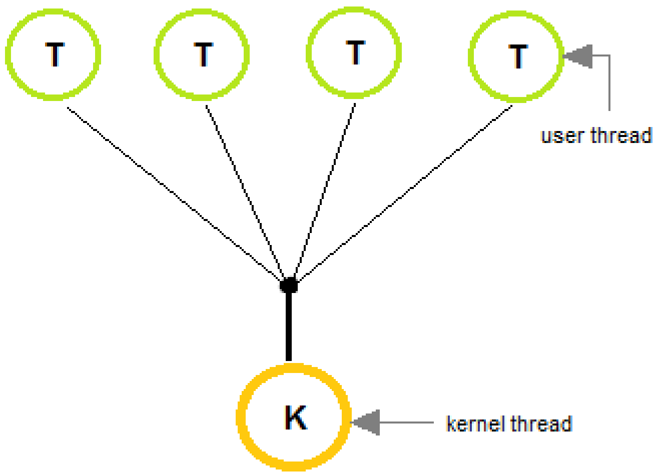
Multithreading Models

The user threads must be mapped to kernel threads, by one of the following strategies.

- Many-To-One Model
- One-To-One Model
- Many-To-Many Model

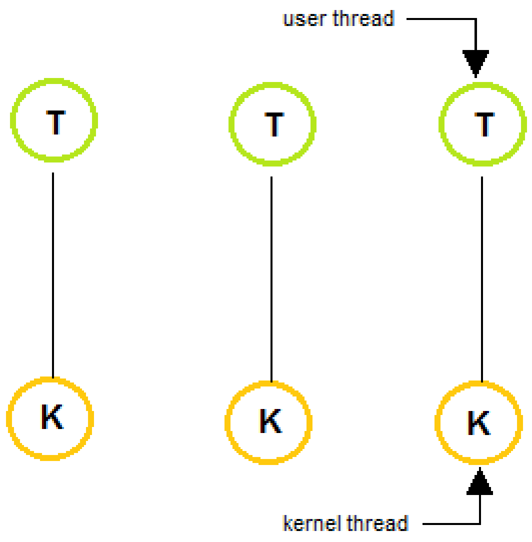
Many-To-One Model

- In the many-to-one model, many user-level threads are all mapped onto a single kernel thread.
- Thread management is handled by the thread library in user space, which is efficient in nature.



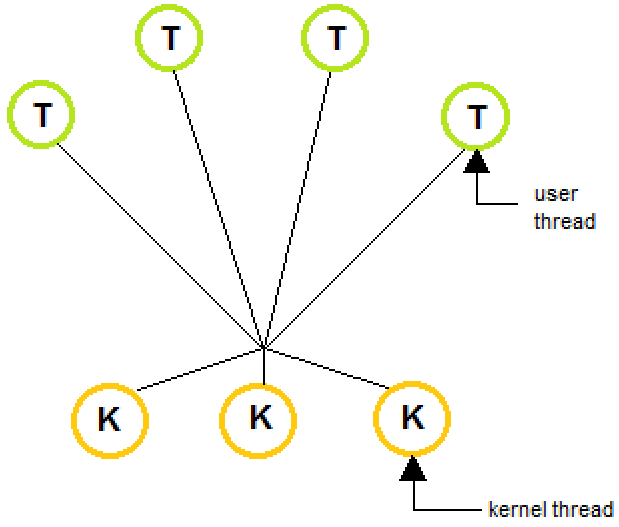
One-To-One Model

- The one-to-one model creates a separate kernel thread to handle each and every user thread.
- 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.



Many-To-Many Model

- The many-to-many model multiplexes any number of user threads onto an equal or smaller number of kernel threads, combining the best features of the one-to-one and many-to-one models.
- Users can create any number of the threads.
- Blocking the kernel system calls does not block the entire process.
- Processes can be split across multiple processors.



Thread Libraries

Thread libraries provides programmers with API for creating and managing of threads.

Thread libraries may be implemented either in user space or in kernel space. The user space involves API functions implemented solely within user space, with no kernel support. The kernel space involves system calls, and requires a kernel with thread library support.

There are three types of thread :

- POSIX Pitheads, may be provided as either a user or kernel library, as an extension to the POSIX standard.
- Win32 threads, are provided as a kernel-level library on Windows systems.
- Java threads - Since Java generally runs on a Java Virtual Machine, the implementation of threads is based upon whatever OS and hardware the JVM is running on, i.e. either Pitheads or Win32 threads depending on the system

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Benefits of Multithreading

1. Responsiveness
2. Resource sharing, hence allowing better utilization of resources.
3. Economy. Creating and managing threads becomes easier.
4. Scalability. One thread runs on one CPU. In Multithreaded processes, threads can be distributed over a series of processors to scale.
5. Context Switching is smooth. Context switching refers to the procedure followed by CPU to change from one task to another.

Multithreading Issues

1. **Thread Cancellation**.

Thread cancellation means terminating a thread before it has finished working. There can be two approaches for this, one is **Asynchronous cancellation**, which terminates the target thread immediately. The other is **Deferred cancellation** allows the target thread to periodically check if it should be cancelled.

2. **Signal Handling**.

   Signals are used in UNIX systems to notify a process that a particular event has occurred. Now in when a Multithreaded process receives a signal, to which thread it must be delivered? It can be delivered to all, or a single thread.

3. **fork() System Call**.

   fork() is a system call executed in the kernel through which a process creates a copy of itself. Now the problem in Multithreaded process is, if one thread forks, will the entire process be copied or not?

4. **Security Issues** because of extensive sharing of resources between multiple threads.

There are many other issues that you might face in a multithreaded process, but there are appropriate solutions available for them. Pointing out some issues here was just to study both sides of the coin.

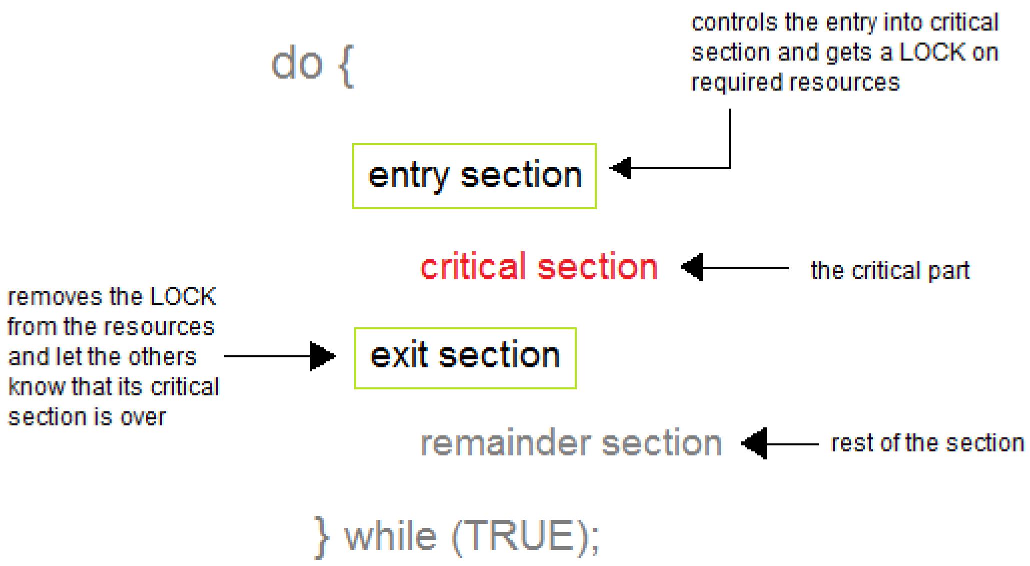
Process Synchronization

Process Synchronization means sharing system resources by processes in a such a way that, Concurrent access to shared data is handled thereby minimizing the chance of inconsistent data. Maintaining data consistency demands mechanisms to ensure synchronized execution of cooperating processes.

Process Synchronization was introduced to handle problems that arose while multiple process executions. Some of the problems are discussed below.

Critical Section Problem

A Critical Section is a code segment that accesses shared variables and has to be executed as an atomic action. It means that in a group of cooperating processes, at a given point of time, only one process must be executing its critical section. If any other process also wants to execute its critical section, it must wait until the first one finishes.


do {
controls the entry into critical section and gets a LOCK on required resources
entry section
critical section
the critical part
removes the LOCK from the resources and let the others know that its critical section is over
exit section
remainder section
rest of the section
} while (TRUE);

Solution to Critical Section Problem

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

1. **Mutual Exclusion**

   Out of a group of cooperating processes, only one process can be in its critical section at a given point of time.

2. **Progress**

   If no process is in its critical section, and if one or more threads want to execute their critical section then any one of these threads must be allowed to get into its critical section.

3. **Bounded Waiting**

   After a process makes a request for getting into its critical section, there is a limit for how many other processes can get into their critical section, before this process's request is granted. So after the limit is reached, system must grant the process permission to get into its critical section.

Synchronization Hardware

Many systems provide hardware support for critical section code. The critical section problem could be solved easily in a single-processor environment if we could disallow interrupts to occur while a shared variable or resource is being modified.

In this manner, we could be sure that the current sequence of instructions would be allowed to execute in order without pre-emption. Unfortunately, this solution is not feasible in a multiprocessor environment.

Disabling interrupt on a multiprocessor environment can be time consuming as the message is passed to all the processors.

This message transmission lag, delays entry of threads into critical section and the system efficiency decreases.

Mutex Locks

As the synchronization hardware solution is not easy to implement fro everyone, a strict software approach called Mutex Locks was introduced. In this approach, in the entry section of code, a LOCK is acquired over the critical resources modified and used inside critical section, and in the exit section that LOCK is released.

As the resource is locked while a process executes its critical section hence no other process can access it.

Semaphores

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. This integer variable is called **semaphore**. So it is basically a synchronizing tool and is accessed only through two low standard atomic operations, wait and signal designated by P() and V() respectively.

The classical definition of wait and signal are :

- Wait : decrement the value of its argument S as soon as it would become non-negative.
- Signal : increment the value of its argument, S as an individual operation.

Properties of Semaphores

1. Simple
2. Works with many processes
3. Can have many different critical sections with different semaphores
4. Each critical section has unique access semaphores
5. Can permit multiple processes into the critical section at once, if desirable.

Types of Semaphores

Semaphores are mainly of two types:

1. **Binary Semaphore**

   It is a special form of semaphore used for implementing mutual exclusion, hence it is often called *Mutex*. A binary semaphore is initialized to 1 and only takes the value 0 and 1 during execution of a program.

2. **Counting Semaphores**

   These are used to implement bounded concurrency.

Limitations of Semaphores

1. Priority Inversion is a big limitation os semaphores.
2. Their use is not enforced, but is by convention only.

3. With improper use, a process may block indefinitely. Such a situation is called Deadlock. We will be studying deadlocks in details in coming lessons.

Classical Problem of Synchronization

Following are some of the classical problem faced while process synchronaization in systems where cooperating processes are present.

Bounded Buffer Problem

- This problem is generalised in terms of the Producer-Consumer problem.
- Solution to this problem is, creating two counting semaphores "full" and "empty" to keep track of the current number of full and empty buffers respectively.

The Readers Writers Problem

- In this problem there are some processes(called readers) that only read the shared data, and never change it, and there are other processes(called writers) who may change the data in addition to reading or instead of reading it.
- There are various type of the readers-writers problem, most centred on relative priorities of readers and writers

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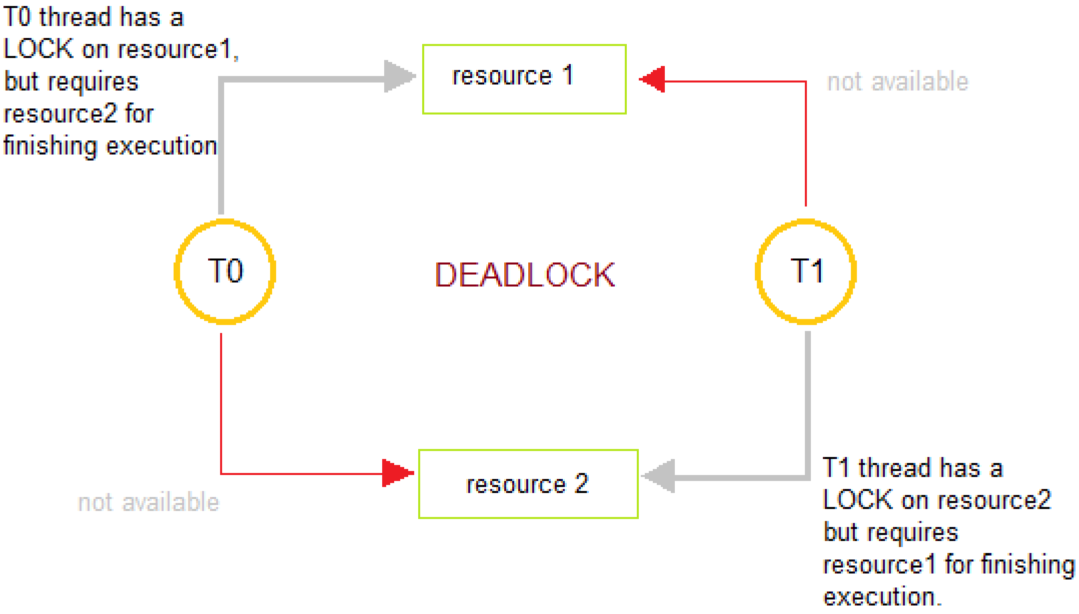
Dining Philosophers Problem

- The dining philosopher's problem involves the allocation of limited resources from a group of processes in a deadlock-free and starvation-free manner.
- There are five philosophers sitting around a table, in which there are five chopsticks kept beside them and a bowl of rice in the centre, When a philosopher wants to eat, he uses two chopsticks - one from their left and one from their right. When a philosopher wants to think, he keeps down both chopsticks at their original place.

What is a Deadlock?

Deadlocks are a set of blocked processes each holding a resource and waiting to acquire a resource held by another process.


T0 thread has a LOCK on resource1, but requires resource2 for finishing execution
resource 1
not available
T0
DEADLOCK
T1
not available
resource 2
T1 thread has a LOCK on resource2 but requires resource1 for finishing execution.

How to avoid Deadlocks

Deadlocks can be avoided by avoiding at least one of the four conditions, because all this four conditions are required simultaneously to cause deadlock.

1. **Mutual Exclusion**

   Resources shared such as read-only files do not lead to deadlocks but resources, such as printers and tape drives, requires exclusive access by a single process.

2. **Hold and Wait**

   In this condition processes must be prevented from holding one or more resources while simultaneously waiting for one or more others.

3. **No Preemption**

   Preemption of process resource allocations can avoid the condition of deadlocks, where ever possible.

4. **Circular Wait**

   Circular wait can be avoided if we number all resources, and require that processes request resources only in strictly increasing(or decreasing) order.

Handling Deadlock

The above points focus on preventing deadlocks. But what to do once a deadlock has occured. Following three strategies can be used to remove deadlock after its occurrence.

1. **Preemption**

   We can take a resource from one process and give it to other. This will resolve the deadlock situation, but sometimes it does causes problems.

2. **Rollback**

   In situations where deadlock is a real possibility, the system can periodically make a record of the state of each process and when deadlock occurs, roll everything back to the last checkpoint, and restart, but allocating resources differently so that deadlock does not occur.

3. **Kill one or more processes**

   This is the simplest way, but it works.

What is a Livelock?

There is a variant of deadlock called livelock. This is a situation in which two or more processes continuously change their state in response to changes in the other process(es) without doing any useful work. This is similar to deadlock in that no progress is made but differs in that neither process is blocked or waiting for anything.

A human example of livelock would be two people who meet face-to-face in a corridor and each moves aside to let the other pass, but they end up swaying from side to side without making any progress because they always move the same way at the same time.

Memory Management

Main Memory refers to a physical memory that is the internal memory to the computer. The word main is used to distinguish it from external mass storage devices such as disk drives. Main memory is also known as RAM. The computer is able to change only data that is in main memory. Therefore, every program we execute and every file we access must be copied from a storage device into main memory.

All the programs are loaded in the main memeory for execution. Sometimes complete program is loaded into the memory, but some times a certain part or routine of the program is loaded into the main memory only when it is called by the program, this mechanism is called **Dynamic Loading**, this enhance the performance.

Also, at times one program is dependent on some other program. In such a case, rather than loading all the dependent programs, CPU links the dependent programs to the main executing program when its required. This mechanism is known as **Dynamic Linking**.

Swapping

A process needs to be in memory for execution. But sometimes there is not enough main memory to hold all the currently active processes in a timesharing system. So, excess process are kept on disk and brought in to run dynamically. Swapping is the process of bringing in each process in main memory, running it for a while and then putting it back to the disk.

Contiguous Memory Allocation

In contiguous memory allocation each process is contained in a single contiguous block of memory. Memory is divided into several fixed size partitions. Each partition contains exactly one process. When a partition is free, a process is selected from the input queue and loaded into it. The free blocks of memory are known as *holes*. The set of holes is searched to determine which hole is best to allocate.

Memory Protection

Memory protection is a phenomenon by which we control memory access rights on a computer. The main aim of it is to prevent a process from accessing memory that has not been allocated to it. Hence prevents a bug within a process from affecting other processes, or the operating system itself, and instead results in a segmentation fault or storage violation exception being sent to the disturbing process, generally killing of process.

Memory Allocation

Memory allocation is a process by which computer programs are assigned memory or space. It is of three types :

1. **First Fit**

   The first hole that is big enough is allocated to program.

2. **Best Fit**

   The smallest hole that is big enough is allocated to program.

3. **Worst Fit**

   The largest hole that is big enough is allocated to program.

Fragmentation

Fragmentation occurs in a dynamic memory allocation system when most of the free blocks are too small to satisfy any request. It is generally termed as inability to use the available memory.

In such situation processes are loaded and removed from the memory. As a result of this, free holes exists to satisfy a request but is non contiguous i.e. the memory is fragmented into large no. Of small holes. This phenomenon is known as **External Fragmentation.**

Also, at times the physical memory is broken into fixed size blocks and memory is allocated in unit of block sizes. The memory allocated to a space may be slightly larger than the requested memory. The difference between allocated and required memory is known as **Internal fragmentation** i.e. the memory that is internal to a partition but is of no use.

Paging

A solution to fragmentation problem is Paging. Paging is a memory management mechanism that allows the physical address space of a process to be non-contagious. Here physical memory is divided into blocks of equal size called **Pages**. The pages belonging to a certain process are loaded into available memory frames.

Page Table

A Page Table is the data structure used by a virtual memory system in a computer operating system to store the mapping between *virtual address* and *physical addresses.*

Virtual address is also known as Logical address and is generated by the CPU. While Physical address is the address that actually exists on memory.

Segmentation

Segmentation is another memory management scheme that supports the user-view of memory. Segmentation allows breaking of the virtual address space of a single process into segments that may be placed in non-contiguous areas of physical memory.

Segmentation with Paging

Both paging and segmentation have their advantages and disadvantages, it is better to combine these two schemes to improve on each. The combined scheme is known as 'Page the Elements'. Each segment in this scheme is divided into pages and each segment is maintained in a page table. So the logical address is divided into following 3 parts :

- Segment numbers(S)
- Page number (P)
- The displacement or offset number (D)

Virtual Memory

Virtual Memory is a space where large programs can store themselves in form of pages while their execution and only the required pages or portions of processes are loaded into the main memory. This technique is useful as large virtual memory is provided for user programs when a very small physical memory is there.

In real scenarios, most processes never need all their pages at once, for following reasons :

- Error handling code is not needed unless that specific error occurs, some of which are quite rare.
- Arrays are often over-sized for worst-case scenarios, and only a small fraction of the arrays are actually used in practice.
- Certain features of certain programs are rarely used.

Benefits of having Virtual Memory :

1. Large programs can be written, as virtual space available is huge compared to physical memory.
2. Less I/O required, leads to faster and easy swapping of processes.
3. More physical memory available, as programs are stored on virtual memory, so they occupy very less space on actual physical memory.

What is page fault and when does it occur?

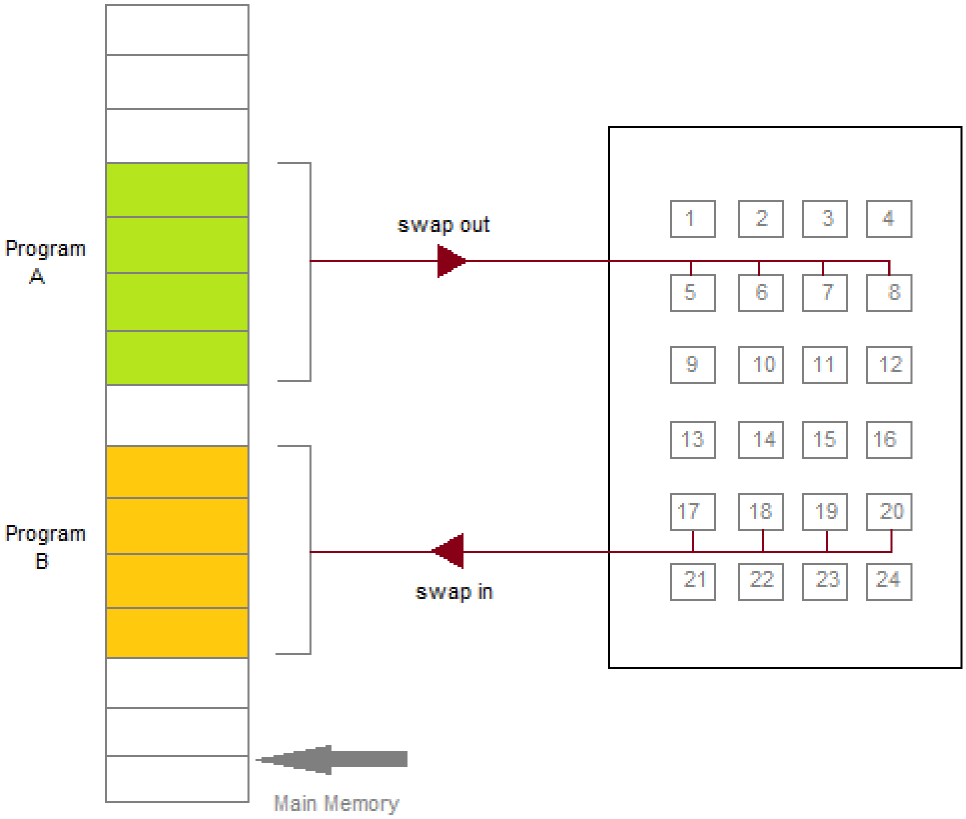
When the page (data) requested by a program is not available in the memory, it is called as a page fault. This usually results in the application being shut down.

What is page fault and when does it occur?

A page is a fixed length memory block used as a transferring unit between physical memory and an external storage. A page fault occurs when a program accesses a page that has been mapped in address space, but has not been loaded in the physical memory.

Demand Paging

The basic idea behind demand paging is that when a process is swapped in, its pages are not swapped in all at once. Rather they are swapped in only when the process needs them(On demand). This is termed as lazy swapper, although a pager is a more accurate term.



Initially only those pages are loaded which will be required the process immediately.

The pages that are not moved into the memory, are marked as invalid in the page table. For an invalid entry the rest of the table is empty. In case of pages that are loaded in the memory, they are marked as valid along with the information about where to find the swapped out page.

When the process requires any of the page that is not loaded into the memory, a page fault trap is triggered and following steps are followed,

1. The memory address which is requested by the process is first checked, to verify the request made by the process.
2. If its found to be invalid, the process is terminated.
3. In case the request by the process is valid, a free frame is located, possibly from a free-frame list, where the required page will be moved.
4. A new operation is scheduled to move the necessary page from disk to the specified memory location. (This will usually block the process on an I/O wait, allowing some other process to use the CPU in the meantime.)
5. When the I/O operation is complete, the process's page table is updated with the new frame number, and the invalid bit is changed to valid.
6. The instruction that caused the page fault must now be restarted from the beginning.

There are cases when no pages are loaded into the memory initially, pages are only loaded when demanded by the process by generating page faults. This is called **Pure Demand Paging**.

The only major issue with Demand Paging is, after a new page is loaded, the process starts execution from the beginning. Its is not a big issue for small programs, but for larger programs it affects performance drastically.

Page Replacement

As studied in Demand Paging, only certain pages of a process are loaded initially into the memory. This allows us to get more number of processes into the memory at the same time. but what happens when a process requests for more pages and no free memory is available to bring them in. Following steps can be taken to deal with this problem :

1. Put the process in the wait queue, until any other process finishes its execution thereby freeing frames.
2. Or, remove some other process completely from the memory to free frames.
3. Or, find some pages that are not being used right now, move them to the disk to get free frames. This technique is called **Page replacement** and is most commonly used. We have some great algorithms to carry on page replacement efficiently.

Basic Page Replacement

- Find the location of the page requested by ongoing process on the disk.
- Find a free frame. If there is a free frame, use it. If there is no free frame, use a page-replacement algorithm to select any existing frame to be replaced, such frame is known as **victim frame**.
- Write the victim frame to disk. Change all related page tables to indicate that this page is no longer in memory.
- Move the required page and store it in the frame. Adjust all related page and frame tables to indicate the change.
- Restart the process that was waiting for this page.

FIFO Page Replacement

- A very simple way of Page replacement is FIFO (First in First Out)
- As new pages are requested and are swapped in, they are added to tail of a queue and the page which is at the head becomes the victim.
- Its not an effective way of page replacement but can be used for small systems.

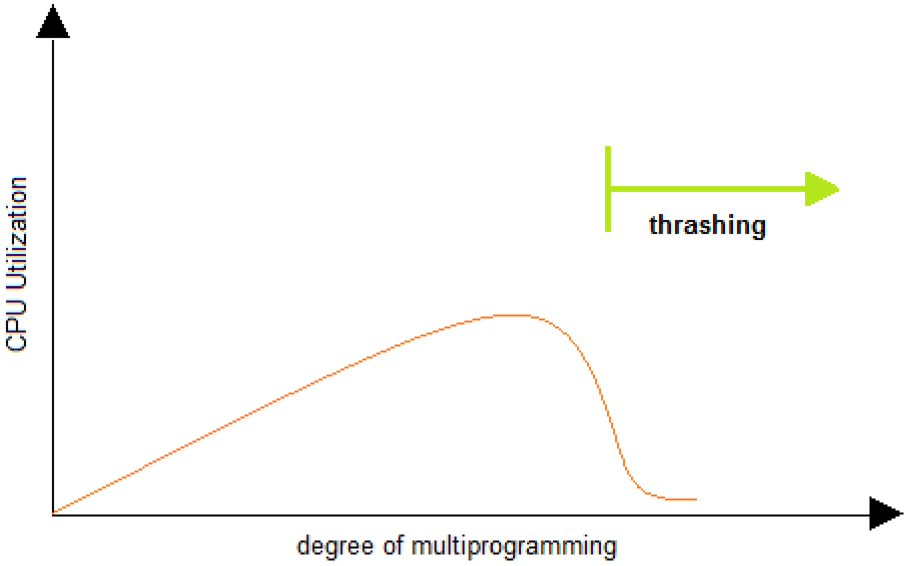
LRU Page Replacement

Below is a video, which will explain LRU Page replacement algorithm in details with an example.

Thrashing

A process that is spending more time paging than executing is said to be thrashing. In other words it means, that the process doesn't have enough frames to hold all the pages for its execution, so it is swapping pages in and out very frequently to keep executing. Sometimes, the pages which will be required in the near future have to be swapped out.

Initially when the CPU utilization is low, the process scheduling mechanism, to increase the level of multiprogramming loads multiple processes into the memory at the same time, allocating a limited amount of frames to each process. As the memory fills up, process starts to spend a lot of time for the required pages to be swapped in, again leading to low CPU utilization because most of the proccesses are waiting for pages. Hence the scheduler loads more processes to increase CPU utilization, as this continues at a point of time the complete system comes to a stop.



To prevent thrashing we must provide processes with as many frames as they really need "right now".

File System

A file can be "free formed", indexed or structured collection of related bytes having meaning only to the one who created it. Or in other words an entry in a directory is the file. The file may have attributes like name, creator, date, type, permissions etc.

File Structure

A file has various kinds of structure. Some of them can be :

- **Simple Record Structure** with lines of fixed or variable lengths.
- **Complex Structures** like formatted document or reloadable load files.
- **No Definite Structure** like sequence of words and bytes etc.

Attributes of a File

Following are some of the attributes of a file :

- **Name** . It is the only information which is in human-readable form.
- **Identifier**. The file is identified by a unique tag(number) within file system.
- **Type**. It is needed for systems that support different types of files.
- **Location**. Pointer to file location on device.
- **Size**. The current size of the file.
- **Protection**. This controls and assigns the power of reading, writing, executing.
- **Time, date, and user identification**. This is the data for protection, security, and usage monitoring.

File Access Methods

The way that files are accessed and read into memory is determined by Access methods. Usually a single access method is supported by systems while there are OS's that support multiple access methods.

Sequential Access

- Data is accessed one record right after another is an order.

- Read command cause a pointer to be moved ahead by one.
- Write command allocate space for the record and move the pointer to the new End Of File.
- Such a method is reasonable for tape.

Direct Access

- This method is useful for disks.
- The file is viewed as a numbered sequence of blocks or records.
- There are no restrictions on which blocks are read/written, it can be dobe in any order.
- User now says "read n" rather than "read next".
- "n" is a number relative to the beginning of file, not relative to an absolute physical disk location.

Indexed Sequential Access

- It is built on top of Sequential access.
- It uses an Index to control the pointer while accessing files.

What is a Directory?

Information about files is maintained by Directories. A directory can contain multiple files. It can even have directories inside of them. In Windows we also call these directories as folders.

Following is the information maintained in a directory :

- **Name** : The name visible to user.
- **Type** : Type of the directory.
- **Location** : Device and location on the device where the file header is located.
- **Size** : Number of bytes/words/blocks in the file.
- **Position** : Current next-read/next-write pointers.
- **Protection** : Access control on read/write/execute/delete.
- **Usage** : Time of creation, access, modification etc.
- **Mounting** : When the root of one file system is "grafted" into the existing tree of another file system its called Mounting.