UNIT - I

Chapter - 1

Operating System

INTRODUCTION :

Operating system is the program that manages computer hardware program and acts as an intermediary between the computer user and the computer hardware. The main purpose of an operating system is to provide an environment in which a user can easily execute their programs and can interface with computer.

An operating system is an important part of almost every computer system.

A computer system can be divided roughly into four components: the hardware, the operating system, the application programs, and the users.

Component of Computer System :

The four component are, the hardware/ the operating system, the application programs/and the users

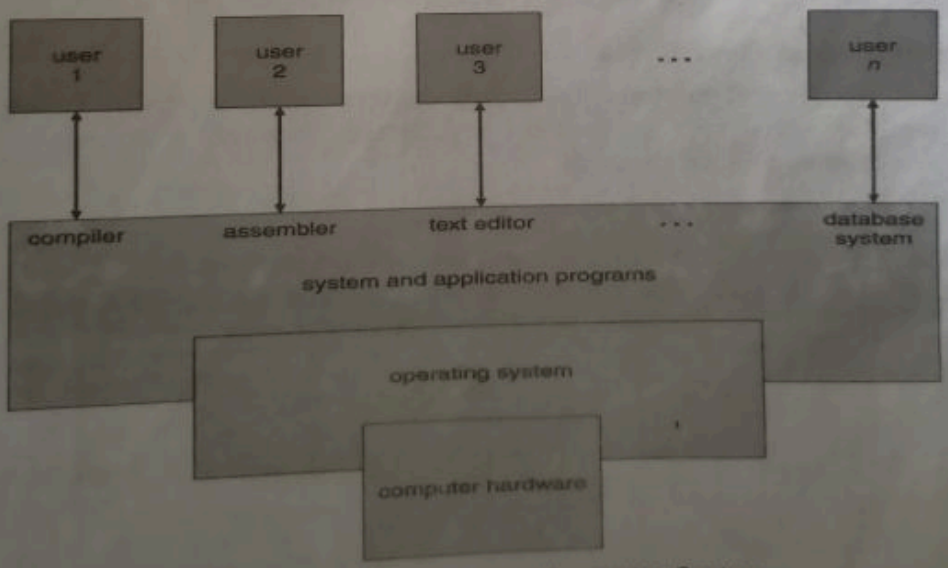


Figure: The Component of Computer System

The hardware the Central Processing Unit, the memory and the Input/Output(I/O) devices-provides the basic computing resources for the system. The application program such as word processors/ spreadsheets/ compilers, and Web browsers-define the ways in which these resources are used

to solve users' computing problems. The operating system controls the hardware and coordinates its use among the various application programs for the various users.

Operating System Role

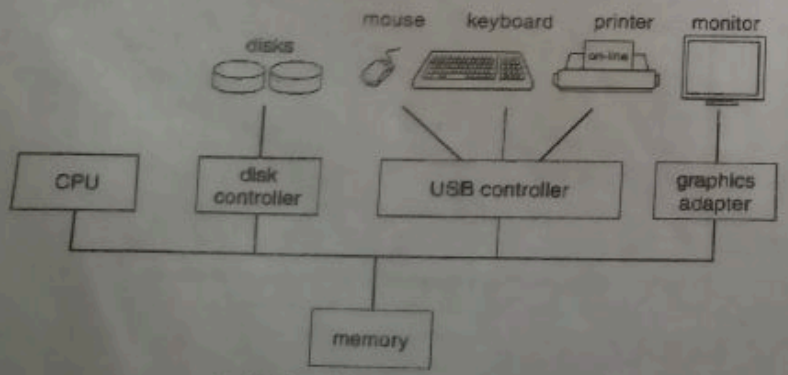
We can also view a computer system as consisting of hardware/ software/ and data. The operating system provides the means for proper use of these resources in the operation of the computer system. An operating system is similar to a *government*. Like a government, it performs no useful function by itself. It simply provides an *environment* within which other programs can do useful work.

The operating system role can be seen from user view and system view

1. **User view :**
   a) The user's view of the computer varies according to the interface being used.
   b) Provides Graphical User Interface(GUI)
   c) Here Computer system can process many programs and share this information and resources through other computer system in network which is accessed by other computer users.
2. **System View :**
   a) From the computer's point of view, the operating system is the program most intimately involved with the hardware. In this context, we can view an operating system as a resource allocator.
   b) Computer system manages the execution of user program to prevent errors which act as a control program.
   c) A computer system has many resources that may be required to solve a problem : CPU time, memory space, file-storage space, I/0 devices, and so on. The operating system acts as the manager of these resources.

Operating System Operations

A modern general-purpose computer system consists of one or more CPUs and a number of device controllers connected through a common bus that provides access to shared memory.



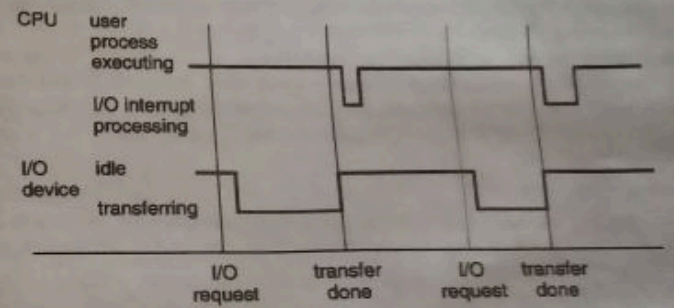
A Modern Computer System

Each device controller is in charge of a specific type of device. The CPU and the device controllers can execute concurrently, competing for memory cycles. To ensure orderly access to the shared memory, a memory controller is provided whose function is to synchronize access to the memory.

Interrupt Processing :

The occurrence of an event is usually signaled by an interrupt from either the hardware or the software. Hardware may trigger an interrupt at any time by sending a signal to the CPU, usually by way of the system bus. Software may trigger an interrupt by executing a special operation called a System Call.

Interrupts are an important part of a computer architecture. Each computer design has its own interrupt mechanism, but several functions are common. The interrupt must transfer control to the appropriate interrupt service routine.



Interrupt time line for a single process doing output

The interrupt architecture must also save the address of the interrupted instruction.

Timer

To interrupt the computer after particular time, time may be fix or variable. A variable timer is introduced by fixed rate clock and counter were the operating system, sets the counter.

We must ensure that the operating system maintains control over the CPU. We cannot allow a User program to get stuck in an infinite loop or to fail. to call system services and never return control to the operating system.

After every clock the counter is decremented, here interrupt is occur when counter reaches to 0.

Here we can use the Timer to prevent a user program from running for log time by providing the counter for the program to be run for that time period only.

Dual Mode

2 modes - User mode & kernal mode. (0 mode bit) (1 mode bit) privileged or system

The dual mode of operation provides us with the means for protecting the operating system from offending user and offending users from one another. We accomplish this protection by designating some of the machine instruction that cause harm as privileged instruction.

If we are executing the privilege instructions in user mode then the hardware dose not execute the instruction.

offending Causing problem

Function of Operating system

1. **Process Management :** According to the priority and Burst time of the process operating system decides which process need to be execute first and then only allocation and de-allocation of the process is done at processor for processing.
2. **File Management :** Creating file, removing the file, storing the file and keeping track of location
3. **Memory Management :** According to the size of the process,memory will be allocated for the specific process this will be decided by the operating system.Its is the main fnction of the operting system.
4. **Device Management :** Maximum utilization of the resources is done by the operating system. Here hardware devices are controlled with the help of software device drivers.
5. **Interface :** Graphical user interface and Command line Interface provided by the operating system
6. **Security :** Operating system protect all type of data which is stored on the computer ,from unauthorized users.
7. **Caching :** Here we have to select the information or data carefully as limited space is provided by the operating system for quick access of the information.

Computing Environment

A computing environment contains computer systems interface and the services which are given by operating system for users. Different types of computing environments are:

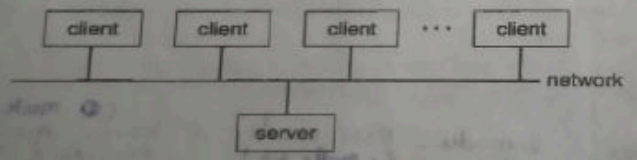
1. **Traditional Computing**

Office environment uses traditional computing and who technology also uses traditional computing. Today, traditional time-sharing systems are uncommon. For a period of time, systems were either batch or interactive.

A timer and scheduling algorithms uses time-sharing system to rapidly cycle processes through the CPU, giving each user a share of the resources. The scheduling are all owned by the same user.

2. **Client-Server Computing**

Terminals connected to centralized systems are now being supplanted by PCs. Specialized form of distributed system which is called a client server system, where systems act as server system to fulfil the requirements of client systems.



Server systems can be categorized into:

The compute-server system acts as an interface where client sends a request to perform some action and response, the server executes action and sends back the results to client. For example, server running a database which gives response to client requests for data.

The file-server system act as an interface where the clients can create, update, read, and delete file. For eg. Web browsers can receive the file from web server.

3. **Peer-to-peer Computing**

In peer to peer computing client and server are not different from one another, all nodes within the system are considered peers and all of them can act as client or a server, depending on request or providing the service.

In a client-server system, the server is a bottleneck; but in a peer-to-peer system, services can be provided by several nodes distributed throughout the network.

4. **Web-based Computing**

Web computing has increased the emphasis on networking. Devices that were not previously networked now include wired or wireless access. Devices that were networked now have faster network connectivity/ provided by either improved networking technology optimized network implementation code/ or both.

The implementation of Web-based computing has given rise to new categories of devices/ such as load balancer.

QUESTIONS

1. Explain Operating System in detail.
2. What are the different function of operating system.
3. Define operating system, explain the roles of operating system.
4. Write a short note on peer-peer system and client-server system.

Springboard@1121

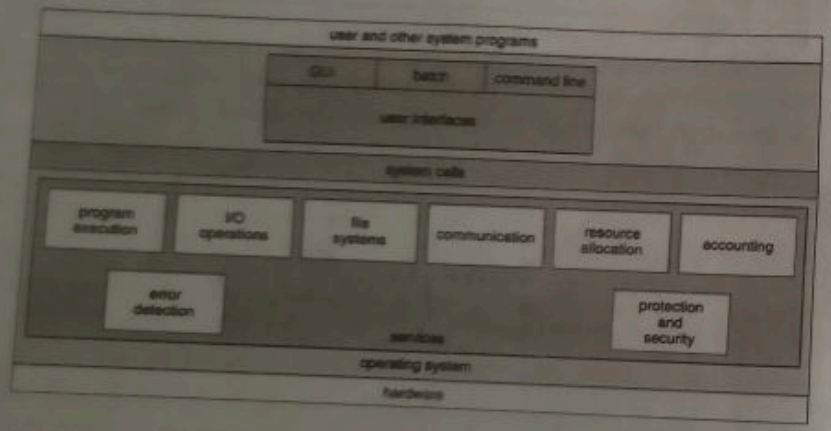
Chapter – 2
Operating System Structure

An operating system provides the environment within which programs are executed.

Operating System Services

An operating system provides an environment for the execution of programs. These operating-system services are provided for the convenience of the programmer, to n1.ake the programming task easier.

It provides certain services to programs and to the users of those programs.



An Operating System supplies different kinds of services to both the users and to the programs as well. It also provides application programs (that run within an Operating system) an environment to execute it freely.

1. User Interface of Operating System

Usually Operating system comes in three forms or types. Depending on the interface their types have been further subdivided. These are:

- Command line interface
- Batch based interface
- Graphical User Interface

2. Program Execution in operating system

The operating system must have the capability to load a program into memory and execute that program. Furthermore, the program must be able to end its execution, either normally or abnormally / forcefully.

3. File system Manipulation

Programs need has to be read and then write them as files and directories. File handling portion of operating system also allows users to create and delete files by specific name along with extension, search for a given file and / or list file information. Some programs comprise of permissions management for allowing or denying access to files or directories based on file ownership.

4. I/O operation

A program which is currently executing may require I/O, which may involve file or other I/O device. For efficiency and protection, users cannot directly govern the I/O devices. So, the OS provide a means to do I/O Input / Output operation which means read or write operation with any file.

5. Communication

Process needs to swap over information with other process. Processes executing on same computer system or on different computer systems can communicate using operating system support. Communication between two processes can be done using shared memory or via message passing.

6. Resource Allocation

When multiple jobs running concurrently, resources must need to be allocated to each of them. Resources can be CPU cycles, main memory storage, file storage and I/O devices. CPU scheduling routines are used here to establish how best the CPU can be used.

7. Error detection

Errors may occur within CPU, memory hardware, I/O devices and in the user program. For each type of error, the OS takes adequate action for ensuring correct and consistent computing.

8. Accounting

This service of the operating system keeps track of which users are using how much and what kinds of computer resources have been used for accounting or simply to accumulate usage statistics.

9. Protection and Security

Protection includes in ensuring all access to system resources in a controlled manner. For making a system secure, the user needs to authenticate him or her to the system before using

User and Operating System Interface

There are two fundamental approaches for users to interface with the operating system. One technique is to provide a command-line interface or command interpreter that allows users to directly enter commands that are to be performed by the operating system. The second approach allows the user to interface with the operating system via a graphical user interface or GUI.

Command Interpreter

- Some operating systems include the command interpreter in the kernel. Others, such as Windows XP and UNIX, treat the command interpreter as a special program that is running when a job is initiated or when a user first logs on (on interactive systems).
- On systems with multiple command interpreters to choose from, the interpreters are known as shells. For example, on UNIX and Linux systems, there are several different shells a user may choose from including the Bourne shell, C shell, Bourne-Again shell, the Korn shell,

etc. Most shells provide similar functionality with only minor differences; most users choose a shell based upon personal preference. The main function of the command interpreter is to get and execute the next user-specified command.

- Many of the commands given at this level manipulate files: create, delete, list, print, copy, execute, and so on. The MS-DOS and UNIX shells operate in this way. There are two general ways in which these commands can be implemented. In one approach, the command interpreter itself contains the code to execute the command.

Graphical User Interface

- A second strategy for interfacing with the operating system is through a user-friendly graphical user interface or GUI.
- Rather than having users directly enter commands via a command-line interface, a GUI allows provides a mouse-based window-and-menu system as an interface.
- A GUI provides a desktop metaphor where the mouse is moved to position its pointer on images, or icons, on the screen (the desktop) that represent programs, files, directories, and system functions.
- Depending on the mouse pointer's location, clicking a button on the mouse can invoke a program, select a file or directory—known as a folder— or pull down a menu that contains commands.

System Calls

To understand system calls, first one needs to understand the difference between **kernel mode** and **user mode** of a CPU.

Kernel Mode

- When CPU is in **kernel mode**, the code being executed can access any memory address and any hardware resource.
- Hence kernel mode is a very privileged and powerful mode.
- If a program crashes in kernel mode, the entire system will be halted.

User Mode

- When CPU is in **user mode**, the programs don't have direct access to memory and hardware resources.
- In user mode, if any program crashes, only that particular program is halted.
- That means the system will be in a safe state even if a program in user mode crashes.
- Hence, most programs in an OS run in user mode.

When a program in user mode requires access to RAM or a hardware resource, it must ask the kernel to provide access to that resource. This is done via something called a **system call**.

When a program makes a system call, the mode is switched from user mode to kernel mode. This is called a **context switch**.

Then the kernel provides the resource which the program requested. After that, another context switch happens which results in change of mode from kernel mode back to user mode.

Generally, system calls are made by the user level programs in the following situations:

- Creating, opening, closing and deleting files in the file system.
- Creating and managing new processes.
- Creating a connection in the network, sending and receiving packets.
- Requesting access to a hardware device, like a mouse or a printer.

Type of System Call

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.

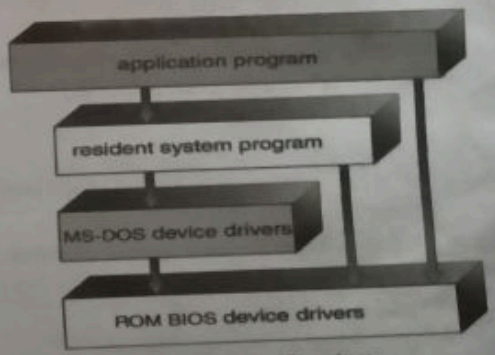
Communication : These system calls are useful for inter process communication. They also deal with creating and deleting a communication connection.

Operating System Structure

A system as large and complex as a modern operating system must be engineered carefully if it is to function properly and be modified easily. A common approach is to partition the task into small components rather than have one monolithic system.

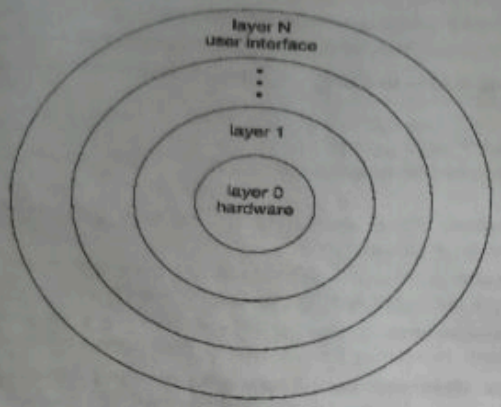
Simple Structure :

Many commercial operating systen1.s do not have well-defined structures. Frequently, such systems started as small, simple, and limited systems and then grew beyond their original scope. MS-DOS is an example of such a system.



MS-DOS Layer Structure

Layered Structure Operating system can be broken into pieces that are smaller and more appropriate with proper hardware support.



Layered Structure

- The Layered approach is broken into a number of layers. The bottom layer(layer 0) is the hardware, highest(layer N) is the user interface
- Layered approach is easy to understand, debug and modify. because changes affect only limited portions of the code, and programmer does not have to know the details of the other layers.
- Information is also kept only where it is needed and is accessible only in certain ways, so bugs affecting that data are limited to a specific module or layer.

Microkernels

- Moves as much from the kernel into "user" space
- Communication takes place between user modules using message passing

Benefits :

- Easier to extend a microkernel
- Easier to port the operating system to new architectures
- More reliable (less code is running in kernel mode)
- More secure

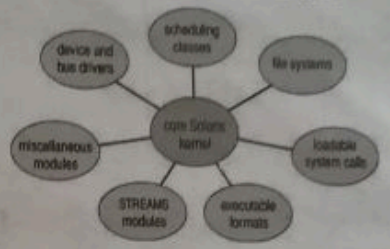
Detriments :

- Performance overhead of user space to kernel space communication

Modules

Most modern operating systems implement kernel modules

- Uses object-oriented approach
- Each core component is separate
- Each talks to the others over known interfaces
- Each is loadable as needed within the kernel
- Overall, similar to layers but with more flexible



Solaris Loadable module

QUESTIONS

1. What are the different services provided by Operating system?
2. Explain system call in detail
3. Explain Operating system structure in detail
4. What is the purpose of the command interpreter? Why it is separate from the kernel.?

Chapter – 3
Process Concept

INTRODUCTION

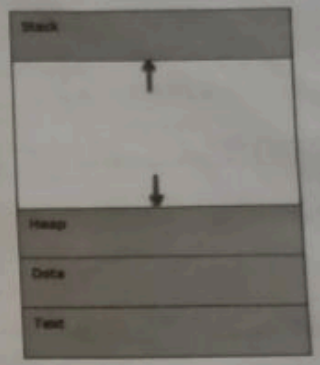
- Now-a-days computer systems allow multiple programs to be loaded into memory and executed concurrently.
- The needs such as firmer control and more compartmentalization of the various programs results in the notion of process, which is a program in execution.
- A system consists of a collection of processes where operating system processes executing system code and user processes executing user code.

Process Concept

- 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. ... Like a task, a **process** is a running program with which a set of data is associated so that the **process** can be kept track of.
- In a single user system, a user may be able to run several programs at one time, for example, a word processor, a web processor and an email package.
- If the user can execute only one program at a time, the operating system supports its own internal activities, such as memory management which we call all of them as processes

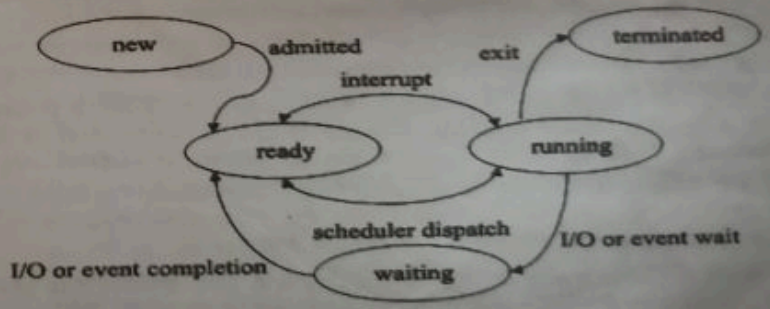
The Process

- A process includes the current activity represented by the value of the program counter and the contents of the processor's registers. It also includes the process stack, a data section and a heap.
- A program is a passive entity, such as a file containing a list of instructions stored on disk whereas a process is an active entity, with a program counter specifying the next instruction to execute and a set of associated resources.
- When an executable file is loaded into memory, a program becomes a process. For loading executable files there are two techniques: double-clicking an icon representing the executable file and entering the name of the executable file on the command line.



Process State

- The state of a process which may be defined in part by the current activity of that process. Each process can be in one of the following states:
- NEW-The process is being created.
- READY- The process is waiting to be assigned to a processor.
- RUNNING- Instructions are being executed.
- WAITING- The process is waiting for some event to occur(such as an I/O completion or reception of a signal).
- TERMINATED-The process has finished execution.
- One process can be running on any processor and others may be in ready or waiting.



Process Control Block

- Process control block also called as task control block which contains many pieces of information:

Process Id
State
Pointer
Priority
Program counter
CPU registers
I/O information
Accounting Information
etc...

Process control block

- **Process state :** The states are new, ready, running, waiting, halted, etc.
- **Program counter :** It indicates the address of the next instruction to be executed for this process.
- **CPU registers :** The registers may be different in number and type, depending on the computer architecture.
- **CPU scheduling information :** Process priority, pointers to scheduling queues and other scheduling parameters.
- **Accounting information:** Amount of CPU used, time limits, account numbers, job or process numbers are included in accounting information.
- **I/O status information :** It consist list of I/O devices allocated to the process, a list of open files.
- **Memory management information :** It contains value of the base and limit registers, the page tables or the segment tables.

Threads

A Thread is a single sequence stream within a process. When a process is running a word-processor program, a single thread of instructions is being executed. This single thread of control allows the process to perform only one task at one time.

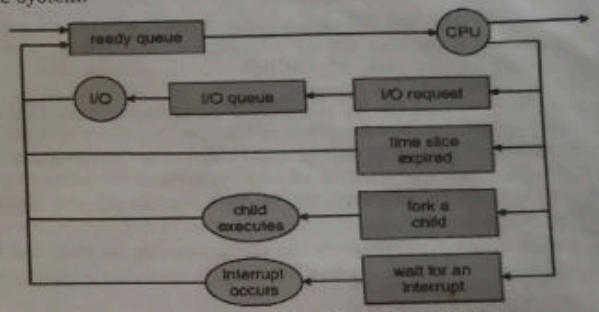
Process Scheduling

To meet the objective of multiprogramming and time sharing the process scheduler selects an available process for program execution on the CPU.

Scheduling Queues

- Processes entering the system are kept in job queue, whereas processes residing in main memory which are ready to execute are kept in ready queue.
- When a process is allocated the CPU, it executes for a while and quits, is interrupted or waits for the occurrence of a particular event, such as the completion of an I/O request.
- The list of processes waiting for a particular I/O device is called a device queue. Each device has its own device queue.

- A common representation of process scheduling is a queuing is as shown in Fig. 3.2.1. Each rectangular box represents a queue. Two types of queues are present, the ready queue and a set of device queues.
- The circles indicate resources and arrows indicate the flow of processes in the system.



Queuing representation of process scheduling

Schedulers

- The operating system must select processes from the queues for scheduling purposes which is carried by the scheduler. Processes are selected by the **long-term scheduler** or job schedule from the pool and loads them into memory for execution.
- Processes that are ready to execute are selected by the **short-term scheduler** or CPU scheduler and allocates the CPU to one of them.
- The short-term scheduler executes at least once every 100 milliseconds where the long-term executes much less frequently.
- If it is stable the long-term scheduler controls the **degree of multiprogramming**, then the average rate of process creation must be equal to the average departure rate of processes leaving the system.
- Most processes are either I/O bound or CPU bound.
- I/O bound process spends most of it time doing I/O rather than doing computations.
- A CPU bound process, in contrast, generates I/O requests infrequently, using more of its time doing computations. It's important that the long-term scheduler selects a good process mix of I/O bound and CPU bound process.
- The short-term scheduler will have little to do if all processes are I/O bound, the ready queue will almost always be empty. If all processes are CPU bound, the I/O queue will almost always be empty, devices will not be unused and the system will be unbalanced.
- The **middle-term** scheduler is advantageous to remove processes from memory and thus it can remove the degree of multiprogramming.
- The process is introduced into memory, and its execution is continued where it left off called swapping.

Context Switch

- a **context switch** is the process of storing the state of processor of a thread, so that it can be restored, and execution resumed from the same point later. This allows multiple processes to share a single CPU, and is an essential feature of a multitasking Operating System
- The precise meaning of the phrase "context switch" varies significantly in usage. In a multitasking context, it refers to the process of storing the system state for one task, so that task can be paused, and another task resumed. A context switch can also occur as the result of an interrupt, such as when a task needs to access Disk storage, freeing up CPU time for other tasks. Some operating systems also require a context switch to move between User mode and kernel mode tasks. The process of context switching can have a negative impact on system performance, although the size of this effect depends on the nature of the switch being performed.
- The kernel saves the context of the old process in its PCB and loads the saved context of the new process scheduled.

Operation on Processes

The process in various systems execute concurrently, and it can be created and deleted dynamically.

Process Creation

- Through a create-process system call a process may create several new processes where the creating process is called a parent process, and the new processes are called the children of that process.
- Each new process creates processes which forms a tree. The processes are identified by unique Process Identifier (PID).
- A process will need certain resources to accomplish its task such as CPU time memory, files, I/O devices.
- The parent partitions it's resources among its children.
- When a process creates a new process, two possibilities exist in terms of execution:
  a) The parent continues to execute concurrently with its children.
  b) The parent waits until some or all of its children have terminated.
- There are also two possibilities of the address space of the new process:
  a) The child process is a duplicate of the parent process.
  b) The child process has a new program loaded into it.

Process Termination

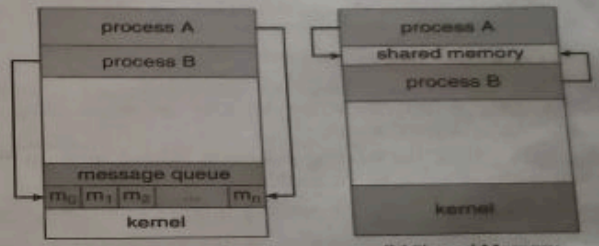
- When a final statement is executed a process terminates by exit() system call where all the resources are de-allocated.
- A parent terminates the execution of its children for various reasons:
  a) The child goes beyond its usage of the resources that it has been allocated.
  b) The task which was assigned to the child is no longer required.
  c) The operating system does not allow a child to continue if its parent terminates.

- In Cascading termination, if a parent terminates normally or abnormally, then all its children must also be terminated.

Inter process Communication

- Process executing simultaneously in the operating system are independent processes or cooperating processes.
- A process is independent if it is not affected by the other processes executing in the system. Here the process that does not share data.
- Cooperating processes requires an Inter process Communications (IPC) mechanism. Two models of Inter process Communications are:

1. **Shared memory model :** Here, a region of memory that is shared by cooperating processes is established.
2. **Message passing model :** Here, communication takes place by means of messages exchanged between the cooperating processes.



(a) Message Passing (b) Shared Memory

Shared memory System

- Inter process communication using shared memory requires communicating processes to establish a region of shared memory. For example: Producer consumer problem.
- A producer process generates information which is consumed by a consumer process. The solution to this problem is shared memory.
- To allow producer and consumer processes to run concurrently, we must have a buffer of items that can be filled by the producer and emptied by the consumer.
- The buffer resides in a region of memory that is shared by the producer and consumer processes. A producer produces one item while the consumer consumes another item.

Two types of buffers are used :

1. **Unbounded buffer :** No practical limit on the size of the buffer.
2. **Bounded buffer :** Assumes a fixed buffer size.

Message Passing System

- Mechanism to allow processes to communicate and synchronize their actions without sharing the same address space which is useful in a distributed environment.

- For example, **chat** program designed where chat participants can communicate with each another by exchanging messages.
- A message passing facility provides at least two operations which are send and receive. Messages sent by a process can be of either fixed or variable size.

1. **Naming**
   - Processes that want to communicate use either direct or indirect communication.
   - Each process that wants to communicate must explicitly name the recipient or sender of the communication in direct communication.
     - Send (P, message) – Send a message to process P.
     - Receive (Q, message) – receive a message from process Q.
   - The messages are sent to and received from mailboxes or ports in indirect communication. A mailbox is an object into which messages can be places by processes and from which messages can be removed. Each mailbox has a unique identification.
     - Send (A, message) – Send a message to mailbox A.
     - Receive (B, message) – receive a message from mailbox B.
2. **Synchronization**
   - Message passing can be either blocking or non-blocking called as synchronous or asynchronous.

1. **Blocking send :** Here, the sending process is blocked until the message is received by the receiving or by the mailbox.
2. **Non-blocking sends :** Here, the sending process sends the message and resumes the operation.
3. **Blocking receive :** Here, the receiver blocks until a message is available.
4. **Non-blocking receives :** Here, the receiver retrieves a valid message or a null.

3. **Buffering**
   - Communicating process reside in a temporary queue which are implemented in three ways :

1. **Zero capacity :** The link cannot have any messages waiting in it as the queue has a maximum length of zero.
2. **Bounded Capacity :** The queue has finite length n, where n message scan resides in it. If the queue is not full when a new message is sent, the message is placed in the queue and the sender can continue execution without waiting. The sender blocks until space is available in the queue if the link is full.
3. **Unbounded capacity :** The queue's length is infinite where any number of the messages can wait in it, the sender never blocks.

QUESTIONS

1. Write a note on process
2. Explain the process stares in detail
3. Write a note on process control block
4. Explain the term scheduling queues

5. Describe the differences among Short-term, medium-term and long-term scheduling
6. Explain the operations on process in detail
7. Write a short on Inter process Communications

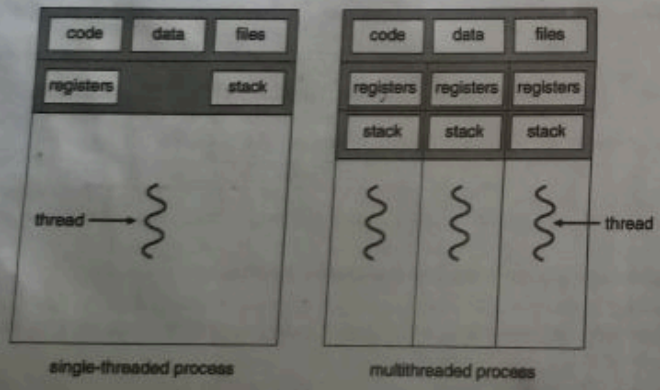
Chapter – 4
Threads

A thread is a stream of execution throughout the process code having its program counter which keeps track of lists of instruction to execute next, system registers which bind its current working variables. Threads are also termed as lightweight process. A thread uses parallelism which provides a way to improve application performance.

Major Types of Threads

Let us take an example where a web browser may have one thread to display images or text while another thread retrieves data from the network. Another example can be a word processor that may have a thread for displaying the UI or graphics while a new thread for responding to keystrokes received from the user and another thread is to perform spelling and grammar checking in the background. In some cases, a single application may be required to perform several similar tasks.

A thread is a basic unit of CPU utilization which has a thread ID, a Program counter, a register set, and a stack.



Advantages/Benefits Of Threads

The advantages of multithreaded programming can be categorized into four major headings

- ***Responsiveness*** : Multithreading is an interactive concept for an application which may allow a program to continue running even when a part of it is blocked or is carrying a lengthy operation, which increases responsiveness to the user.

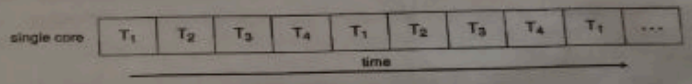
- **Resource sharing :** Mostly threads share the memory and the resources of any process to which they fit in. The advantage of sharing code is that it allows any application to have multiple different threads of activity inside the same address space.
- **Economy** : In OS, allocation of memory and resources for process creation seems costly. Because threads can distribute resources of any process to which they belong, it became more economical to create and develop context-switch threads.
- **Utilization of multiprocessor architectures** : The advantages of multithreading can be greatly amplified in a multiprocessor architecture, where there exist threads which may run in parallel on diverse processors.

Multicore Programming

Multithreaded programming provides a mechanism for more efficient use of multiple cores and improved concurrency

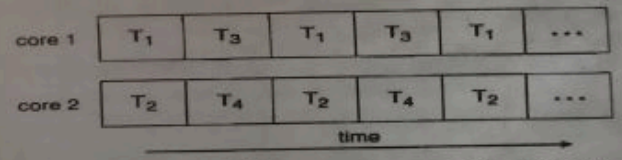
A recent trend in system design has been to place multiple computing cores on a single chip, where each core appears as a separate processor to the operating system.

On a system with a single computing core, concurrency merely means that the execution of the threads will be interleaved over time



Concurrent execution on a single-core system.

Parallel Execution of a Multi-core system



Here thread can run in parallel, as a system can assign a separate thread to each core.

Challenges in programming for multicore system

Dividing activities. This involves examining applications to find areas that can be divided into separate, concurrent tasks and thus can run in parallel on individual cores.

Balance. While identifying tasks that can run in parallel, programmers must also ensure that the tasks perform equal work of equal value. In some instances, a certain task may not contribute as much value to the overall process as other tasks; using a separate execution core to run that task may not be worth the cost.

Data splitting. Just as applications are divided into separate tasks, the data accessed and manipulated by the tasks must be divided to run on separate cores.

Data dependency. The data accessed by the tasks must be examined for dependencies between two or more tasks. In instances where one task depend-

on data from another, programmers must ensure that the execution of the tasks is synchronized to accommodate the data dependency.

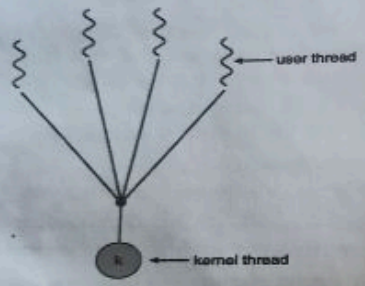
Testing and debugging. When a program is running in parallel on multiple cores, there are many different execution paths. Testing and debugging such concurrent programs is inherently more difficult than testing and debugging single-threaded applications.

Multithreading Models

All the threads must have a relationship between them (i.e., user threads and kernel threads). Here is a list which tells the three common ways of establishing this relationship.

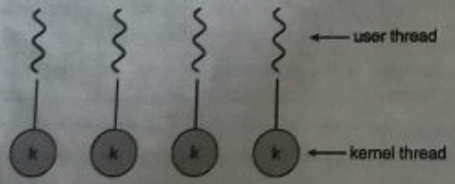
Many-to-One Model

In the many-to-one model plots several user-level threads to a single kernel thread.



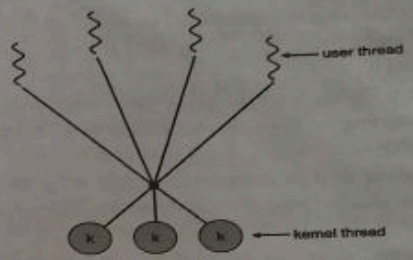
One-to-One Model

In the one-to-one model maps every user thread to a kernel thread and provides more concurrency compare to many-to-one model.



Many-to-Many Model

In the many-to-many model, many user-level threads get mapped to a smaller or equal quantity of kernel threads. The number of kernel threads might be exact to either a application or to a particular machine.



QUESTIONS

1. Explain the concept of Thread in detail
2. What are the benefits of Multithreaded programming
3. Explain the concept of multicore programming
4. Explain the various types of multithreading models.
5. What are the different challenges in multi core system?

Objective Questions

I. Multiple Choice Questions

1. This allows many user level threads to be mapped to many kernel threads
   a) Scheduling b) Process spool
   c) Many-to-many model d) None of these
2. Multi-processor system gives a
   a) small system b) tightly coupled system
   c) loosely coupled system d) both a and b
3. Multiprocessor system have advantage of
   a) Increased Throughput b) Expensive hardware
   c) operating system d) both a and b
4. Multiprogramming of the computer system increases
   a) Memory b) Storage
   c) CPU utilization d) Cost
5. A common representation of process scheduling is a,
   a) PCB b) Queuing Diagram
   c) Scheduler d) None of these
6. Which of these is true about Operating System?
   a) It acts as an interface between user and the keyboard
   b) It acts as an interface between user and the computer hardware
   c) It acts as an interface between processor and the computer hardware
   d) It is a hardware.
7. Which of this is not a component of computer system?
   a) Hardware b) Operating system
   c) Application program d) Keyboard

8. Which of the following determines the performance of the OS?
   a) Speed of execution b) Kind of graphics involved
   c) Both a and b d) None of these.
9. Which of the following is not a class of operating system?
   a) Multiprocessing b) Multiprogramming
   c) Windows XP d) Batch Processing
10. Translator for low level programming language were termed as
   a) Assembler b) Compiler
   c) Linker d) Loader

[Ans.: (1 – c), (2 – b), (3 – a), (4 – c),(5 – b), (6 – b), (7 – d), (8 – a), (9 – c), (10 – a) **]**

II. True or False

1. An Operating System is a software program that manages the computer hardware.
2. The file-server system can not act as an interface where the client can create, update, read and delete files.
3. Program Execution is one of the services provided by Operating-System.
4. System Call are for writing a message on the display and reading from keyboard.
5. Program after execution called as Process.
6. A thread generally is a basic unit of CPU utilization.
7. Threads are implemented in Two ways, User level Threads and Kernel level Threads
8. In Many-to-one model maps many user-level threads to many kernel level threads.
9. The list of Processes waiting for a I/O device is called a device queue.
10. Send, receive messages is not a part of system call under communication.

[Ans.: True : 1, 3, 4, 6,7, 9 **False :** 2, 5, 8, 10 **]**

UNIT – II

Chapter – 5
Process Synchronization

2.1 PROCESS SYNCHRONIZATION

2.1.1. General Structure of a typical process-

There are two types of Processes in Operating Systems:-

1. Independent Process

The process that does not affect or is affected by the other process whiles its execution then the process is called Independent Process.

These processes run independently without sharing any variable, memory of file.

2. Cooperating Process

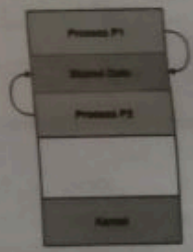


Figure 1: Cooperating Processes

The process that affect or is affected by the other process while its execution is called a Cooperating Process.

The processes that share file, memory, variable, database, etc. are the Cooperating Process.

Process Synchronization- is a technique which is used to coordinate the processes that use shared Data/shared memory/shared file. Concurrent access to shared data results in inconsistency. To avoid inconsistency in the data, process synchronization is necessary.

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

2.1.2. Race Condition

When several processes access and manipulate the shared data concurrently, the outcome of the execution depends on the particular order in which the access takes place, is called a race condition.

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

Example of race condition-

Consider producer-consumer processes with bounded buffer. There is a buffer of n slots and each slot is capable of storing one unit of data. There are two processes running, namely, **producer** and **consumer**, which are operating on the buffer. A producer inserts data into an empty slot of the buffer and consumer removes the data from a filled slot in the buffer. Both the processes must run concurrently for proper execution.

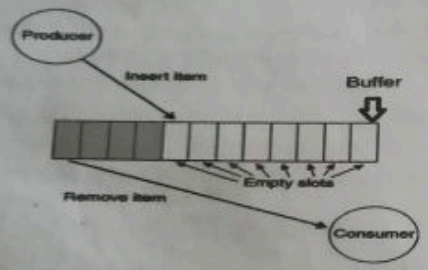
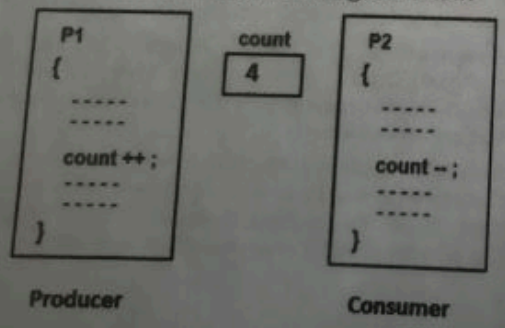


Figure 2: Bounded Buffer (Producer-Consumer)

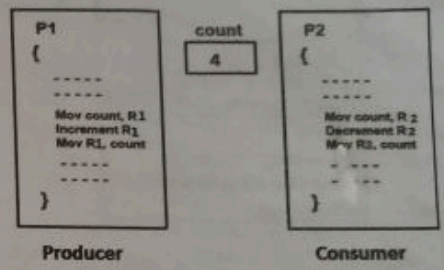
Both the processes share a common variable named "count" which indicates number of filled slots in buffer. When producer inserts the data in buffer, count is incremented by one and when consumer removes the data from buffer, count will be decremented by 1.

Suppose initial value of count = 4, indicating 4 slots of buffer are filled.

Producer process P_1 inserts the item in buffer and tries to increment the value of count. At the same time consumer process P_2 removes item from buffer and tries to decrement the value of count as shown in diagram below.



In assembly language, the instructions of the processes are written as-



Now, when these processes execute concurrently without synchronization, different results may be produced as shown below-

T_0 :	*producer*	execute	R_1 = count	$\{R_1 = 4\}$
T_1:	*producer*	execute	$R_1 = R_1 + 1$	$\{R_1 = 5\}$
T_2:	*consumer*	execute	R_2 = count	$\{R_2 = 4\}$
T_3:	*consumer*	execute	$R_2 = R_2 - 1$	$\{R_2 = 3\}$
T_4:	*producer*	execute	count = R_1	$\{count = 5\}$
T_5:	*consumer*	execute	count = R_2	$\{count = 3\}$

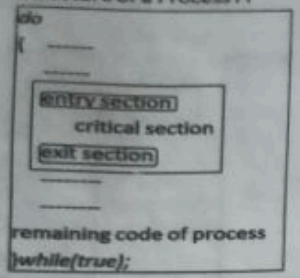
Notice that we have arrived at the incorrect state "count== 3", indicating that three buffer slots are full, when, in fact, four buffers are full. If we reversed the order of the statements at T_4 and T_5, we would arrive at the incorrect state "count == 5".

Here, we have arrived at incorrect state because both processes are trying to manipulate the shared variable *count* concurrently. A situation like this, where several processes access and manipulate the same data concurrently and the outcome of the execution depends on the particular order in which the access takes place, is called a race condition. To avoid the race condition above, we need to ensure that only one process at a time can be manipulating the variable count. To make such a guarantee, we require that the processes be synchronized in some way.

2.1.3 Critical Section Problem-

Consider a system with n cooperating processes $P_1, P_2, \ldots, P_n$. Each process has a small segment of code called as Critical section. Critical Section is a part of a program where shared resources (variable/memory/file) are accessed. To avoid race condition, only one process at a time can execute critical section. When one process is executing a critical section, remaining processes must wait.

Structure of a Process Pi



General structure of a process is shown in diagram above. Each process must request to get an entry in critical section. The section of code implementing this request is the entry section. If critical section is free (no other process is execution critical section), permission will be granted. Once the critical code is executed, process must exit the critical section so that other process can execute critical section.

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

1. **Mutual exclusion :** If process one process is executing in its critical section, then no other processes can enter critical sections.
2. **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.
3. **Bounded waiting :** Each process must have limited waiting time. No process should have to wait forever to enter the critical section.

2.1.4 Peterson's Solution-

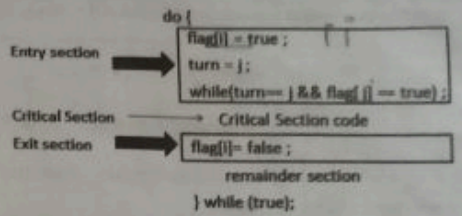
The Peterson's solution solves the critical section problem by satisfying all the three conditions listed above.

It is two process solution- Pi and Pj. When one process is in critical section other process executes remainder section.

The two data items *int turn and boolean flag* are used to decide which process will enter critical section. Turn decides whose turn is it to enter a critical section. Flag has two values true and false. Flag decides whether a process is ready to execute critical code or not.

If turn==i, then Process Pi is allowed to execute its critical section. If flag[i]==true, then Pi is ready to enter the critical section. If turn==j, then Process Pj is allowed to execute its critical section. If flag[j]==true, then Pj is ready to enter the critical section.

For a process to be in critical section turn and flag both variables must be true. E.g. if Pi is in critical section, (turn==i && flag[i]==true)



1. **Entry Section-**
   i) Process Pi wants to enter the critical section. So set flag of Pi as True.
   ii) After Pi, Pj has a next turn to enter the critical section. So set turn to j.
   iii) Check for mutual exclusion. If Pj is in critical section, Process Pi cannot enter the critical section. If both turn and flag of Pj are true, it means Pj is in critical section. So process Pi will wait. While leaving the critical section, process Pj will set its flag as false and exits. So now Pi will enter the critical section.
2. **Critical Section-** Now Pi will execute critical section and modifies shared data/memory/file.
3. **Exit Section-** Pi will leave the critical section by setting flag false, so that Pj can enter the critical section.

Advantages - with the Peterson's Solution, mutual exclusion is preserved, the progress requirement is satisfied and the bounded-waiting requirement is met.

Drawback - It is only 2 process solution.

2.1.5 Synchronization Hardware-

All these solutions are based on the concept of locking — that is, protecting critical regions through the use of locks. Some simple hardware instructions are available on many systems to solve the critical-section problem.

The critical-section problem can be solved in single-processor systems if we prevent interrupts from occurring while a shared variable is being modified. In this way, we can ensure that the current set of instructions will be executed in order without any pre-emption. As interrupts are disabled, no other instructions can run, so no unexpected modifications could be made to the shared variable. This is often the approach taken by non-preemptive kernels.

But this solution is not as feasible in multiprocessor systems. Disabling interrupts on a multiprocessor can be time consuming, since the message is passed to all the processors. This message passing delays entry into each critical section, and system efficiency decreases.

2.1.6 Mutex Locks-

A Mutex lock is a software tool to solve critical section problem. *Mut* stands for mutual and *ex* is exclusion. So *Mutex* stands for *Mutual Exclusion*. Mutex locks are used to protect critical section and thus to avoid race conditions.

Critical section problem using mutex locks	boolean available[] = {true, false} ;

do
{
acquire () ;
critical section;
release () ;
remainder section ;
} while(true)
	acquire()
	{
	if (available==true) // if Critical section is available,
	available = false; lock the critical section
	else
	wait(till critical section is available) ;
	}
	
	release()
	{
	Available = true; // unlock critical section and leave
	}

Process must acquire lock before entering a critical section and process must release the lock before leaving. The *acquire()* function locks the critical region and *release()* function unlocks it. One Boolean variable *available* is used to check if critical section is free or not. If critical section is free, the lock is available, i.e. *available=true*. If critical section is busy (locked), lock is unavailable i.e. *available=false*.

If the critical section is free, a call to *acquire()* succeeds, and the lock is then considered unavailable. A process that attempts to acquire an unavailable lock is blocked until the lock is released. Mutex locks are very simple to implement.

Drawbacks-

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

So we need more sophisticated ways for processes to synchronize their activities.

2.1.7 Semaphores

A semaphore S is an integer variable which is used to achieve mutual exclusion for preventing race condition. Semaphore S is accessed only through two standard atomic operations: *wait()* and *signal()*.

S can be +ve or zero.If S=0; indicates shared resource is not available. Another process is using critical region. If S>0; Indicates resource is available i.e. critical region is free.

Variable S is altered by two atomic operations-

i) **Wait(down)** – Decrements semaphore or Waits for semaphore to become greater than zero.

ii) **Signal(up)** - Increments semaphore by 1

Wait (s)	Signal (S)

{
if S > 0
S= S – 1;
else (wait till S>0)
}
	{
	S=S+1;
	}

A process which wants to access critical region, must follow following steps.

i) Execute Wait().

ii) If execution of wait is successful, access critical region. Decrement semaphore.

iii) If execution of wait is unsuccessful, critical region is busy. Wait till process leaves the critical region and semaphore becomes greater than zero again.

iv) Before leaving the critical region, increment semaphore by 1 by waking up other waiting processes so that another process can use it.

Types of Semaphores-

1. Binary Semaphore

Binary Semaphore S can take only two values-0 and 1. Hence, binary semaphore is similar to mutex locks. Basically, binary semaphore is used to protect critical section. If S=0 , it indicates critical region is already occupied. So process waits till S becomes greater than 0. If S=1, critical section is free.

2. Counting Semaphore

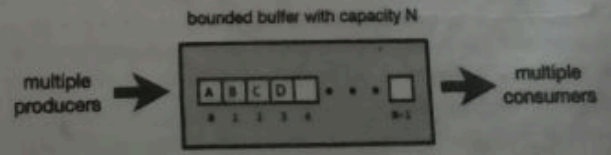
Counting Semaphore is used to control access to the multiple resources available in the system. The variable S is assigned to number of resources available. Suppose S=5, i.e. 5 resources are available. Each process that requires a resource, executes wait() operation. If resource is available, it will be allocated to the process and count of available resources is decremented by 1 (i.e. S=4). When process releases the source, it executes signal() operation and count of available resources will be incremented by 1 (i.e. S=5). When no resource is available (S = 0), process will block until count becomes greater than zero.

2.1.8 Classic Problem of Synchronization-

All the synchronization problems can be solved by making use of semaphores. Here we are going to discuss three classic problems- Bounded Buffer Problem, Readers-Writers Problem and Dinning Philosophers problem.

1. Bounded Buffer Problem-

Problem - The bounded-buffer problem (producer-consumer problem) is a classic example of concurrent access to a shared resource. Producers write data to the buffer and consumers read data from the buffer. Multiple producers and consumers share a single buffer.



Without Synchronization, following errors can occur-

i) Producer tries to enter the data into full buffer.
ii) Consumer tries to remove data from empty buffer.
iii) Multiple producers try to write data in same buffer slots.
iv) Multiple consumers try to read data from same buffer slots.

Solution-

All updates to the buffer state must be done in a critical section. So for the mutual exclusion **binary semaphore** is used.

semaphore *mutex*=1;

Let buffer has 'n' slots, Producers must block if the buffer is full. Consumers must block if the buffer is empty. Two **counting semaphores** can be used for this. Suppose currently buffer is empty.

semaphore *empty*= n // n free slots in buffer
semaphore *full* = 0 // empty buffer

```
void producer()
{
while (TRUE)
{
wait (empty);        // decrement no of empty slots
wait (mutex);        // enter critical section
insert item;
signal (mutex);      //leave critical region
signal (full);       // increment no of full slots
}
```

```
void consumer()
{
while (TRUE)
{
wait (full);         // decrement no of full slots
wait (mutex);        // enter critical region
remove item;
signal (mutex);      // leave critical region
signal (empty);      // increment no of empty slots
}
```

2. Readers-Writers Problem-

Problem

This deals with shared database. There is a shared database which multiple processes are accessing simultaneously for reading and writing. Multiple processes can read the database simultaneously. If two readers access the object at the same time there is no problem. However if two writers try to manipulate object at the same time, it will lead to inconsistent data. Also when one reader and one writer access the object at the same time, there may be problems.

Solution-

To solve this situation, a writer should get exclusive access to the database i.e. when a writer is accessing the database, no reader or writer may access it. However, multiple readers can access the database at the same time. So mutual exclusion is required for writing processes. Following semaphores are shared by readers and writers processes.


```
semaphore write= 1;
semaphore read = 1;
int reader_count = 0
```

Writer Process-

```
do {
        wait(write);          // writer requests for critical section
  // performs the write
        signal(write);        // leaves the critical section
} while(true);
```

Reader Process-

```
do {
        wait(read);           // Reader Wants to enter critical section
        reader_count++;       // The number of readers has now increased by 1
        if (reader_count==1)  // if there is at-least one reader in critical section,
        wait(write);          no writer can enter
        signal(read);         // other readers can enter while this reader is inside the
                              critical section
    // current reader performs reading here
        wait(read);           // a reader wants to leave
        reader_count--;       // The number of readers has now decreased by 1
        if (reader_count == 0)// if  no reader is left in the critical section, writer can enter
        signal(write);        // writers can enter
        signal(read);         // reader leaves
 } while(true);
```

When a reader wants to access the resource, first it increments **reader_count** value. Then, access the resource. After that, it decrements the **reader_count** value. The semaphore **write** is used by the first reader (which enters in the Critical Section) and last reader (which leaves the Critical Section). This is because when the first readers enter in the Critical Section, the writer cannot enter in the Critical Section. Only new reader can access the critical section now.

Similarly, when the last reader leaves the Critical Section, it signals the **write** semaphore. This is because there are no readers that are using the critical section now. So, a writer can access the resource now.

3. Dining Philosopher's Problem

Problem

Five silent philosophers sit at a round table with bowls of spaghetti. Chopsticks are placed between each pair of adjacent philosophers. A philosopher can only eat spaghetti when he has both left and right chopsticks. But there are only five chopsticks, so not all philosophers can eat simultaneously. So each philosopher must alternately think and eat. When a philosopher gets hungry, he tries to take left and then right chopsticks, one at a time. If successful in acquiring two chopsticks, he eats for a while, then puts down the chopsticks, and continues to think.

Two problems can occur in this case-

i) **Deadlock-** All the philosophers took left chopstick simultaneously such as no philosopher can eat.

ii) **Starvation-** A situation, in which all the programs continue to run indefinitely but fail to make any progress, is called **starvation**. (All philosophers won't be able to eat at all)

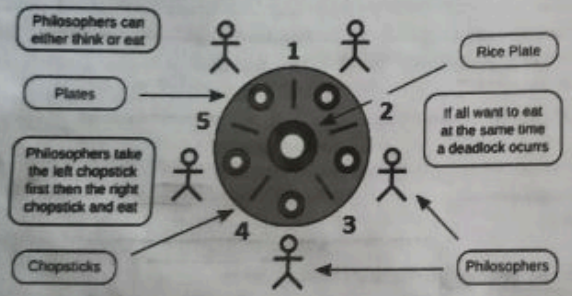


Figure 3: Dining Philosophers Problem

Solution-

This problem is similar to the problem that arises in real computer programming when multiple programs need exclusive access to shared resources. Mutual exclusion is the basic idea of the problem. It can be achieved using semaphore and mutex variables.

Each philosopher can be in one of the 2 stages- **Thinking and Eating**.

```
do
 {
   THINK;   // Thinking Stage

  // pickup both left and right chopsticks if available and eat.
    Else continue thinking stage

  PICKUP(CHOPSTICK[i], CHOPSTICK[i+1 mod 5]);
  EAT;
  PUTDOWN(CHOPSTICK[i], CHOPSTICK[i+1 mod 5]);
  // Put chopsticks down after eating and continue thinking stage.
 } while(true)
```


One simple solution is to represent each chopstick with a semaphore. Each chopstick is numbered. A philosopher tries to grab a chopstick by executing a wait() operation on that semaphore. She releases her chopsticks by executing the signal() operation on the appropriate semaphores.

2.1.9 Monitors

A monitor is a collection of procedures, variables, and data structures that are all grouped together in a special kind of module or package. Processes can call the procedures in a monitor, but they cannot directly access the monitor's internal data structures. Monitor is one of the ways to achieve Process synchronization. Monitor is supported by programming languages to achieve mutual exclusion between processes.

Structure of a Monitor-

1. It is the collection of condition variables and procedures combined together in a special kind of module or a package.
2. The processes running outside the monitor can't access the internal variable of monitor but can call procedures of the monitor.
3. Only one process at a time can execute code inside monitors.

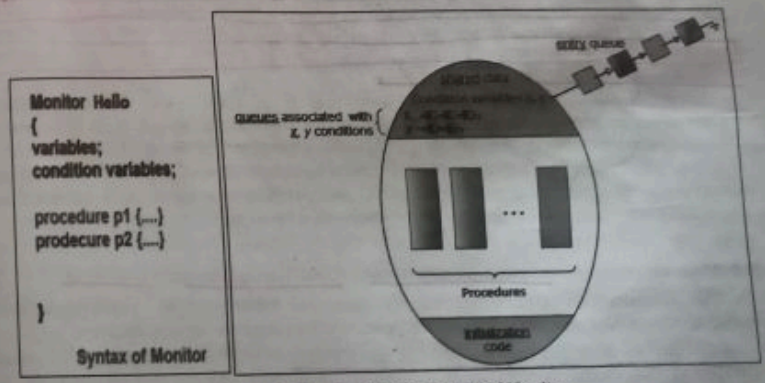


Figure 4: Syntax and Structure of Monitor

Entry Queue

A monitor guarantees mutual exclusion. Only one process can execute any monitor procedure at any time. If one process is in the monitor and at the same time second process invokes a monitor procedure, then second process blocks and placed in a waiting queue. So the monitor has to have a wait queue. If a process within a monitor blocks, another one from the queue can enter.

Queues associated with Condition Variables

We also need a way for processes to block when they cannot proceed. In the producer-consumer problem, it is easy to write monitor procedures to test buffer-full and buffer-empty, but how should the producer blocks when it finds the

buffer full? E.g. In the producer-consumer problem, the producer must be blocked when the buffer is full.

The solution lies in the introduction of condition variables, along with two operations on them, wait and signal. When a monitor procedure discovers that it cannot continue (e.g., the producer finds the buffer full), it does a wait on some condition variable, say, full. This causes the calling process to block. It also allows another process waiting in a queue to enter monitor now.

Let say we have 2 condition variables

condition x, y; //Declaring variable

Wait operation

x.wait() : Process performing wait operation on any condition variable is blocked. The suspended processes are placed in block queue of that condition variable. Note that each condition variable has its unique block queue.

Signal operation

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

2.2 CPU SCHEDULING

2.2.1 Basic Concepts-

In multiprogramming systems, several processes are kept in a memory at one time. When current process goes into the waiting state, operating system takes away CPU from current blocked process and gives CPU to another process stored in a memory. This pattern continues. Every time one process has to wait, another process can take over use of the CPU.

In multi-programmed operating systems, it is necessary to switch CPU rapidly from one process to another process to enhance speed and efficiency. CPU utilization is also improved as CPU doesn't sit idle. To do so, it is important to decide which process will run next, for how much time and how to switch from one process to another. Here, basic CPU scheduling concepts and scheduling algorithms are discussed.

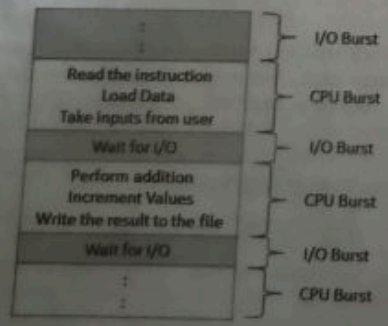
CPU- I/O Burst Cycle-

Process execution consists of two cycles- CPU Execution and I/O Wait.

The Process execution continuously switches between CPU burst and I/O burst until the process terminates as shown in diagram.

CPU Burst- Amount of time process uses CPU.

I/O Burst- Amount of time required for I/O operations. So process is in waiting state (process is taken away from CPU) till I/O operations are carried out.



CPU Scheduler

When the process that CPU is currently executing goes in waiting state, operating system must select another process to execute. **CPU Scheduler** or **short-term scheduler** is the one that decides which process is to be executed next. The scheduler arranges the processes which are ready to execute in a queue depending upon algorithm. When current process goes into waiting state, scheduler schedules the next process in the queue for execution.

Preemptive and non-preemptive Scheduling

Preemptive Sceduling- Take the CPU away from current process and assign it to another process.

Suppose CPU is executing one process, and another higher priority process is arrived. Then CPU is pre-empted from current process and higher priority process is executed first.

Non-Preemptive Scheduling- Once CPU is assigned to one process; it canfiot be stopped until it completes the execution.

Suppose CPU is executing one process, and another higher priority process is arrived. In this case, CPU cannot be taken away from the current process until that process terminates.

Dispatcher-

A dispatcher is a special program which comes into play after the scheduler. When the scheduler completes its job of selecting a process, it is the dispatcher which takes that process to the desired state/queue. It is the module that gives control of the CPU to the process selected by the scheduler. This function involves the following:

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

The dispatcher should be as fast as possible, since it is invoked during every process switch. The time taken by the dispatcher to stop one process and start another is known as the **dispatch latency.**

Dispatch latency should be as low as possible.

2.2.2 Scheduling Criteria

CPU Utilization- Keep the CPU busy all the time. Ideally CPU should not sit idle. In real system it ranges from 40 % (lightly loaded systems) to 90 % (Heavily loaded systems).

Throughput- Number of processes completed by CPU in unit time is known as Throughput. Throughput is a measure of CPU utilization. Higher the throughput, higher is the CPU utilization, resulting in higher efficiency.

Turn-around time (TAT)- The time between submission of the process and the completion of the process is known as Turn-around time.

TAT= Finish Time- Arrival Time

Burst Time- Amount of time process uses the CPU.

Waiting time- The total amount of time spent by the process in a ready queue is known as waiting time.

Waiting time= TAT- Burst Time

Response time- The amount of time from the submission of a request until the first response is produced. This measure, called response time, is the time it takes to start responding.

It is desirable to maximize CPU utilization and throughput and to minimize turnaround time, waiting time, and response time.

2.2.3 Scheduling Algorithms

1. First Come First Served (FCFS)-

This is the simplest scheduling algorithm used by operating system. Process which requests CPU first, is allocated the CPU first. Scheduler maintains the FIFO queue. The processes are arranged in First In First Out manner. When CPU is free, first process in a queue is scheduled next for execution.

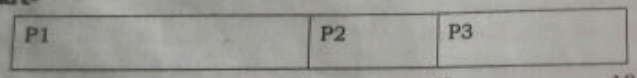
Example-

Consider the following set of processes that arrive at time 0, with the length of the CPU burst given in milliseconds:

Process	Arrival Time	Burst Time
P_1	0	9
P_2	0	4
P_3	0	5

If the processes arrive in the order P1, P2, P3, and are served in FCFS order, we get the result shown in the following Gantt chart, which is a bar chart that illustrates a particular schedule, including the start and finish times of each of the participating processes:

Gantt Chart-



Process	Arrival Time AT	Burst Time BT	Finish Time FT	Wait time= FT-BT-AT	TAT = FT-AT
P_1	0	9	9	9-9-0 = 0	9-0 = 9
P_2	0	4	13	13-4-0 = 9	13-0 = 13
P_3	0	5	18	18-5-0 = 13	18-0 = 18

Average Waiting time= (0+9+13) / 3 = 7.33 ms

Average Turnaround Time= (9+13+18) / 3 = 13.33 ms

Note : FCFS scheduling algorithm is non-preemptive. Once the CPU is allocated to a process, that process keeps the CPU until it releases the CPU.

Advantages- Simple, easy to understand and implement.

Disadvantages-

- Average waiting time is more.
- High priority process will have to wait in queue.

2. Shortest Job First (SJF)

This algorithm examines the burst time of each process in a queue. When CPU is available, the process with smallest burst time is scheduled for its execution. This is also known as **shortest-next- CPU-burst** algorithm, because scheduling depends on the length of the next CPU burst of a process, rather than its total length. If the next CPU burst time of two processes is the same, FCFS scheduling is used to break the tie.

This is non-preeemptive SJF algorithm.

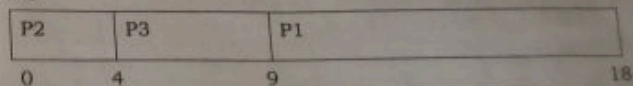
Example 1- Arrival Time of each process is same.

Consider the following set of processes that arrive at time 0, with the length of the CPU burst given in milliseconds:

Process	Arrival Time	Burst Time
P_1	0	9
P_2	0	4
P_3	0	5

Here, the sequence of execution will be $P_2 \rightarrow P_3 \rightarrow P_1$ as P_2 has minimum burst time as P_1 has maximum. We get the result shown in the following Gantt chart, which is a bar chart that illustrates a particular schedule, including the start and finish times of each of the participating processes:

Gantt Chart-



Process	Arrival Time AT	Burst Time BT	Finish Time FT	Wait time= FT-BT-AT	TAT = FT-AT
P_2	0	4	4	4-4-0 = 0	4-0 = 4
P_3	0	5	9	9-5-0 = 4	9-0 = 9
P_1	0	9	18	18-9-0 = 9	18-0 = 18

Average Waiting time= (0+4+9) / 3 = 4.33 ms

Average Turnaround Time= (4+9+18) / 3 = 10.33 ms

Advantages - A compared to FCFS, average waiting time and average turnaround time is reduced in SJF algorithm.

Disadvantages

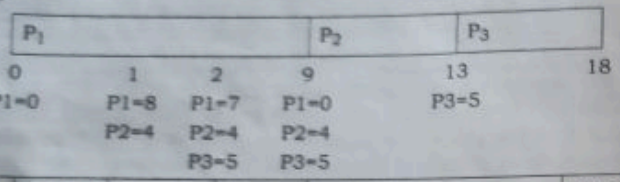
- A process with high burst time may starve forever.
- High priority process with long CPU burst will have to wait in queue.
- Not a fair scheduling algorithm.

Example 2 : Arrival time of each process is different.

Process	Arrival Time	Burst Time
P_1	0	9
P_2	1	4
P_3	2	5

Gantt Chart

- At instant 0, only one process P_1 is arrived. So CPU starts executing P_1.
- At instant 1, another process P_2 arrives with burst time less than P_1, but as it is non-preeemptive, once CPU starts executing one process, CPU cannot be taken away unless the process terminates. So CPU continues executing P_1.
- At instant 2, another process P_3 arrives as shown in Gantt chart below. But as it is non-preeemptive, CPU continues executing P_1.
- P_1 is completed at 9ms. At that point CPU starts executing process with less burst time P_2. Once P_2 is completed, CPU starts and finishes Process P_3.



Process	Arrival Time AT	Burst Time BT	Finish Time FT	Wait time= FT-BT-AT	TAT = FT-AT
P_1	0	9	9	0	9
P_2	1	4	13	8	12
P_3	2	5	18	11	16

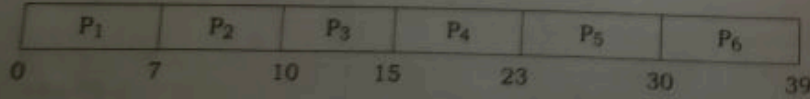
Average Waiting time= (0+8+11) / 3 = 6.33 ms
Average Turnaround Time= (9+12+16) / 3 = 12.33 ms

Example 2 (MU Question Paper Apr 18)-
Solve for FCFS and SJF.

Process	Arrival Time	Burst Time
P_1	0	7
P_2	2	3
P_3	2	5
P_4	2	8
P_5	3	7
P_6	3	9

1. FCFS-

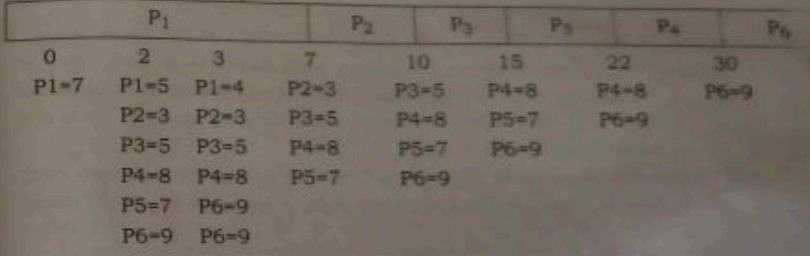
Gantt Chart-



Process	Arrival Time AT	Burst Time BT	Finish Time FT	Wait time= FT-BT-AT	TAT = FT-AT
P_1	0	7	7	7-7-0 = 0	7 -0 = 7
P_2	2	3	10	10-3-2 = 5	10-2 = 8
P_3	2	5	15	15-5-2 = 8	15-2 = 13
P_4	2	8	23	23-8-2 = 13	23-2 = 21
P_5	3	7	30	30-7-3 = 20	30-3 = 27
P_6	3	9	39	39-9-3 =27	39-3 = 36

Average Waiting time= (0+5+8+13+20+27) / 6 = 12.17 units
Average Turnaround Time= (7+8+13+21+27+36) / 6 = 18.67 units

2. SJF



Process	Arrival Time AT	Burst Time BT	Finish Time FT	Wait time= FT-BT-AT	TAT = FT-AT
P_1	0	7	7	7-7-0 = 0	7 -0 = 7
P_2	2	3	10	10-3-2 = 5	10-2 = 8
P_3	2	5	15	15-5-2 = 8	15-2 = 13
P_5	3	7	22	22-3-7 = 12	22-3 = 19
P_4	2	8	30	30-8-2 = 20	30-2 = 28
P_6	3	9	39	39-9-3 =27	39-3 = 36

Average Waiting time= (0+5+8+12+20+27) / 6 = 12 units
Average Turnaround Time= (7+8+13+21+27+36) / 6 = 18.67 units

3. Shortest Remaining Time First-

Shortest-remaining-time-first scheduling is also known as **Preemptive SJF** algorithm. Job with less execution time is executed first. When new job comes

total time is compared with current processes' remaining time. If new job needs less time to finish than current running process, then current process is suspended (preempted) and start new job first.

Example-

Let us consider the same example taken above in non-preemptive SJF algorithm.

Process	Arrival Time (ms)	Burst Time (ms)
P_1	0	9
P_2	1	4
P_3	2	5

Gantt Chart-

- At instant 0, only one process P_1 is arrived. So CPU starts executing P_1.
- At time instant 1, another process P_2 arrives with burst time 4ms. Till time 1, P_1 is already executed for 1ms time and 8ms of process P_1 is remaining. So burst time of P_2 is less than remaining time of P_1. As it is preeemptive, CPU suspends P_1 and starts executing process P_2.
- At instant 2, another process P_3 arrives with burst time 5ms. Now at instant 2, remaining time of P_1 is 8ms, remaining time of P_2 is 3ms and burst time of P_3 is 5ms. CPU continues executing P_2 as P_2's remaining time is shortest amongst all.
- P_2 is completed at 5ms. At that point CPU starts executing process with less burst time P_3. Once P_3 is completed, CPU starts and finishes Process P_1.

P1	P2	P3	P1

0 1 2 5 10 18

P1=9 P1=8 P1=8 P1=8 P1=8

P2=4 P2=3 P3=5

P3=5

Process	Arrival Time AT	Burst Time BT	Finish Time FT	Wait time= FT-BT-AT	TAT = FT-AT
P_1	0	9	18	9	18
P_2	1	4	5	0	4
P_3	2	5	10	3	8

Average Waiting time= (9+0+3) / 3 = 4 ms

Average Turnaround Time= (18+4+8) / 3 = 10 ms

4. Priority Scheduling

A priority is associated with each process, and the CPU is allocated to the process with the highest priority.

- Priorities are generally indicated by some fixed range of numbers e.g. 1 to 7, such as lower number represents higher priority.
- Priority scheduling can be either preemptive or non-preemptive.
- When a process arrives at the ready queue, its priority is compared with the priority of the currently running process.
- A preemptive priority scheduling algorithm will preempt the CPU if the priority of the newly arrived process is higher than the priority of the currently running process.
- A nonpreemptive priority scheduling algorithm will simply put the new process at the head of the ready queue.

Example

Process	Arrival Time	Burst Time	Priority
P_1	0	9	2
P_2	0	4	4
P_3	0	5	1
P_4	0	3	3

Gantt Chart-

As per priorities, sequence of execution will be P3 →P1→P4→P2

P3	P1	P4	P2

0 5 14 17 21

Process	Arrival Time AT	Burst Time BT	Finish Time FT	Wait time= FT-BT-AT	TAT = FT-AT
P_3	0	5	5	5-5-0 = 0	5-0 = 5
P_1	0	9	14	14-9-0 = 5	14-0 = 14
P_4	0	3	17	17-3-0 = 14	17-0 = 17
P_2	0	4	21	21-4-0=17	21-0 = 21

Average Waiting time= (0+5+14+17) / 4 = 9 ms

Average Turnaround Time= (5+14+17+21) / 4 = 14.25 ms

5. Round Robin Scheduling (RR)-

Round Robin algorithm is also known as **Preemptive FCFS scheduling**. RR works in following manner.

- Processes are arranged in a FIFO queue. Each process is assigned a time interval, called **quantum** or **Time Slice.**
- When CPU is free, the first process from the queue is scheduled.
- Once the quantum assigned is finished, CPU places that process at the end of FIFO queue and start executing next process as shown in diagram below.

total time is compared with current processes' remaining time. If new job needs less time to finish than current running process, then current process is suspended (preempted) and start new job first.

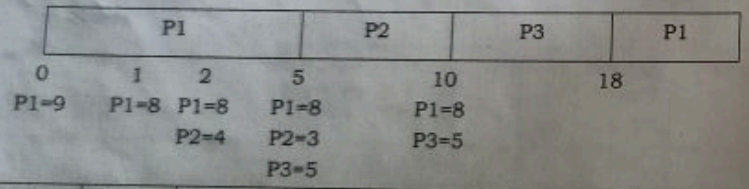
Example-

Let us consider the same example taken above in non-preemptive SJF algorithm.

Process	Arrival Time (ms)	Burst Time (ms)
P_1	0	9
P_2	1	4
P_3	2	5

Gantt Chart-

- At instant 0, only one process P_1 is arrived. So CPU starts executing P_1.
- At time instant 1, another process P_2 arrives with burst time 4ms. Till time 1, P_1 is already executed for 1ms time and 8ms of process P_1 is remaining. So burst time of P_2 is less than remaining time of P_1. As it is preeemptive, CPU suspends P_1 and starts executing process P_2.
- At instant 2, another process P_3 arrives with burst time 5ms. Now at instant 2, remaining time of P_1 is 8ms, remaining time of P_2 is 3ms and burst time of P_3 is 5ms. CPU continues executing P_2 as P_2's remaining time is shortest amongst all.
- P_2 is completed at 5ms. At that point CPU starts executing process with less burst time P_3. Once P_3 is completed, CPU starts and finishes Process P_1.



Process	Arrival Time AT	Burst Time BT	Finish Time FT	Wait time= FT-BT-AT	TAT = FT-AT
P_1	0	9	18	9	18
P_2	1	4	5	0	4
P_3	2	5	10	3	8

Average Waiting time= (9+0+3) / 3 = 4 ms

Average Turnaround Time= (18+4+8) / 3 = 10 ms

4. Priority Scheduling

A priority is associated with each process, and the CPU is allocated to the process with the highest priority.

- Priorities are generally indicated by some fixed range of numbers e.g. 1 to 7, such as lower number represents higher priority.
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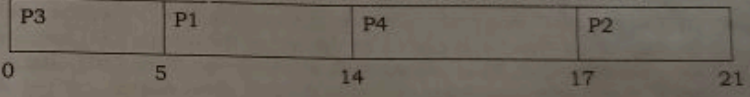
- A preemptive priority scheduling algorithm will preempt the CPU if the priority of the newly arrived process is higher than the priority of the currently running process.
- A nonpreemptive priority scheduling algorithm will simply put the new process at the head of the ready queue.

Example

Process	Arrival Time	Burst Time	Priority
P_1	0	9	2
P_2	0	4	4
P_3	0	5	1
P_4	0	3	3

Gantt Chart-

As per priorities, sequence of execution will be P3 →P1→P4→P2



Process	Arrival Time AT	Burst Time BT	Finish Time FT	Wait time= FT-BT-AT	TAT = FT-AT
P_3	0	5	5	5-5-0 = 0	5-0 = 5
P_1	0	9	14	14-9-0 = 5	14-0 = 14
P_4	0	3	17	17-3-0 = 14	17-0 = 17
P_2	0	4	21	21-4-0=17	21-0 = 21

Average Waiting time= (0+5+14+17) / 4 = 9 ms

Average Turnaround Time= (5+14+17+21) / 4 = 14.25 ms

5. Round Robin Scheduling (RR)-

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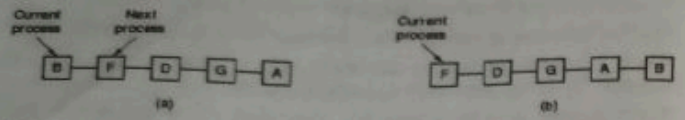
- Processes are arranged in a FIFO queue. Each process is assigned a time interval, called **quantum** or **Time Slice.**
- When CPU is free, the first process from the queue is scheduled.
- Once the quantum assigned is finished, CPU places that process at the end of FIFO queue and start executing next process as shown in diagram below.

- This process continues in Round Robin manner.



Advantages

- Fair scheduling scheme.
- No starvation. All the processes will get equal chance.

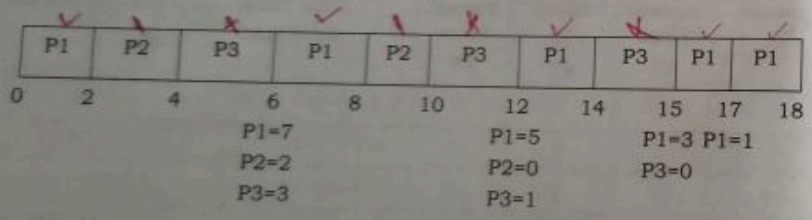
Example 1

Let Time Slice (Quantum) = 2ms

Process	Arrival Time	Burst Time
P_1	0	9
P_2	0	4
P_3	0	5

Gantt Chart

- As per FIFO queue, sequence of execution is P1 → P2 → P3.
- CPU starts executing process P1. As quantum is 2ms, P1 will be executed for 2ms. After that P1 is placed at the end of the queue. CPU executes P2 for 2ms. After that P2 is placed back at the end of the queue. Then CPU executes P3 for 2ms and after that P3 is placed at the end of the queue.
- This cycle continues until all the processes are finished.



Process	Arrival Time AT	Burst Time BT	Finish Time FT	Wait time= FT-BT-AT	TAT = FT-AT
P_1	0	9	18	18-9-0 = 9	18-0 = 18
P_2	0	4	10	10-4-0 = 6	10-0 = 10
P_3	0	5	15	15-5-0 = 10	15-0 = 15

Average Waiting time= (9+6+10) / 3 = 8.33 ms

Average Turnaround Time= (18+10+15) / 3 = 14.33 ms

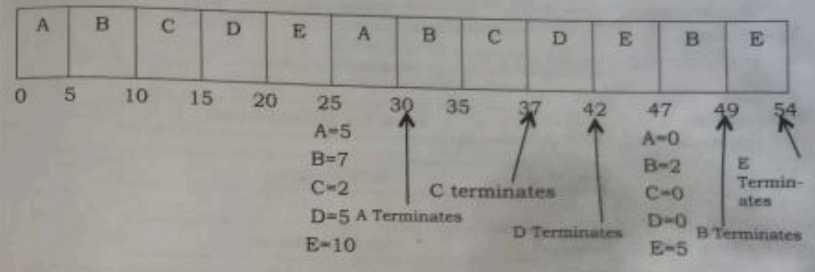
Example 2 (MU Question Paper Nov 17)

Consider following processes with time slice 5 units. Find average waiting for each process.

Process	A	B	C	D	E
CPU Burst	10	12	7	10	15

Ans :

Gantt Chart-



Process	Arrival Time AT	Burst Time BT	Finish Time FT	Wait time= FT-BT-AT	TAT = FT-AT
A	0	10	30	30-10-0=20	30-0=30
B	0	12	49	49-12-0=37	49-0=49
C	0	7	37	37-07-0=30	37-0=37
D	0	10	42	42-10-0=32	42-0=42
E	0	15	54	54-15-0=39	54-0=54

Average Waiting time= (20+37+30+32+39) / 5 = 31.6 units

Average Turnaround Time= (30+49+37+42+54) / 5 = 42.4 units

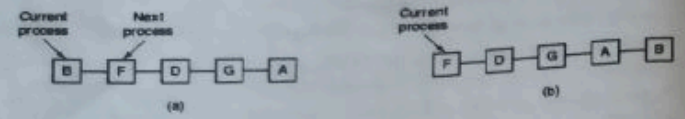
6. Multilevel Queue Scheduling-

- Multilevel queue scheduling algorithm is used when we can classify processes into different groups.
- In this scheduling, ready queue is partitioned into several separate queues.
- **Processes are divided into different queues based on their process type, memory size and process priority.**
- **Consider an example of a multilevel queue scheduling algorithm with five queues, listed below in order of decreasing priority:**

1. **System processes**
2. **Interactive processes**
3. **Interactive editing processes**
4. **Batch processes**
5. **Student processes**

- **Each queue has its own scheduling algorithm.**

- This process continues in Round Robin manner.



Advantages

- Fair scheduling scheme.
- No starvation. All the processes will get equal chance.

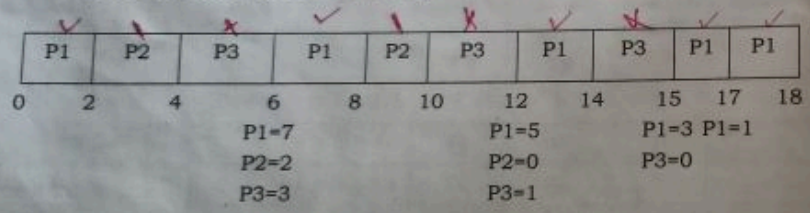
Example 1

Let Time Slice (Quantum) = 2ms

Process	Arrival Time	Burst Time
P_1	0	9
P_2	0	4
P_3	0	5

Gantt Chart

- As per FIFO queue, sequence of execution is P1 → P2 → P3.
- CPU starts executing process P1. As quantum is 2ms, P1 will be executed for 2ms. After that P1 is placed at the end of the queue. CPU executes P2 for 2ms. After that P2 is placed back at the queue. Then CPU executes P3 for 2ms and after that P3 is placed at the end of the queue.
- This cycle continues until all the processes are finished.



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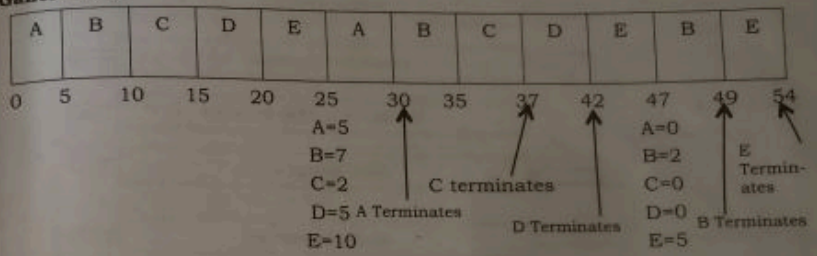
Example 2 (MU Question Paper Nov 17)

Consider following processes with time slice 5 units. Find average waiting for each process.

Process	A	B	C	D	E
CPU Burst	10	12	7	10	15

Ans :

Gantt Chart-



Process	Arrival Time AT	Burst Time BT	Finish Time FT	Wait time= FT-BT-AT	TAT = FT-AT
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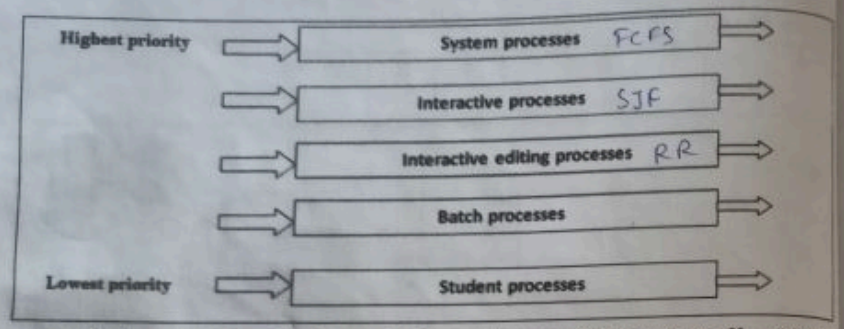
1. **System processes**
2. **Interactive processes**
3. **Interactive editing processes**
4. **Batch processes**
5. **Student processes**

- **Each queue has its own scheduling algorithm.**

- **For example given below, queue1 (system process) uses FCFS (First Come First Serve), queue2 (interactive process) uses SJF (Shortest Job First) while queue3 uses RR (Round Robin) to schedule their processes and so on.**

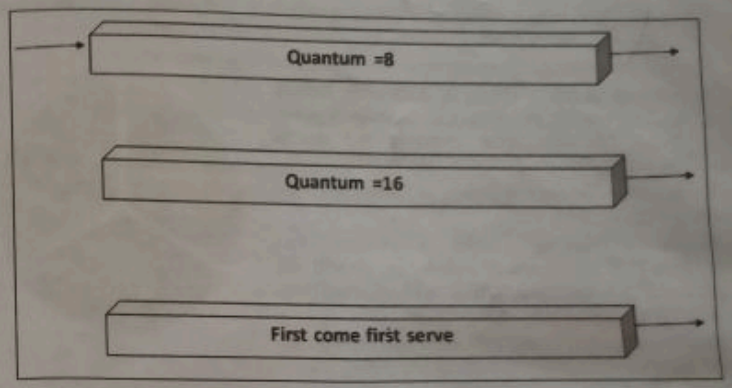


- Each queue has absolute priority over lower-priority queues. No process in the batch queue can run unless the queues for system processes, interactive processes, and interactive editing processes are all empty.
- If an interactive editing process entered the ready queue while a batch process was running, the batch process would be preempted.

7. Multilevel Feedback Queue Scheduling-

- In multilevel Queue scheduling, processes are permanently placed into a queue when they are born. Once the queue is assigned to a process, it is permanent until process terminates. i.e. processes cannot move from one queue to another.
- Multilevel feedback queue scheduling algorithms allows the processes to change the queue.
- Here in multilevel feedback scheme, processes are classified based on CPU burst time.
- If process uses too much CPU time, it will be moved to lower priority queue.
- This scheme generally keeps interactive processes in high priority queue.
- To solve starvation problem, if process is in waiting state for too long in a lower priority queue, it is moved to higher priority queue.
- Consider the following example with three queues numbered from 0 to 2 with queue 0 at highest priority and queue 2 at lowest priority. .
- Any process with burst time less than or equal to 8 milliseconds is given a highest priority i.e. is placed in queue 0.
- Processes that need more than 8 but less than 24 milliseconds are also served quickly, although with lower priority than shorter processes.
- Queue 2 has long processes and is scheduled in FCFS order with any CPU cycles left over from queues 0 and 1.
- A process entering the ready queue is put in queue 0. A process in queue 0 is executed for 8ms quantum. If it does not finish within this time, it is moved to the end of queue 1.

- If queue 0 is empty, the process at the beginning of queue 1 is given a quantum of 16 milliseconds. If it does not complete, it is preempted and is put into queue 2.
- Processes in queue 2 are run on an FCFS basis but are run only when queues 0 and 1 are empty.



2.2.4 Thread Scheduling-

There are two types of threads in a system, Kernel Level Threads and User Level Threads. Some operating systems provide a combined user level thread and Kernel level thread facility. In a combined thread approach, multiple threads within the same application can run in parallel on multiple processors and a blocking system call need not block the entire process. Multithreading models are three types

1. Many to Many Mapping

The many-to-many model multiplexes many number of user threads onto an equal number of kernel threads. In this model, developers can create as many user threads as required and the corresponding Kernel threads can run in parallel on a multiprocessor machine. This model provides the best accuracy on concurrency and when a thread performs a blocking system call, the kernel can schedule another thread for execution.

2. Many to One Mapping-

This model maps many user level threads to one Kernel-level thread. Thread management is done in user space by the thread library. When thread makes a blocking system call, the entire process will be blocked. Only one thread can access the Kernel at a time, so multiple threads are unable to run in parallel on multiprocessors. If the user-level thread libraries are implemented in the operating system in such a way that the system does not support them, then the Kernel threads use the many-to-one relationship modes.

3. One to One Mapping

There is one-to-one relationship of user-level thread to the kernel-level thread. This model provides more concurrency than the many-to-one model. It also allows another thread to run when a thread makes a blocking system call. It supports multiple threads to execute in parallel on microprocessors.

2.3 DEADLOCK

2.3.1 System Model-

Resources-

Resource is a physical or virtual component available in a system to perform a requested operation.

Physical resources- Every device connected to a system e.g. CPU, printer, scanner, etc.

Virtual Resources- Files, network connection, memories, etc.

A process must request a resource before using it, and must release the resource after using it. A process can request as many resources it requires to perform the desired task.

A process must acquire a resource in following sequence-

1. **Request-** Process places a request for resource, if resource is available, it will be granted to a process. Otherwise process will wait till the resource is available.
2. **Use-** Process performs desired task using the resource.
3. **Release-** Process must release the resource after using the resource.

Deadlock

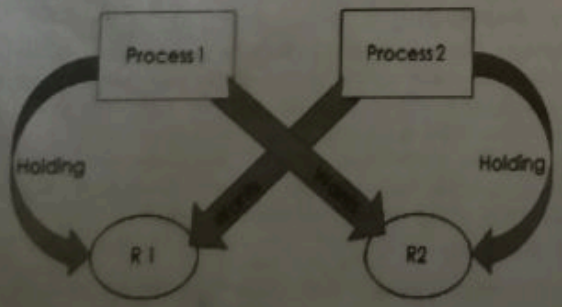
Introduction

In multiprogramming systems, multiple processes run at the same time and they share limited number of resources available in the system. So processes compete for finite number of resources. Process places a request for resource, if resource is available, it will be granted to a process. Otherwise process will wait till the resource is available.

Definition

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

The cause of deadlocks: Each process needing what another process has. And the program cannot proceed further.



Example

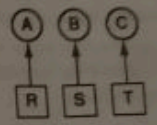
- *Two processes A and B, each want to scan a document and record it on a CD.*

- So resources required are scanner and CD recorder.
- **Process A** requests to use the **scanner** and acquires it.
- **Process B** requests the **CD recorder** first and it is granted to process B.
- Now A requests for the CD recorder, but CD recorder is with process B. So the request is suspended until B releases it.
- Similarly, B asks for the scanner which process A has. So each process is requesting for a resource which another process has.
- At this point both processes are blocked and will remain in blocked state forever.
- This situation is called a **deadlock.**

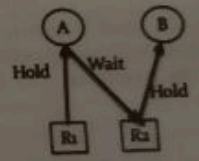
2.3.2 Deadlock Characterization

Necessary Conditions for occurrence of deadlock-

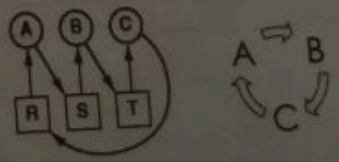
1. **Mutual exclusion-** Resources are non-sharable. Resource should be used by a single process at a time.



2. **Hold-and-wait-** Processes currently holding resources can request new resources that are being held by other processes.



3. **No-preemption-** Resources previously granted cannot be forcibly taken away from a process. They must be released by the process holding them.
4. **Circular wait condition-** There must be a circular list of two or more processes, each of which is waiting for a resource held by the next member of the chain. Waiting processes- $\{P_0, P_1, P_2, \ldots\ldots, P_n\}$ are such that P_0 is waiting for resource that is held by P_1, P_1 is waiting for a resource that is held by P_2, and so on. P_n is waiting for resource that P_0 has.



All these four conditions must hold good for a deadlock to occur in a system.

Resource Allocation Graph-

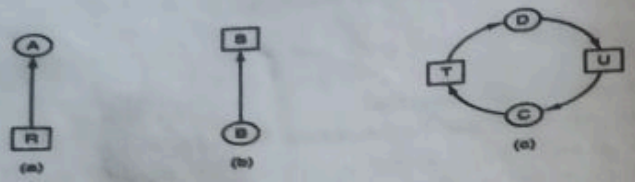
Deadlocks are represented precisely in terms of a directed graph called a system **resource-allocation graph.**

The graphs have two types of nodes-

1. Circles- Processes are shown as circles
2. Squares- Resources are shown as squares

A directed arc from a resource (square) to a process (circle) means that the resource is currently held by that process.

A directed arc from a process to a resource means that the process is currently waiting for that resource, as shown in diagram below.



- resource R assigned to process A
- process B is requesting/waiting for resource S
- Process D has resource T and waiting for resource U (which process C has)
  Process C has resource U and waiting for resource T (which process D has)

So diagram (c) represents deadlock.

If the graph contains no cycles, then no process in the system is deadlocked.

If the graph contains a cycle, then a deadlock exists in a system as shown in fig (c).

2.3.3 Deadlock Prevention-

In the above section, we have seen necessary conditions for occurrence of deadlock. We can prevent the deadlock by assuring that at least one of the four conditions fails to hold good. So deadlock can be prevented by attacking the above mentioned conditions.

1. Attacking Mutual Exclusion-

If the resources are sharable, mutual exclusion is not required. In order to prevent the deadlock, make resources sharable. A process never needs to wait for a sharable resource. E.g. read only file can be accessed by many users at a time. But some resources cannot be sharable. E.g Mutex locks- they cannot be shared by several processes at a time. So in these cases we cannot avoid mutual exclusion condition.

2. Attacking Hold and Wait-

To avoid hold and wait condition, allocate all the resources needed for a process before it begins execution. If all resources are available, process will start its execution. If one or more resources are busy, then process will go into waiting state.

Problem many processes do not know how many resources they will need until they start running.

Alternative solution is to allow process to request resources only when it doesn't have any resource. A process may request some resources and use them. Before it can request any additional resources, it must release all the resources that it is currently allocated.

3. Attacking no preemption-

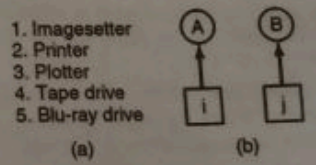
Resources assigned to the process can be taken away to prevent deadlock situation. If a process is holding some resources and requests another resource that cannot be immediately allocated to it (that is, the process must wait), then all resources the process is currently holding are preempted. Some resources can be virtualized to avoid this situation.

4. Attacking Circular Wait-

To attack circular wait, assign a unique number to each resource type as shown in diagram (a) below. Each process requests the resources in increasing order of assigned numbers.

A process can request first a printer and then a tape drive, but it cannot request first a plotter and then an imagesetter.

As shown in diagram (b), Process A has resource numbered i=2 (printer) and process B has resource numbered j=3 (plotter). Dedlock can occur only when A requests for plotter and B requests for printer. But B cannot request for printer as process is allowed to request the resources in increasing order of assigned numbers. So there is no circular wait and hence there is no deadlock.



(a) Numerically ordered resources. (b) A resource graph.

2.3.4 Deadlock Avoidance-

Deadlock avoidance mechanism requires that the system has some additional information about the resources-

Each process must declare the maximum number of resources of each type that it may need before it begins its execution.

The deadlock-avoidance algorithm examines the resource-allocation state to ensure that there can never be a circular-wait condition.

Resource-allocation state is defined by the number of available and allocated resources, and the maximum demands of the processes.

Safe state

Definition

A state is said to be **safe** if there is some scheduling order in which every process can run to completion even if all of them suddenly request their maximum number of resources immediately.

A safe state is not a deadlocked state. An unsafe state may lead to a deadlock.

Example-

Suppose total 10 resources are available and three processes P_1, P_2 and P_3 want to access resources. The processes have already acquired the few resources and also declared the maximum resources required for the execution as shown below-

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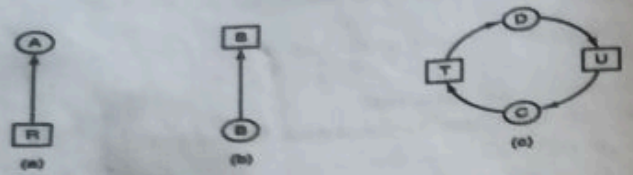

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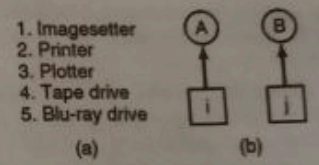

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Example-

Suppose total 10 resources are available and three processes P_1, P_2 and P_3 want to access resources. The processes have already acquired the few resources and also declared the maximum resources required for the execution as shown below-

	Has	Max
P1	3	9
P2	2	4
P3	2	7

Free: 3 (a)

	Has	Max
P1	3	9
P2	4	4
P3	2	7

Free: 1 (b)

	Has	Max
P1	3	9
P2	0	–
P3	2	7

Free: 5 (c)

	Has	Max
P1	3	9
P2	0	–
P3	7	7

Free: 0 (d)

	Has	Max
P1	3	9
P2	0	–
P3	0	–

Free: 7 (e)

As shown in fig(a), P1 requires maximum 9 resources out of which it already has 3, P_2 has 2 and its maximum requirement is 4 and P_3 has 2 and it needs 7 for its execution. So out of 10 3+3+2= 7 resources are already allocated, which mean only 3 resources are available.

Now P_1 needs 6, P_2 needs 2 and P_3 needs 5 more resources to complete the execution. Only 3 resources are available, so P_2 can immediately be allocated 2 resources as shown in fig(b).

Now P_2 has all the resources it needs to complete its execution. As P_2 terminates, it releases all the resources it had as shown in fig(c). Now available resources are 5.

As shown in fig (d) and fig (e), P_3 is granted with 5 resources. Now P_3 has all the resources required for its completion. As soon as P3 finishes the task, it releases all the resources it had.

Now P_1's request can be fulfilled and all the three processes can finish the execution without any deadlock. So $<P_3 \rightarrow P_2 \rightarrow P_1>$ is a safe sequence in which we can execute the processes without deadlock in the system.

Banker's Algorithm

Banker's algorithm is resource allocation and deadlock avoidance algorithm. It follows the safety algorithm to check whether the system is in safe state or not. It is modelled in the way a banker might deal with a group of customers to whom he has granted loan

1. **Data structures needed to implement Banker's algorithm are-**

   a. n= Number of processes in system (P1, P2, ----, Pn)

   b. m= Number of Resource Classes.

   c. E= Existing resource matrix.

e.g. Suppose there are for resource classes- Tape drives, plotters, scanners and blu-rays.

There are 4 tape drives, 2 plotters, 3 scanners and 1 blu-ray available in the system.

Tape drives, Plotters, Scanners, Blu-rays

$E = (4 \quad 2 \quad 3 \quad 1)$

d. Allocation- it is (n x m) matrix that defines how many resources of each class are allocated to each process.

Tape drives, Plotters, Scanners, Blu-rays

$$\text{Allocation} = \begin{matrix} P_1 \\ P_2 \\ P_3 \end{matrix} \begin{bmatrix} 0 & 0 & 1 & 0 \\ 2 & 0 & 0 & 1 \\ 0 & 1 & 2 & 0 \end{bmatrix}$$

As shown in diagram Process P_1 currently has no tape drive, no plotters, 1 scanner and 0 blu-rays. P_2 currently has 2 tape drives and 1 blu-ray. P3 has 1 plotter and 2 scanners.

e) Max =(n x m) matrix which defines maximum number of resources each process needs to complete its execution.

f) Available= A vector of length m indicates number of available resources of each type after the allocation.

Out of 4 tape drives, 2 are already allocated to processes so now available tape drives are 2. Same is true for remaining resources. After allocation, 2 tape drives, 1 plotter, 0 scanners and 0 blu-rays are available.

Tape drives, Plotters, Scanners, Blu-rays

$A = (2 \quad 1 \quad 0 \quad 0)$

g) Need= (n x m) matrix indicating how many resources are required by each process in addition to complete its execution.

$$\text{Need} = \begin{bmatrix} 2 & 0 & 0 & 1 \\ 1 & 0 & 1 & 0 \\ 2 & 1 & 0 & 0 \end{bmatrix}$$

As per the diagram, Process P1 needs 2 more tape drives and 1 blu-ray to complete its execution. P2 requires 1 more tape drive and 1 scanner and P3 requires 2 tape drives and 1 plotter to complete its execution.

2. **Safety Algorithm-**

This algorithm is designed to determine whether the system is in safe state or note.

a) Let *Finish* be vector of length n indicating whether a process is finished or not.
   Initialize *Finish [i]* = false for i = 1,2,-----, n (Process i is not finished)

b) Find process i such that- *Finish [i] == false*
   Verify if resources needed are less than availability *Need i <= Available*
   If yes, allocate needed resources to process. Update allocation matrix.
   Allocation= Allocation + Need
   If no such process exists, go to step d.

c) Process i finishes and releases all the allocated resources.
   Available = Available + Allocation i
   Finish [i] =true
   Go to step b

d) If *Finish[i] == true* for all i, then system is in safe state.

3. **Resource- request algorithm-**

This algorithm is designed to verify if the request can be safely granted.

a) Let Request be the request matrix of process i.
   If *Request <= Need* go to step b.
   Else error – process has exceeded maximum claimed resources.

b) If *Request <= Available* go to step c.
   Else Pi mist wait since resources are not available.

c) Update the matrices-
   Available= Available – Request
   Allocation= Allocation + Request
   Need = Need – Request

Examples on Banker's Algorithm-

Example 1-

	Allocation A B C	Max A B C	Available A B C
P_0	0 1 0	7 5 3	3 3 2
P_1	2 0 0	3 2 2	
P_2	3 0 2	9 0 2	
P_3	2 1 1	2 2 2	
P_4	0 0 2	4 3 3	

To find-

1. Need Matrix
2. Safe state and sequence

Ans :

Need= Max – Allocation

	Allocation A B C	Max A B C	Available A B C	Need A B C
P_0	0 1 0	7 5 3	3 3 2	7 4 3
P_1	2 0 0	3 2 2		1 2 2
P_2	3 0 2	9 0 2		6 0 0
P_3	2 1 1	2 2 2		0 1 1
P_4	0 0 2	4 3 3		4 3 1

Compare each processes' Need matrix with Available and find down a process i such that Need (i) <= Available

1. For process P_1, Need (P_1) <= Available, So P_1 will be granted all the resources required.
   Available= Available- Need= (3 3 2) - (1 2 2) = (2 1 0)
   Allocation (P_1) = Max= (3 2 2)
   P_1 completes its execution and releases all the resources.
   Available= Allocation (P1) + Available = (3 2 2) + (2 1 0) = (5 3 2)
2. For process P_3, Need (P_3) <= Available, So P_3 will be granted all the resources required.
   Available= Available- Need= (5 3 2) - (0 1 1) = (5 2 1)
   Allocation (P_3) = Max= (2 2 2)
   P_3 completes its execution and releases all the resources.
   Available= Allocation (P_3) + Available = (2 2 2) + (5 2 1) = (7 4 3)
3. For process P_4, Need (P_4) <= Available, So P_4 will be granted all the resources required.
   Available= Available- Need= (7 4 3) - (4 3 1) = (3 1 2)
   Allocation (P_4) = Max= (4 3 3)

P_4 completes its execution and releases all the resources.
Available= Allocation (P_4) + Available = (4 3 3) + (3 1 2) = (7 4 5)

4. For process P_0, Need (P_0) <= Available, So P_0 will be granted all the resources required.
   Available= Available- Need= (7 4 5) - (7 4 3) = (0 0 2)
   Allocation (P_0) = Max= (7 5 3)
   P_0 completes its execution and releases all the resources.
   Available= Allocation (P0) + Available = (7 5 3) + (0 0 2) = (7 5 5)
5. For process P_2, Need (P_2) <= Available, So P0 will be granted all the resources required.
   Available= Available- Need= (7 5 5) - (6 0 0) = (1 5 5)
   Allocation (P_2) = Max= (9 0 2)
   P_2 completes its execution and releases all the resources.
   Available= Allocation (P_2) + Available = (9 0 2) + (1 5 5) = (10 5 7)

So all the processes are executed without any deadlock. We can conclude that System is in **safe state.**

Safe sequence = $P_1 \rightarrow P_3 \rightarrow P_4 \rightarrow P_0 \rightarrow P_2$

Example 2 (MU Nov 18)

Assume-

1. Total Resources in a System-
   A B C D
   6 5 7 6
2. Available System Resources are-
   A B C D
   3 1 1 2
3. Currently Allocated Resources-

	A	B	C	D
P_1	1	2	2	1
P_2	1	0	3	3
P_3	1	2	1	0

4. Maximum resources required by each process

	A	B	C	D
P_1	3	3	2	2
P_2	1	2	3	4
P_3	1	3	5	0

Compute need array. Check whether system is in safe state or not. Also compute safe sequence.

Ans :

Need= Max- Allocation

	Allocation A B C D	Max A B C D	Available A B C D	Need A B C D
P_1	1 2 2 1	3 3 2 2	3 1 1 2	2 1 0 1
P_2	1 0 3 3	1 2 3 4		0 2 0 1
P_3	1 2 1 0	1 3 5 0		0 1 4 0

1. Start with P_1, Compare Need with Available resources.
   Here Need <= Available, So P_1 will be granted all the resources required.
   Available= Available- Need= (3 1 1 2) - (2 1 0 1) = (1 0 1 1)
   Allocation (P_1) = Max= (3 3 2 2)
   P_1 completes its execution and releases all the resources.
   Available= Allocation (P_1) + Available = (3 3 2 2) + (1 0 1 1) = (4 3 3 3)
2. Look for process P_2. Compare Need with Available resources.
   Here Need <= Available, So P_2 will be granted with all the resources required.
   Available= Available- Need= (4 3 3 3) - (0 2 0 1) = (4 1 3 2)
   Allocation (P_2) = Max= (1 2 3 4)
   P_2 completes its execution and releases all the resources.
   Available= Allocation (P1) + Available = (1 2 3 4) + (4 1 3 2) = (5 3 6 6)
3. Look for process P_3, Compare Need with Available resources.
   Here Need <= Available, So P_3 will get all the resources required.
   Available= Available- Need= (5 3 6 6) - (0 1 4 0) = (5 2 2 6)
   Allocation (P_3) = Max= (1 3 5 0)
   P_2 completes its execution and releases all the resources.
   Available= Allocation (P_3) + Available = (1 3 5 0) + (5 2 2 6) = (6 5 7 6)

So all the processes are executed without any deadlock. We can conclude that System is in **safe state.**

Safe sequence = $P_1 \rightarrow P_2 \rightarrow P_3$

2.3.5 Deadlock Detection

If a system fail to prevent deadlock or deadlock avoidance algorithm fails to work, then Deadlock is going to occur in a system. So it is necessary to study deadlock detection algorithm. We are going to study deadlock detection algorithm for two different situations- (1) Deadlock detection with single resource of each type (2) Deadlock Detection with multiple resources of each type.

1. Deadlock detection with single resource of each type

Consider a system with one resource of each type.

E.g. System with 1 printer, 1 scanner, 1 plotter and 1 CD recorder.

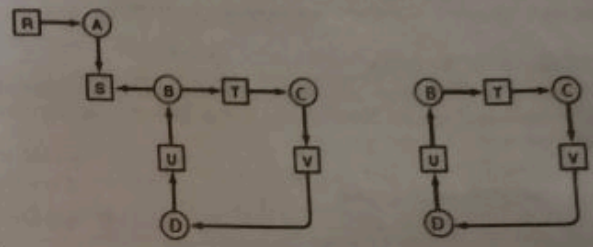
Steps to detect deadlock-

1. Construct a resource graph.
2. If this graph contains one or more cycles, a deadlock exists.

3. If no cycle exists, the system is not deadlocked.

Example-

- Process A holds R and wants S.
- Process B holds U and wants S and T.
- Process C holds T and wants V.
- Process D holds V and wants U.



Conclusion

In above graph, there exists a cycle as shown above.

Processes B, C and D are deadlocked, as they are in circular wait.

Process A can is not in deadlocked state.

2. Deadlock Detection with multiple resources of each type-

It is a matrix-based algorithm for detecting deadlock.

Let total P processes want to run and m resource classes are available.

E is the **existing resource vector** with E_1 resourcesof class 1, E_2 resources of class 2, Em resources of class m.

E= (E_1, E_2, E_3, ..., Em)

E.g. Consider system with 3 processes and 4 resource classes with 4 tape drives, 2 plotters, 3 scanners and 1 Blu-ray.

E = (4 2 3 ...)

P= 3 processes (P_1,P_2,P_3)

m=4 resource classes

Let C be **current allocation matrix**, Cij is the number of instances of resource j that are held by process i.

$$C = \begin{matrix} P_1 \\ P_2 \\ P_3 \end{matrix} \begin{bmatrix} 0 & 0 & 1 & 0 \\ 2 & 0 & 0 & 1 \\ 0 & 1 & 2 & 0 \end{bmatrix}$$

Let *A* be the **available resource vector**, with A1 unallocated resources of class 1, upto Am unallocated resources of class m.

A = (2 1 0 0)

A= (A_1, A_2, A_3, ..., A_m)

Let *R* be the **request matrix**. Rij is the number of instances of resource j that Process i wants.

$$R = \begin{bmatrix} 2 & 0 & 0 & 1 \\ 1 & 0 & 1 & 0 \\ 2 & 1 & 0 & 0 \end{bmatrix}$$

The deadlock detection algorithm can now be given as follows.

- Look for process Pi , for which the ith row of R is less than or equal to A.
- If such a process is found, add the ith row of C to A, mark the process, and go back to step 1.
- If no such process exists, the algorithm terminates.

Consider request matrix 1, request of P3 will be fulfilled. So no deadlock in system.

Consider request matrix 2, request of neither of the processes will be fulfilled. So all processes are stuck and there is a deadlock in system.

2.3.6 Recovery from Deadlock

Once the deadlock detection is carried out by Deadlock Detection algorithms, next would be recover a system from deadlock. The recovery can be done through following measures-

1. Process Termination-

i) Abort one process at a time-

a) Abort one process at a time, run deadlock detection algorithm to check whether deadlock is solved or not.

b) If not continue step (a) until deadlock cycle is eliminated.

ii) Abort all deadlocked processes-

Aborting all deadlocked processes can eliminate deadlock immediately, but there are consequences. The aborted processes may need to run again as results of the computation are discarded.

Selecting a process to abort is a difficult task. It depends on priority of the process, its type, how long the process is running, how much computation the process is done, the types and number of resources process has, etc. That process should be aborted whose termination will incur minimum cost.

2. Resource Preemption-

To eliminate the deadlock, take away some resources from processes and give these pre-empted resources to other processes. In case of preemption, following factors need to be considered-

i) Selecting a victim- Which resource to be taken away from which process? The process which has acquired the resources but currently doing some other tasks is chosen in this case. Temporarily take away a resource from its current owner and give it to another process.

ii) Rollback- Once we select a process to be preeempted, it cannot continue with its normal execution as some resources are taken away from the process. Hence the solution is to rollback that process to some safe state and restarts it again from that state.

iii) Starvation- If the same process is selected as a victim to pre-empt again and again, it will lead to starvation. As a result, the starved process won't be able to finish the desired task. So we need to count number of rollbacks for each process. If rollbacks for a particular process exceed the threshold value, that process cannot be pre-empted.

QUESTIONS

1. Write a note on Semaphores
2. Define Deadlock. What are the characteristics of Deadlock?

3. Explain scheduling with its criteria.
4. Explain FCFS scheduling algorithm with example.
5. Explain SJF scheduling algorithm with example.
6. Explain Priority scheduling with example.
7. Explain RR scheduling algorithm with example
8. What are the different methods of handling Deadlock?
9. What are different Dead lock prevention techniques?
10. What are different Deadlock Avoidance techniques?
11. Explain Resource allocation graph.
12. How to recover from the deadlock?
13. Explain Pre-emption and non-pre-emption techniques.
14. Write a short note on Thread scheduling.

Objective Questions

I. Multiple Choice Questions

1. The software layer providing the virtualization is called a _____.
   a) Application Virtual Memory b) Virtual Machine Monitor
   c) System Virtual Monitor d) Process Virtual Machine
2. You can close a file by using_____.
   a) Closed System Call b) Open System Call
   c) Create System Call d) Cancel System Call
3. VPS stands for _____.
   a) Virtual Private Service b) Virtual Private Source
   c) Virtual Private Servers d) Virtual Private Sector
4. Unix _____ call is used for creating child process.
   a) NEW b) EXIT
   c) CREATE d) FORK
5. A Virtual machine is less efficient than a real machine when it access the hardware indirectly
   a) TRUE b) False
   c) None d) Cannot be determined
6. Memory are normally classified according to their
   a) speed b) cost
   c) Index d) both a and b
7. Static program of computer system are stored in
   a) RAM b) ROM
   c) Hard Disk d) CD
8. Which of the following condition is required for deadlock to be possible?
   a) mutual exclusion
   b) a process may hold allocated resources while awaiting assignment of other resources
   c) no resource can be forcibly removed from a process holding it
   d) all of the mentioned

9. 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
10. Which one of the following is the deadlock avoidance algorithm?
   a) banker's algorithm
   b) round-robin algorithm
   c) elevator algorithm
   d) karn's algorithm

[Ans.: (1 – b), (2 – a), (3 – c), (4 – d), (5 – a), (6 – d), (7 – b), (8 – d), (9 – a), (10 – a) **]**

II. True or False

1. Critical section is a code of segment that access shared variable and has to be executed as an atomic action on behalf of one process at a time.
2. Mutual exclusion is, when one process executing in its critical section at that time any other process can execute in its critical section.
3. A monitor is a collection of data structure, variables and procedures and it grouped together.
4. CPU scheduling is to make the system efficient, fast and fair.
5. FCFC meaning First come First Serve.
6. I/O Burst Cycle consists of read and write operations.
7. Pre-emption process will not halt its execution because of some high priority process.
8. Waiting Time of process is less in Non-pre-emptive scheduling.
9. SJF stand for Shortest Job Fail.
10. Round Robin Scheduling Algorithm is designed for Time sharing System.

[Ans.: True : 1, 3, 4, 5, 6, 8, 10 **False :** 2, 7, 9 **]**

UNIT – III

Chapter – 6
Memory Management

MEMORY MANAGEMENT

Memory management is the functionality of an operating system which handles or manages primary memory and moves processes back and forth between main memory and disk during execution. Memory management keeps track of each memory location either it is allocated to some process or it is free. It checks how much memory is to be allocated to processes. It decides which process will get memory at what time. It tracks whenever some memory gets freed or unallocated and correspondingly it updates the status.

Responsibilities of memory management are:

To provide a detailed description of various ways of organizing memory hardware

To discuss various memory-management techniques, including paging and segmentation

To provide a detailed description of the Intel Pentium, which supports both pure segmentation and segmentation with paging Program must be brought (from disk) into memory and placed within a process for it to be run

Main memory and registers are only storage CPU can access directly

Register access in one CPU clock (or less)

Main memory can take many cycles

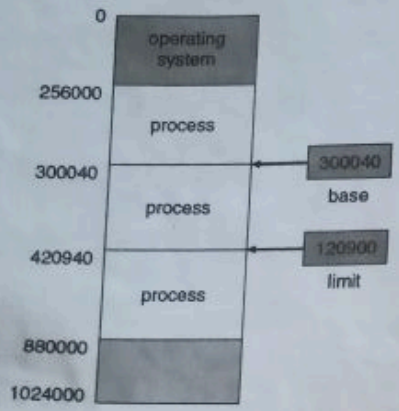
Cache sits between main memory and CPU registers

Protection of memory required to ensure correct operation

MAIN MEMORY

Memory consists of a large array of words or bytes each having its own address. The CPU fetches instructions from the memory according to the value of the program counter. To improve the utilization of CPU the computer must keep several processes in the memory. To utilize the memory many memory management schemes are proposed. Selection of a memory management schemes depends on many factors such as hardware of the system.

Basics of memory management

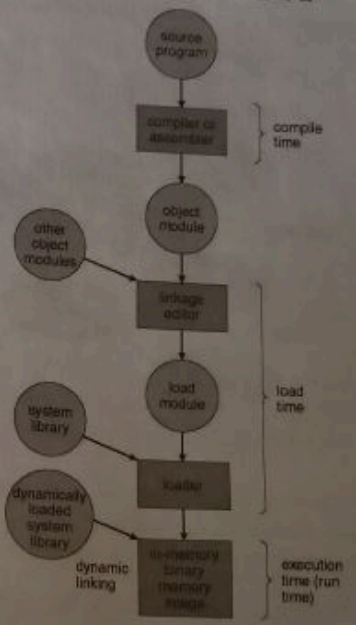


ADDRESS BINDING

A user program goes through several steps such as compiling, loading, and linking. Addresses may be represented in different ways during these steps. Addresses in the source program are generally symbolic. A compiler will bind these addresses to relocatable addresses. The loader will in turn bind these addresses to absolute addresses. Each binding is a mapping from one address space to another.

The binding of instructions and data can be done in the following ways.

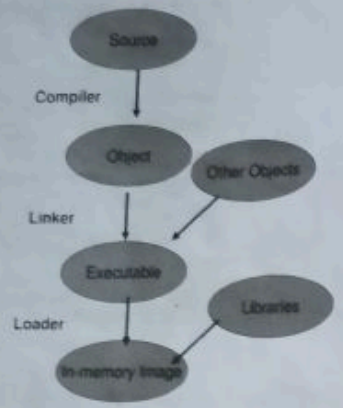
1. Compile time-If it is known at compile time where the process will reside in memory, then absolute code can be generated. If address changes at compile time the program is recompiled.
2. Load time-If it is not known at compile time where the process will reside in the memory, than the compiler must generate relocatable code.
3. Execution time-Binding delayed until run time if the process can be moved during its execution from one memory segment to another. Need hardware support for address maps. (Eg.base and limit registers).



Address Binding

LOGICAL V/S PHYSICAL ADDRESS SPACE

- The address generated by the CPU is a ***logical address***, whereas the address actually seen by the memory hardware is a ***physical address***.
- Addresses bound at compile time or load time have identical logical and physical addresses.
- Addresses created at execution time, however, have different logical and physical addresses.
- In this case the logical address is also known as a ***virtual address***, and the two terms are used interchangeably by our text.
- The set of all logical addresses used by a program composes the ***logical address space***, and the set of all corresponding physical addresses composes the ***physical address space.***
- The run time mapping of logical to physical addresses is handled by the ***memory-management unit, MMU***.
- The MMU can take on many forms. One of the simplest is a modification of the base-register scheme described earlier.
- The base register is now termed a ***relocation register***, whose value is added to every memory request at the hardware level.
- Note that user programs never see physical addresses. User programs work entirely in logical address space, and any memory references or manipulations are done using purely logical addresses. Only when the address gets sent to the physical memory chips is the physical memory address generated.



DYNAMIC LOADING

Routine is no loaded until it is called.

Better memory space utilization, unused routine is never loaded.

Useful when large amounts of code are needed to handle in frequently occurring cases.

There is no special support from the OS is required implemented through program design.

Dynamic Linking

Linking postponed until execution time.

+ Small piece of code, stub, used to locate the appropriate memory-resident library routine.

+ Stub replaces itself with the address of the routine, and executes the routine.

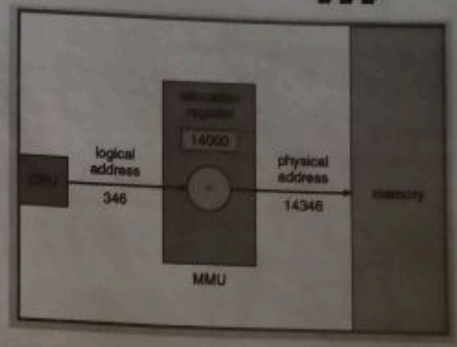
+ Operating system needed to check if routine is in processes' memory address.

+ Dynamic linking is particularly useful for libraries.

Memory management unit:

A memory management unit translates addresses between the CPU and physical memory. This translation process is often known as memory mapping because addresses are mapped from a logical space into a physical space.

Hardware device that maps virtual to physical address - In MMU scheme, the value in the relocation register is added to every address generated by a user process at the time it is sent to memory - The user program deals with logical addresses; it never sees the real physical addresses



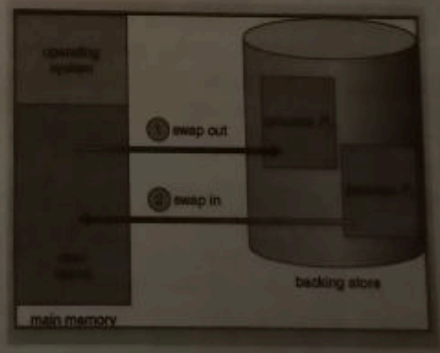
e.g:

1. Here in the diagram the CPU has generated logical address for 346
2. For which the MMU has generated relocation register(base register) for 14000
3. In Memory physical address is located at (346+14000= 14346)

Swapping

Swapping is a mechanism in which a process can be swapped temporarily out of main memory (or move) to secondary storage (disk) and make that memory available to other processes.

At some later time, the system swaps back the process from the secondary storage to main memory. Though performance is usually affected by swapping process but it helps in running multiple and big processes in parallel and that's the reason Swapping is also known as a technique for memory compaction. The total time taken by swapping process includes the time it takes to move the entire process to a secondary disk and then to copy the process back to memory, as well as the time the process takes competing to regain main memory.



Roll out, roll in – It is a swapping variant used for priority-based scheduling algorithms; lower-priority process is swapped out so higher-priority process can be loaded and executed.

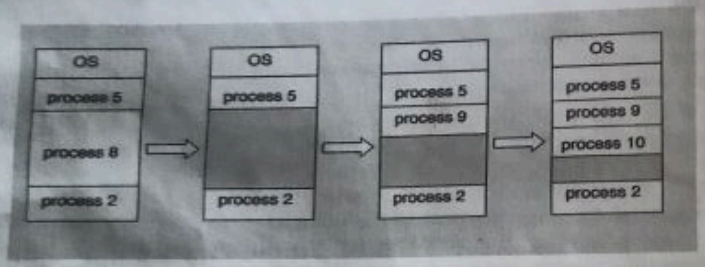
Major part of swap time is transfer time; total transfer time is directly proportional to the amount of memory swapped

Contiguous Allocation

Main memory usually divide into two partitions:

- Resident operating system, usually held in low memory with interrupt vector
- User processes then held in high memory
- Each (Single partition) allocation
- Relocation-register scheme used to protect user processes from each other, and from changing operating-system code and data
- Relocation register contains value of smallest physical address; limit register contains range of logical addresses – each logical address must be less than the limit register
- Multiple-partition allocation

  In this type of allocation, main memory is divided into several fixed-sized partitions where each partition should contain only one process. When a partition is free, a process is selected from the input queue and is loaded into the free partition. When the process terminates, the partition becomes available for another process.



Dynamic Storage -Allocation Problem

How to satisfy a request of size n from a list of free holes

First-fit : Allocate the first hole that is big enough

- **Best-fit:** Allocate the smallest hole that is big enough; must search entire list, unless ordered by size. Produces the smallest leftover hole.
- **Worst-fit:** Allocate the largest hole; must also search entire list. Produces the largest leftover hole.

First-fit and best-fit better than worst-fit in terms of speed and storage utilization

Fragmentation

As processes are loaded and removed from memory, the free memory space is broken into little pieces. It happens after sometimes that processes can not be allocated to memory blocks considering their small size and memory blocks remains unused. This problem is known as Fragmentation.

External fragmentation

a) It exists when there is enough total memory space available to satisfy a request, but available memory space are not contiguous.

b) Storage space is fragmented into large number of small holes.

c) Both first fit and best fit strategies suffer from this.

d) First fit is better in some systems, whereas best fit is better for other.

e) Depending on the total amount of memory storage, size, external fragmentation may be minor or major problem.

f) Statistically N allocated block, Another 0.5 N blocks will be lost to fragmentation. The 1/3 of memory is unusable. It is called 50 - Percent Rule

Internal fragmentation

Consider a multiple partition allocation scheme with a hole of 18,462 bytes. The next process request with 18,462 bytes. If we allocate, we are left with a hole of 2 bytes.

The general approach to avoid this problem is to :-

a) Break physical memory into fixed sized blocks and allocate memory in units based on block size.

b) Memory allocated to a process may be slightly large than the requested memory.

Solution to Internal Fragmentation

1. Compaction
2. The goal is to shuffle the memory content. so as to place all free memory together in one large block.

It is not always possible due to

If relocation is static and done at assembly or load time

It is possible

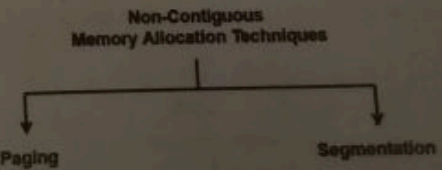
1. Only if relocation is dynamic and is done at execution time
2. Permit the logical address space to the processes to be non-contagious.

Non-Contiguous Memory Allocation

- Non-contiguous memory allocation is a memory allocation technique.
- It allows to store parts of a single process in a non-contiguous fashion.
- Thus, different parts of the same process can be stored at different places in the main memory.

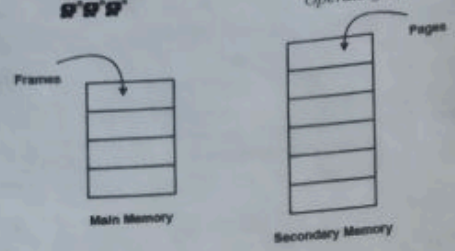
Techniques

There are two popular techniques used for non-contiguous memory allocation-



Paging

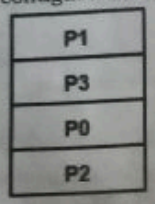
- Paging is a fixed size partitioning scheme.
- In paging, secondary memory and main memory are divided into equal fixed size partitions.
- The partitions of secondary memory are called as **pages**.
- The partitions of main memory are called as **frames**.



- Each process is divided into parts where size of each part is same as page size.
- The size of the last part may be less than the page size.
- The pages of process are stored in the frames of main memory depending upon their availability.

Example-

- Consider a process is divided into 4 pages P0, P1, P2 and P3.
- Depending upon the availability, these pages may be stored in the main memory frames in a non-contiguous fashion as shown-



Main Memory

Translating Logical Address into Physical Address-

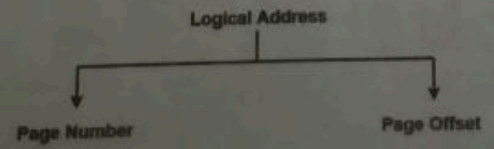
- CPU always generates a logical address.
- A physical address is needed to access the main memory.

Following steps are followed to translate logical address into physical address-

Step-01:

CPU generates a logical address consisting of two parts-

1. Page Number
2. Page Offset



- Page Number specifies the specific page of the process from which CPU wants to read the data.

- Page Offset specifies the specific word on the page that CPU wants to read.

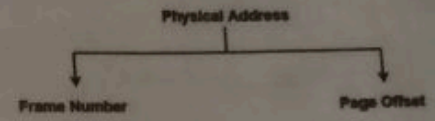
Step-02 :

For the page number generated by the CPU,

- **Page Table** provides the corresponding frame number (base address of the frame) where that page is stored in the main memory.

Step-03:

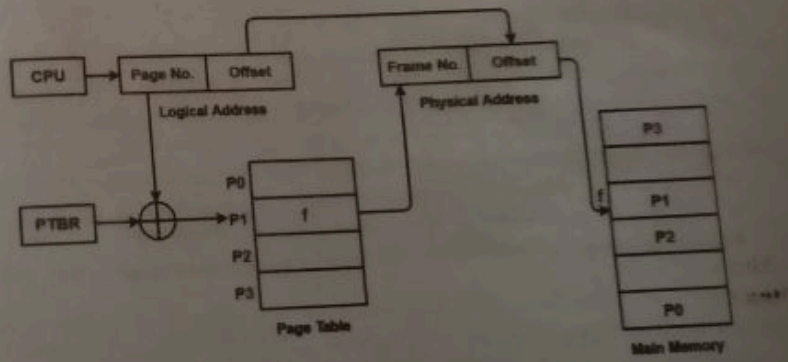
- The frame number combined with the page offset forms the required physical address.



- Frame number specifies the specific frame where the required page is stored.
- Page Offset specifies the specific word that has to be read from that page.

Diagram-

The following diagram illustrates the above steps of translating logical address into physical address-



Translating Logical Address into Physical Address

Advantages-

The advantages of paging are-

- It allows to store parts of a single process in a non-contiguous fashion.
- It solves the problem of external fragmentation.

Disadvantages-

The disadvantages of paging are-

- It suffers from internal fragmentation.
- There is an overhead of maintaining a page table for each process.

- The time taken to fetch the instruction increases since now two memory accesses are required.

Page Table

Page Table is a data structure used by the virtual memory system to store the mapping between logical addresses and physical addresses.

Logical addresses are generated by the CPU for the pages of the processes therefore they are generally used by the processes.

Physical addresses are the actual frame address of the memory. They are generally used by the hardware or more specifically by RAM subsystems.

The image given below considers,

Physical Address Space = M words

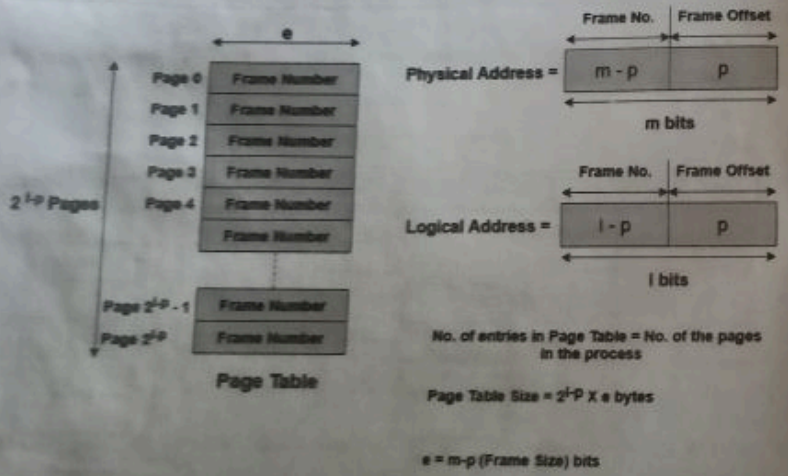
Logical Address Space = L words

Page Size = P words

Physical Address = log 2 M = m bits

Logical Address = log 2 L = l bits

page offset = log 2 P = p bits



The CPU always accesses the processes through their logical addresses. However, the main memory recognizes physical address only.

In this situation, a unit named as Memory Management Unit comes into the picture. It converts the page number of the logical address to the frame number of the physical address. The offset remains same in both the addresses.

To perform this task, Memory Management unit needs a special kind of mapping which is done by page table. The page table stores all the Frame numbers corresponding to the page numbers of the page table.

In other words, the page table maps the page number to its actual location (frame number) in the memory.

In the image given below shows, how the required word of the frame is accessed with the help of offset.

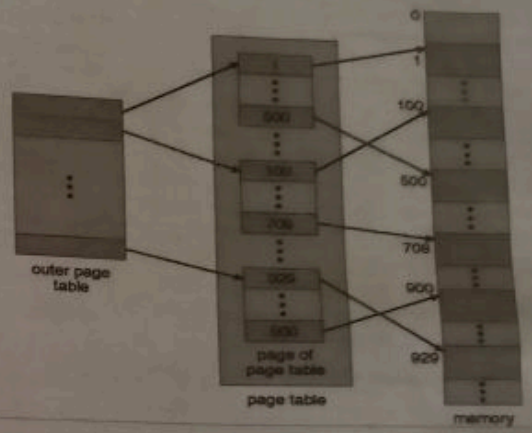
Page table structure :

The techniques for structuring the page table are:

Hierarchical paging :

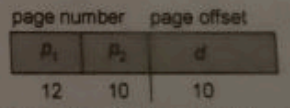
Here we Break up the logical address space into multiple page tables, because if the page table is too large then it is quite difficult to search the page number.

A simple technique is two level page table.



A logical address (on 32-bit machine with 1K page size) is divided into: – a page number consisting of 22 bits – a page offset consisting of 10 bits

- Since the page table is paged, the page number is further divided into: – a 12-bit page number – a 10-bit page offset
- Thus, a logical address is as follows:



- where p1 is an index into the outer page table, and p2 is the displacement within the page of the inner page table
- Known as forward-mapped page table

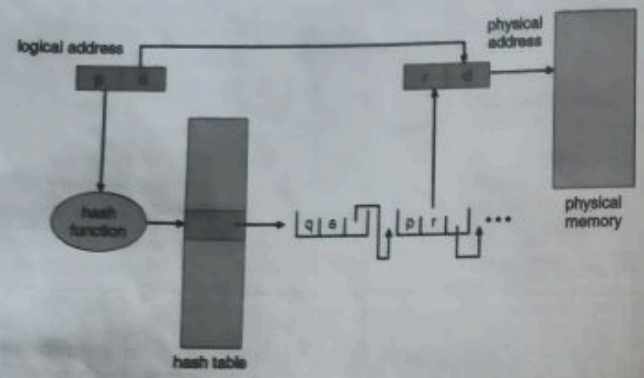
Hashed Page Table

Common in address spaces > 32 bits

- The virtual page number is hashed into a page table
  - This page table contains a chain of elements hashing to the same location
- Each element contains
  - (1) the virtual page number
  - (2) the value of the mapped page frame
  - (3) a pointer to the next element
- Virtual page numbers are compared in this chain searching for

a match

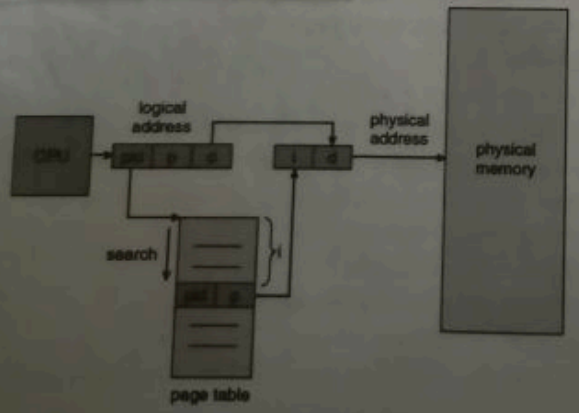
- If a match is found, the corresponding physical frame is extracted
- Variation for 64-bit addresses is clustered page tables
- Similar to hashed but each entry refers to several pages (such as 16) rather than 1
  - Especially useful for sparse address spaces (where memory references are non-contiguous and scattered)



Inverted Page table :

Rather than each process having a page table and keeping track of all possible logical pages, – track all physical pages

- One entry for each real page of memory
- Entry consists of – the virtual address of the page stored in that real memory location, – information about the process that owns that page
- Decreases memory needed to store each page table – but increases time needed to search the table when a page reference occurs
- Use hash table to limit the search to one/few page-table entries – TLB can accelerate access
- But how to implement shared memory? – One mapping of a virtual address to the shared physical address



Advantages and Disadvantages of Paging

This reduces external fragmentation but still suffer from internal fragmentation.

This is simple to implement and assumed as an efficient memory management technique.

Due to equal size of the pages and frames, swapping becomes very easy.

Page table requires extra memory space, so may not be good for a system having small RAM.

Segmentation

Till now, we were using Paging as our main memory management technique. Paging is closer to Operating system rather than the User. It divides all the process into the form of pages although a process can have some relative parts of functions which needs to be loaded in the same page.

Operating system doesn't care about the User's view of the process. It may divide the same function into different pages and those pages may or may not be loaded at the same time into the memory. It decreases the efficiency of the system.

It is better to have segmentation which divides the process into the segments. Each segment contains same type of functions such as main function can be included in one segment and the library functions can be included in the other segment,

In Operating Systems, Segmentation is a memory management technique in which, the memory is divided into the variable size parts. Each part is known as segment which can be allocated to a process.

The details about each segment are stored in a table called as segment table. Segment table is stored in one (or many) of the segments.

Segment table contains mainly two information about segment:

1. Base : It is the base address of the segment
2. Limit : It is the length of the segment.

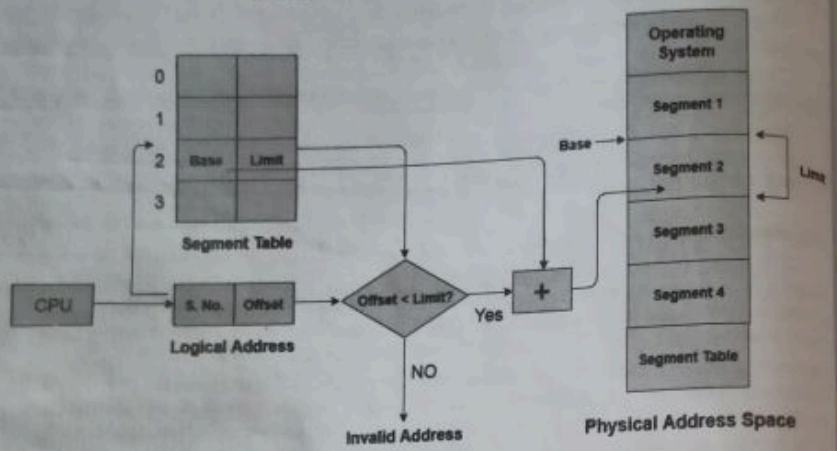
Translation of Logical address into physical address by segment table

CPU generates a logical address which contains two parts:

1. Segment Number
2. Offset

The Segment number is mapped to the segment table. The limit of the respective segment is compared with the offset. If the offset is less than the limit then the address is valid otherwise it throws an error as the address is invalid.

In the case of valid address, the base address of the segment is added to the offset to get the physical address of actual word in the main memory.



Advantages of Segmentation

1. No internal fragmentation
2. Average Segment Size is larger than the actual page size.
3. Less overhead
4. It is easier to relocate segments than entire address space.
5. The segment table is of lesser size as compare to the page table in paging.

Disadvantages

1. It can have external fragmentation.
2. it is difficult to allocate contiguous memory to variable sized partition.
3. Costly memory management algorithms.

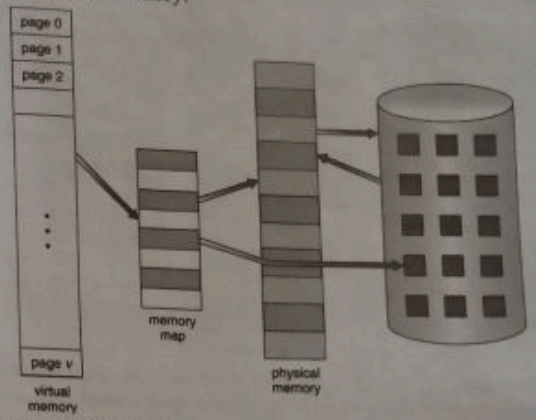
Virtual Memory

- In practice, most real processes do not need all their pages, or at least not all at once, for several reasons:

1. Error handling code is not needed unless that specific error occurs, some of which are quite rare.
2. Arrays are often over-sized for worst-case scenarios, and only a small fraction of the arrays are used in practice.
3. Certain features of certain programs are rarely used, such as the routine to balance the federal budget. :-)

- The ability to load only the portions of processes that were needed (and only *when* they were needed) has several benefits:
  - Programs could be written for a much larger address space (virtual memory space) than physically exists on the computer.
  - Because each process is only using a fraction of their total address space, there is more memory left for other programs, improving CPU utilization and system throughput.
  - Less I/O is needed for swapping processes in and out of RAM, speeding things up.

- Figure shows the general layout of ***virtual memory***, which can be much larger than physical memory:



Benefits of having Virtual Memory

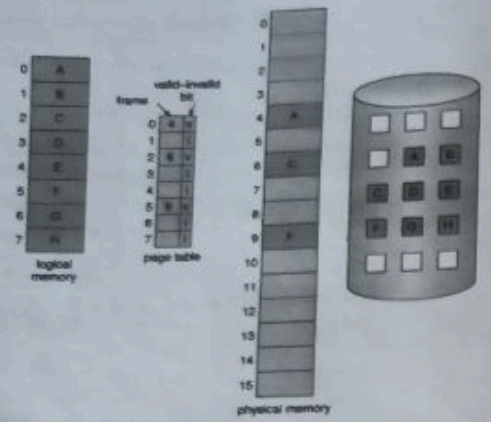
1. Large programs can be written, as virtual space available is huge compared to physical memory.
2. Less I/O required, leads to faster and easy swapping of processes.
3. More physical memory available, as programs are stored on virtual memory, so they occupy very less space on actual physical memory.
4. System libraries can be shared by mapping them into the virtual address space of more than one process.
5. Processes can also share virtual memory by mapping the same block of memory to more than one process.
6. Process pages can be shared during a fork( ) system call, eliminating the need to copy all of the pages of the original (parent) process.

Virtual memory is implemented using the following techniques:

- Demand paging
- Demand Segmentation

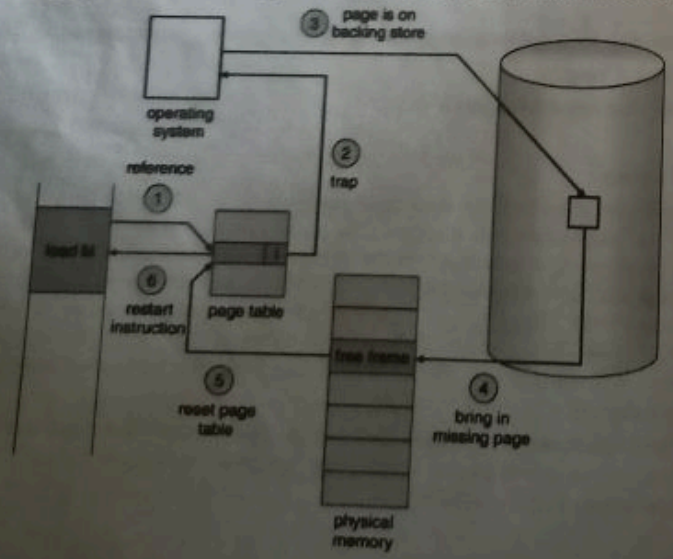
Demand Paging :

- 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 a ***lazy swapper***, although a ***pager*** is a more accurate term. Pages that are not loaded into memory are marked as invalid in the page table, using the invalid bit. (The rest of the page table entry may either be blank or contain information about where to find the swapped-out page on the hard drive.)
- If the process only ever accesses pages that are loaded in memory (memory *resident* pages), then the process runs exactly as if all the pages were loaded in to memory.



- On the other hand, if a page is needed that was not originally loaded up, then a ***page fault trap*** is generated, which must be handled in a series of steps:

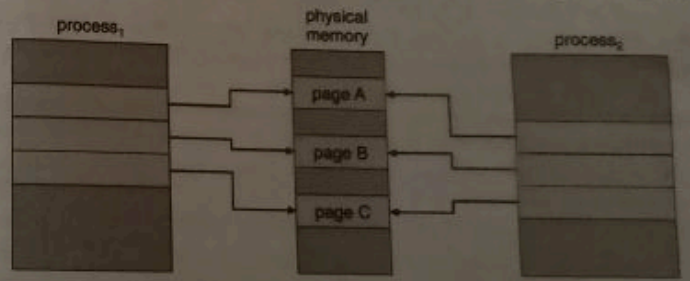
1. The memory address requested is first checked, to make sure it was a valid memory request.
2. If the reference was invalid, the process is terminated. Otherwise, the page must be paged in.
3. A free frame is located, possibly from a free-frame list.
4. A disk operation is scheduled to bring in the necessary page from disk. (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 indicate that this is now a valid page reference.
6. The instruction that caused the page fault must now be restarted from the beginning, (as soon as this process gets another turn on the CPU.)



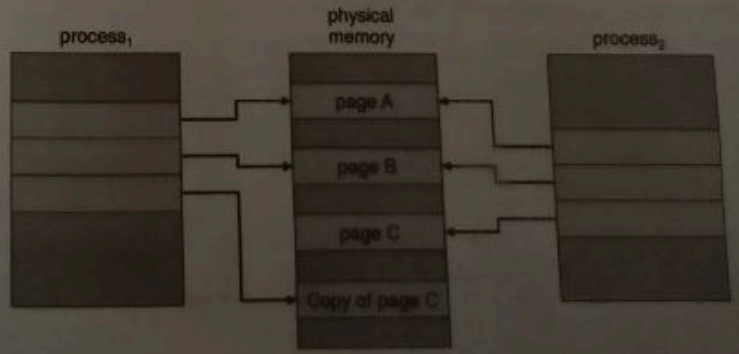
- In an extreme case, NO pages are swapped in for a process until they are requested by page faults. This is known as ***pure demand paging.***
- In theory each instruction could generate multiple page faults. In practice this is very rare, due to ***locality of reference***
- The hardware necessary to support virtual memory is the same as for paging and swapping : A page table and secondary memory.
- A crucial part of the process is that the instruction must be restarted from scratch once the desired page has been made available in memory. For most simple instructions this is not a major difficulty. However there are some architectures that allow a single instruction to modify a fairly large block of data, (which may span a page boundary), and if some of the data gets modified before the page fault occurs, this could cause problems. One solution is to access both ends of the block before executing the instruction, guaranteeing that the necessary pages get paged in before the instruction begins.

Copy-on-Write

- The idea behind a copy-on-write fork is that the pages for a parent process do not have to be copied for the child until one or the other of the processes changes the page. They can be simply shared between the two processes in the meantime, with a bit set that the page needs to be copied if it ever gets written to. This is a reasonable approach, since the child process usually issues an exec() system call immediately after the fork.



Before process 1 modifies page C.



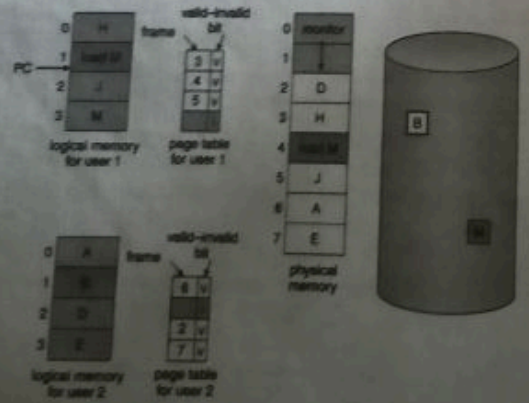
After process 1 modifies page C.

- Obviously only pages that can be modified even need to be labeled as copy-on-write. Code segments can simply be shared.
- Pages used to satisfy copy-on-write duplications are typically allocated using ***zero-fill-on-demand***, meaning that their previous contents are zeroed out before the copy proceeds.
- Some systems provide an alternative to the fork() system call called a ***virtual memory fork, vfork()***. In this case the parent is suspended and the child uses the parent's memory pages. This is very fast for process creation, but requires that the child not modify any of the shared memory pages before performing the exec() system call. (In essence this addresses the question of which process executes first after a call to fork the parent or the child. With vfork, the parent is suspended, allowing the child to execute first until it calls exec(), sharing pages with the parent in the meantime.

Page Replacement

- In order to make the most use of virtual memory, we load several processes into memory at the same time. Since we only load the pages that are needed by each process at any given time, there is room to load many more processes than if we had to load in the entire process.
- However memory is also needed for other purposes (such as I/O buffering), and what happens if some process suddenly decides it needs more pages and there aren't any free frames available? There are several possible solutions to consider:

1. Adjust the memory used by I/O buffering, etc., to free up some frames for user processes. The decision of how to allocate memory for I/O versus user processes is a complex one, yielding different policies on different systems. (Some allocate a fixed amount for I/O, and others let the I/O system contend for memory along with everything else.)
2. Put the process requesting more pages into a wait queue until some free frames become available.
3. Swap some process out of memory completely, freeing up its page frames.
4. Find some page in memory that isn't being used right now, and swap that page only out to disk, freeing up a frame that can be allocated to the process requesting it. This is known as ***page replacement*** and is the most common solution. There are many different algorithms for page replacement, which is the subject of the remainder of this section.

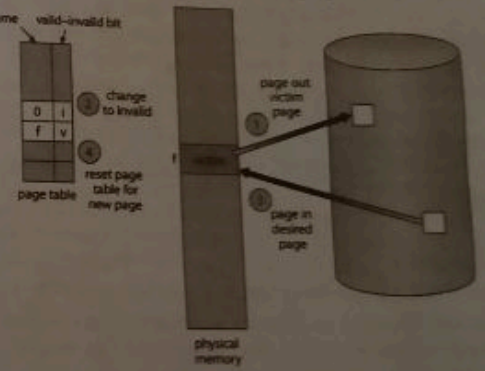


Need for page replacement.

Basic Page Replacement

- The previously discussed page-fault processing assumed that there would be free frames available on the free-frame list. Now the page-fault handling must be modified to free up a frame if necessary, as follows:

1. Find the location of the desired page on the disk, either in swap space or in the file system.
2. Find a free frame:
   a) If there is a free frame, use it.
   b) If there is no free frame, use a page-replacement algorithm to select an existing frame to be replaced, known as the *victim frame*.
   c) Write the victim frame to disk. Change all related page tables to indicate that this page is no longer in memory.
3. Read in the desired page and store it in the frame. Adjust all related page and frame tables to indicate the change.
4. Restart the process that was waiting for this page.

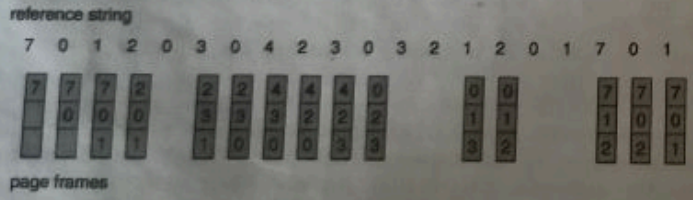


- Note that step 3c adds an extra disk write to the page-fault handling, effectively doubling the time required to process a page fault. This can be alleviated somewhat by assigning a ***modify bit,*** or ***dirty bit*** to each page, indicating whether or not it has been changed since it was last loaded in from disk. If the dirty bit has not been set, then the page is unchanged, and does not need to be written out to disk. Otherwise the page write is required. It should come as no surprise that many page replacement strategies specifically look for pages that do not have their dirty bit set, and preferentially select clean pages as victim pages. It should also be obvious that unmodifiable code pages never get their dirty bits set.
- There are two major requirements to implement a successful demand paging system. We must develop a ***frame-allocation algorithm*** and a ***page-replacement algorithm.*** The former centers around how many frames are allocated to each process (and to other needs), and the latter deals with how to select a page for replacement when there are no free frames available.
- The overall goal in selecting and tuning these algorithms is to generate the fewest number of overall page faults. Because disk access is so slow relative to memory access, even slight improvements to these algorithms can yield large improvements in overall system performance.

- Algorithms are evaluated using a given string of memory accesses known as a ***reference string,*** which can be generated in one of (at least) three common ways:
  1. Randomly generated, either evenly distributed or with some distribution curve based on observed system behavior. This is the fastest and easiest approach, but may not reflect real performance well, as it ignores locality of reference.
  2. Specifically designed sequences. These are useful for illustrating the properties of comparative algorithms in published papers and textbooks, (and also for homework and exam problems. :-))
  3. Recorded memory references from a live system. This may be the best approach, but the amount of data collected can be enormous, on the order of a million addresses per second. The volume of collected data can be reduced by making two important observations:
     1. Only the page number that was accessed is relevant. The offset within that page does not affect paging operations.
     2. Successive accesses within the same page can be treated as a single page request, because all requests after the first are guaranteed to be page hits. (Since there are no intervening requests for other pages that could remove this page from the page table.)
- So for example, if pages were of size 100 bytes, then the sequence of address requests (0100, 0432, 0101, 0612, 0634, 0688, 0132, 0038, 0420) would reduce to page requests (1, 4, 1, 6, 1, 0, 4)
- As the number of available frames increases, the number of page faults should decrease

FIFO Page Replacement

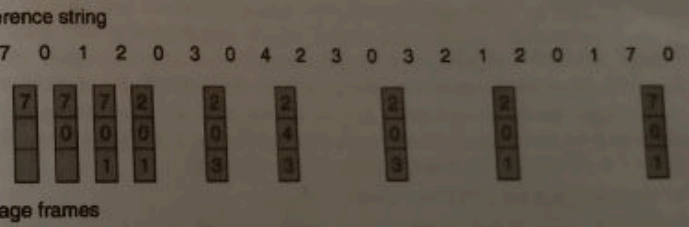
- A simple and obvious page replacement strategy is ***FIFO***, i.e. first-in-first-out.
- As new pages are brought in, they are added to the tail of a queue, and the page at the head of the queue is the next victim. In the following example, 20 page requests result in 15 page faults:



- Although FIFO is simple and easy, it is not always optimal, or even efficient.
- An interesting effect that can occur with FIFO is ***Belady's anomaly***, in which increasing the number of frames available can actually ***increase*** the number of page faults that occur! Consider, for example, the following chart based on the page sequence (1, 2, 3, 4, 1, 2, 5, 1, 2, 3, 4, 5) and a varying number of available frames. Obviously the maximum number of faults is 12 (every request generates a fault), and the minimum number is 5 (each page loaded only once), but in between there are some interesting results:

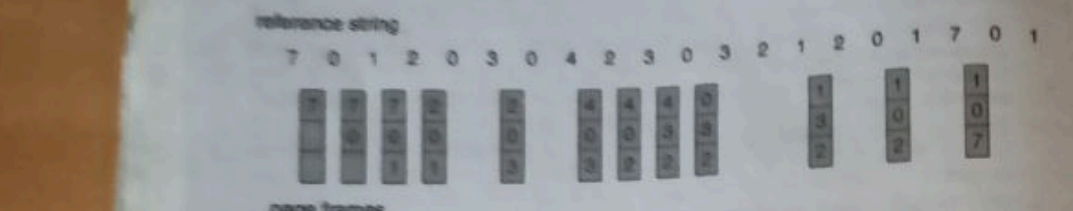
Optimal Page Replacement

- The discovery of Belady's anomaly lead to the search for an ***optimal page-replacement algorithm***, which is simply that which yields the lowest of all possible page-faults, and which does not suffer from Belady's anomaly.
- Such an algorithm does exist, and is called ***OPT or MIN.*** This algorithm is simply "Replace the page that will not be used for the longest time in the future."
- For example, Figure 9.14 shows that by applying OPT to the same reference string used for the FIFO example, the minimum number of possible page faults is 9. Since 6 of the page-faults are unavoidable (the first reference to each new page), FIFO can be shown to require 3 times as many (extra) page faults as the optimal algorithm. (Note: The book claims that only the first three page faults are required by all algorithms, indicating that FIFO is only twice as bad as OPT)
- Unfortunately OPT cannot be implemented in practice, because it requires foretelling the future, but it makes a nice benchmark for the comparison and evaluation of real proposed new algorithms.
- In practice most page-replacement algorithms try to approximate OPT by predicting (estimating) in one fashion or another what page will not be used for the longest period of time. The basis of FIFO is the prediction that the page that was brought in the longest time ago is the one that will not be needed again for the longest future time, but as we shall see, there are many other prediction methods, all striving to match the performance of OPT.



LRU Page Replacement

- The prediction behind ***LRU,*** the ***Least Recently Used,*** algorithm is that the page that has not been used in the longest time is the one that will not be used again in the near future. (Note the distinction between FIFO and LRU: The former looks at the oldest ***load*** time, and the latter looks at the oldest ***use*** time.)
- Some view LRU as analogous to OPT, except looking backwards in time instead of forwards. (OPT has the interesting property that for any reference string S and its reverse R, OPT will generate the same number of page faults for S and for R. It turns out that LRU has this same property.)
- The following LRU for our sample string, yielding 12 page faults, (as compared to 15 for FIFO and 9 for OPT.)



- LRU is considered a good replacement policy, and is often used. The problem is how exactly to implement it. There are two simple approaches commonly used:

1. **Counters.** Every memory access increments a counter, and the current value of this counter is stored in the page table entry for that page. Then finding the LRU page involves simple searching the table for the page with the smallest counter value. Note that overflowing of the counter must be considered.
2. **Stack.** Another approach is to use a stack, and whenever a page is accessed, pull that page from the middle of the stack and place it on the top. The LRU page will always be at the bottom of the stack. Because this requires removing objects from the middle of the stack, a doubly linked list is the recommended data structure.
   - Note that both implementations of LRU require hardware support, either for incrementing the counter or for managing the stack, as these operations must be performed for ***every*** memory access.
   - Neither LRU or OPT exhibit Belady's anomaly. Both belong to a class of page-replacement algorithms called ***stack algorithms,*** which can never exhibit Belady's anomaly. A stack algorithm is one in which the pages kept in memory for a frame set of size N will always be a subset of the pages kept for a frame size of N + 1. In the case of LRU, (and particularly the stack implementation thereof), the top N pages of the stack will be the same for all frame set sizes of N or anything larger.

LRU-Approximation Page Replacement

- Unfortunately full implementation of LRU requires hardware support, and few systems provide the full hardware support necessary.
- However many systems offer some degree of HW support, enough to approximate LRU fairly well. (In the absence of ANY hardware support, FIFO might be the best available choice.)
- In particular, many systems provide a ***reference bit*** for every entry in a page table, which is set anytime that page is accessed. Initially all bits are set to zero, and they can also all be cleared at any time. One bit of precision is enough to distinguish pages that have been accessed since the last clear from those that have not, but does not provide any finer grain of detail.

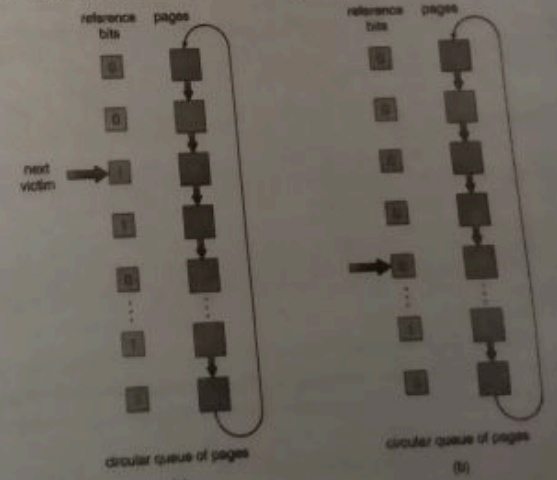
Additional-Reference-Bits Algorithm

- Finer grain is possible by storing the most recent 8 reference bits for each page in an 8-bit byte in the page table entry, which is interpreted as an unsigned int.
- At periodic intervals (clock interrupts), the OS takes over, and right-shifts each of the reference bytes by one bit.

- The high-order (leftmost) bit is then filled in with the current value of the reference bit, and the reference bits are cleared.
- At any given time, the page with the smallest value for the reference byte is the LRU page.
- Obviously the specific number of bits used and the frequency with which the reference byte is updated are adjustable, and are tuned to give the fastest performance on a given hardware platform.

Second-Chance Algorithm

- The ***second chance algorithm*** is essentially a FIFO, except the reference bit is used to give pages a second chance at staying in the page table.
- When a page must be replaced, the page table is scanned in a FIFO (circular queue) manner.
- If a page is found with its reference bit not set, then that page is selected as the next victim.
- If, however, the next page in the FIFO **does** have its reference bit set, then it is given a second chance:
  - The reference bit is cleared, and the FIFO search continues.
  - If some other page is found that did not have its reference bit set, then that page will be selected as the victim, and this page (the one being given the second chance) will be allowed to stay in the page table.
  - If, however, there are no other pages that do not have their reference bit set, then this page will be selected as the victim when the FIFO search circles back around to this page on the second pass.
  - If all reference bits in the table are set, then second chance degrades to FIFO, but also requires a complete search of the table for every page-replacement.
  - As long as there are some pages whose reference bits are not set, then any page referenced frequently enough gets to stay in the page table indefinitely.
  - This algorithm is also known as the **clock** algorithm, from the hands of the clock moving around the circular queue.



Enhanced Second-Chance Algorithm

- The **enhanced second chance algorithm** looks at the reference bit and the modify bit (dirty bit) as an ordered page, and classifies pages into one of four classes:
  1. (0, 0) - Neither recently used nor modified.
  2. (0, 1) - Not recently used, but modified.
  3. (1, 0) - Recently used, but clean.
  4. (1, 1) - Recently used and modified.
- This algorithm searches the page table in a circular fashion (in as many as four passes), looking for the first page it can find in the lowest numbered category. I.e. it first makes a pass looking for a (0, 0), and then if it can't find one, it makes another pass looking for a (0, 1), etc.
- The main difference between this algorithm and the previous one is the preference for replacing clean pages if possible.

Counting-Based Page Replacement

- There are several algorithms based on counting the number of references that have been made to a given page, such as:
  - ***Least Frequently Used, LFU :*** Replace the page with the lowest reference count. A problem can occur if a page is used frequently initially and then not used any more, as the reference count remains high. A solution to this problem is to right-shift the counters periodically, yielding a time-decaying average reference count.
  - ***Most Frequently Used, MFU:*** Replace the page with the highest reference count. The logic behind this idea is that pages that have already been referenced a lot have been in the system a long time, and we are probably done with them, whereas pages referenced only a few times have only recently been loaded, and we still need them.
- In general counting-based algorithms are not commonly used, as their implementation is expensive and they do not approximate OPT well.

Page-Buffering Algorithms

There are a number of page-buffering algorithms that can be used in conjunction with the afore-mentioned algorithms, to improve overall performance and sometimes make up for inherent weaknesses in the hardware and/or the underlying page-replacement algorithms:

- Maintain a certain minimum number of free frames at all times. When a page-fault occurs, go ahead and allocate one of the free frames from the free list first, to get the requesting process up and running again as quickly as possible, and then select a victim page to write to disk and free up a frame as a second step.
- Keep a list of modified pages, and when the I/O system is otherwise idle, have it write these pages out to disk, and then clear the modify bits, thereby increasing the chance of finding a "clean" page for the next potential victim.
- Keep a pool of free frames, but remember what page was in it before it was made free. Since the data in the page is not actually cleared out when the page is freed, it can be made an active page again without having to load in any new data from disk. This is useful when an algorithm mistakenly replaces a page that in fact is needed again soon.

Applications and Page Replacement

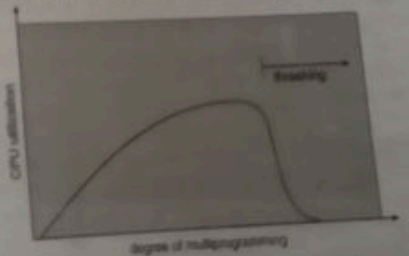
- Some applications (most notably database programs) understand their data accessing and caching needs better than the general-purpose OS, and should therefore be given reign to do their own memory management.
- Sometimes such programs are given a ***raw disk partition*** to work with, containing raw data blocks and no file system structure. It is then up to the application to use this disk partition as extended memory or for whatever other reasons it sees fit.

Thrashing

- If a process cannot maintain its minimum required number of frames, then it must be swapped out, freeing up frames for other processes. This is an intermediate level of CPU scheduling.
- But what about a process that can keep its minimum, but cannot keep all of the frames that it is currently using on a regular basis? In this case it is forced to page out pages that it will need again in the very near future, leading to large numbers of page faults.
- A process that is spending more time paging than executing is said to be ***thrashing.***

Cause of Thrashing

- Early process scheduling schemes would control the level of multiprogramming allowed based on CPU utilization, adding in more processes when CPU utilization was low.
- The problem is that when memory filled up and processes started spending lots of time waiting for their pages to page in, then CPU utilization would lower, causing the schedule to add in even more processes and exacerbating the problem! Eventually the system would essentially grind to a halt.
- Local page replacement policies can prevent one thrashing process from taking pages away from other processes, but it still tends to clog up the I/O queue, thereby slowing down any other process that needs to do even a little bit of paging (or any other I/O for that matter)



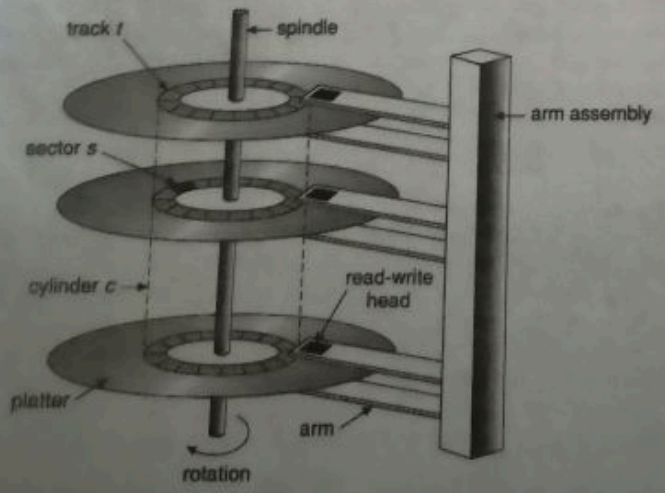
- To prevent thrashing we must provide processes with as many frames as they really need "right now", but how do we know what that is?
- The ***locality model*** notes that processes typically access memory references in a given **locality,** making lots of references to the same general area of memory before moving periodically to a new locality, as shown in Figure 9.19 below. If we could just keep as many frames as are involved in the current locality, then page faulting would occur primarily on switches from one locality to another. (E.g. when one function exits and another is called.)

Mass Storage Structure

Overview of Mass-Storage Structure

Magnetic Disks

- Traditional magnetic disks have the following basic structure:
  - One or more *platters* in the form of disks covered with magnetic media. *Hard disk* platters are made of rigid metal, while "*floppy*" disks are made of more flexible plastic.
  - Each platter has two working *surfaces*. Older hard disk drives would sometimes not use the very top or bottom surface of a stack of platters, as these surfaces were more susceptible to potential damage.
  - Each working surface is divided into several concentric rings called *tracks*. The collection of all tracks that are the same distance from the edge of the platter, (i.e. all tracks immediately above one another in the following diagram) is called a *cylinder*.
  - Each track is further divided into *sectors*, traditionally containing 512 bytes of data each, although some modern disks occasionally use larger sector sizes. (Sectors also include a header and a trailer, including checksum information among other things. Larger sector sizes reduce the fraction of the disk consumed by headers and trailers, but increase internal fragmentation and the amount of disk that must be marked bad in the case of errors.)
  - The data on a hard drive is read by read-write *heads*. The standard configuration (shown below) uses one head per surface, each on a separate *arm*, and controlled by a common *arm assembly* which moves all heads simultaneously from one cylinder to another. (Other configurations, including independent read-write heads, may speed up disk access, but involve serious technical difficulties.)
  - The storage capacity of a traditional disk drive is equal to the number of heads (i.e. the number of working surfaces), times the number of tracks per surface, times the number of sectors per track, times the number of bytes per sector. A physical block of data is specified by providing the head-sector-cylinder number at which it is located.



Moving-head disk mechanism

- In operation the disk rotates at high speed, such as 7200 rpm (120 revolutions per second.) The rate at which data can be transferred from the disk to the computer is composed of several steps:
  - The *positioning time*, a.k.a. the *seek time* or *random access time* is the time required to move the heads from one cylinder to another, and for the heads to settle down after the move. This is typically the slowest step in the process and the predominant bottleneck to overall transfer rates.
  - The *rotational latency* is the amount of time required for the desired sector to rotate around and come under the read-write head. This can range anywhere from zero to one full revolution, and on the average will equal one-half revolution. This is another physical step and is usually the second slowest step behind seek time. (For a disk rotating at 7200 rpm, the average rotational latency would be 1/2 revolution / 120 revolutions per second, or just over 4 milliseconds, a long time by computer standards.
  - The *transfer rate*, which is the time required to move the data electronically from the disk to the computer. (Some authors may also use the term transfer rate to refer to the overall transfer rate, including seek time and rotational latency as well as the electronic data transfer rate.)
- Disk heads "fly" over the surface on a very thin cushion of air. If they should accidentally contact the disk, then a *head crash* occurs, which may or may not permanently damage the disk or even destroy it completely. For this reason it is normal to *park* the disk heads when turning a computer off, which means to move the heads off the disk or to an area of the disk where there is no data stored.
- Floppy disks are normally *removable*. Hard drives can also be removable, and some are even *hot-swappable*, meaning they can be removed while the computer is running, and a new hard drive inserted in their place.
- Disk drives are connected to the computer via a cable known as the *I/O Bus*. Some of the common interface formats include Enhanced Integrated Drive Electronics, EIDE; Advanced Technology Attachment, ATA; Serial ATA, SATA, Universal Serial Bus, USB; Fiber Channel, FC, and Small Computer Systems Interface, SCSI.
- The *host controller* is at the computer end of the I/O bus, and the disk *controller* is built into the disk itself. The CPU issues commands to the host controller via I/O ports. Data is transferred between the magnetic surface and onboard *cache* by the disk controller, and then the data is transferred from that cache to the host controller and the motherboard memory at electronic speeds.

Magnetic Tapes

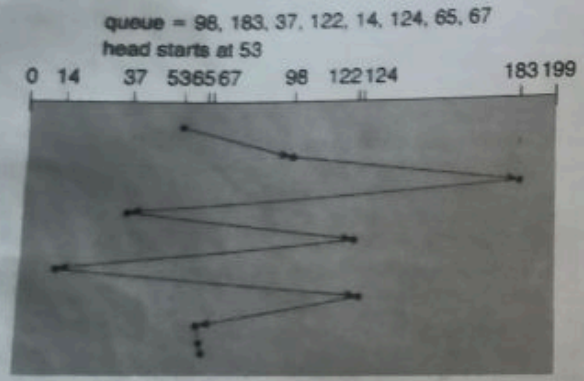
- Magnetic tapes were once used for common secondary storage before the days of hard disk drives, but today are used primarily for backups.
- Accessing a particular spot on a magnetic tape can be slow, but once reading or writing commences, access speeds are comparable to disk drives.
- Capacities of tape drives can range from 20 to 200 GB, and compression can double that capacity.

Disk Scheduling

- Disk transfer speeds are limited primarily by ***seek times*** and ***rotational latency***. When multiple requests are to be processed there is also some inherent delay in waiting for other requests to be processed.
- ***Bandwidth*** is measured by the amount of data transferred divided by the total amount of time from the first request being made to the last transfer being completed, (for a series of disk requests.)
- Both bandwidth and access time can be improved by processing requests in a good order.
- Disk requests include the disk address, memory address, number of sectors to transfer, and whether the request is for reading or writing.

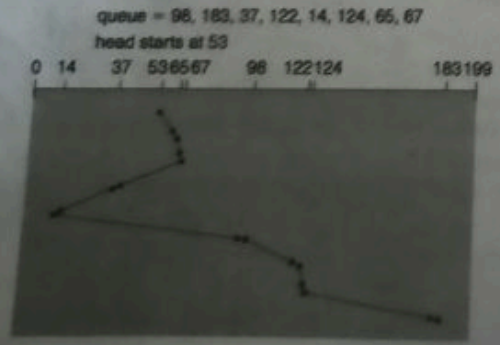
FCFS Scheduling

First-Come First-Serve is simple and intrinsically fair, but not very efficient. Consider in the following sequence the wild swing from cylinder 122 to 14 and then back to 124:



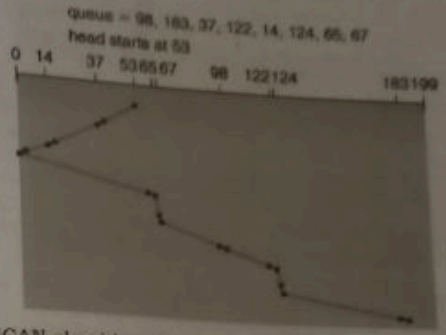
SSTF Scheduling

- *Shortest Seek Time First* scheduling is more efficient, but may lead to starvation if a constant stream of requests arrives for the same general area of the disk.
- SSTF reduces the total head movement to 236 cylinders, down from 640 required for the same set of requests under FCFS. Note, however that the distance could be reduced still further to 208 by starting with 37 and then 14 first before processing the rest of the requests.



SCAN Scheduling

The SCAN algorithm, a.k.a. the elevator algorithm moves back and forth from one end of the disk to the other, similarly to an elevator processing requests in a tall building.

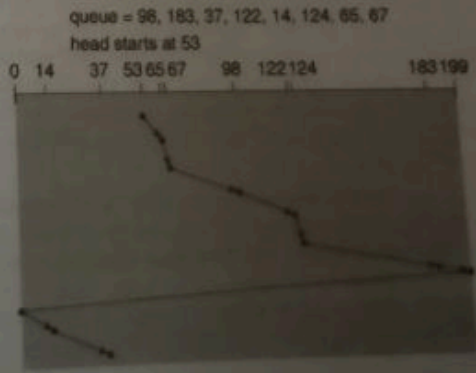


Under the SCAN algorithm, If a request arrives just ahead of the moving head then it will be processed right away, but if it arrives just after the head has passed, then it will have to wait for the head to pass going the other way on the return trip. This leads to a wide variation in access times which can be improved upon.

Consider, for example, when the head reaches the high end of the disk: Requests with high cylinder numbers just missed the passing head, which means they are all recent requests, whereas requests with low numbers may have been waiting for a much longer time. Making the return scan from high to low then ends up accessing recent requests first and making older requests wait that much longer.

C-SCAN Scheduling

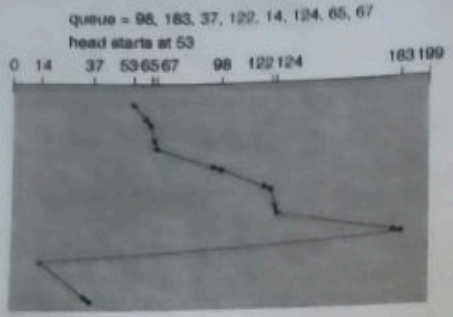
The Circular-SCAN algorithm improves upon SCAN by treating all requests in a circular queue fashion - Once the head reaches the end of the disk, it returns to the other end without processing any requests, and then starts again from the beginning of the disk:



LOOK Scheduling

- ***LOOK*** scheduling improves upon SCAN by looking ahead at the queue of pending requests, and not moving the heads any farther towards the end of

the disk than is necessary. The following diagram illustrates the circular form of LOOK.



DISK MANAGEMENT

Disk Formatting

- Before a disk can be used, it must be ***low-level formatted***, which means laying down all the headers and trailers marking the beginning and ends of each sector. Included in the header and trailer are the linear sector numbers, and ***error-correcting codes, ECC,*** which allow damaged sectors to not only be detected, but in many cases for the damaged data to be recovered (depending on the extent of the damage) Sector sizes are traditionally 512 bytes, but may be larger, particularly in larger drives.
- ECC calculation is performed with every disk read or write, and if damage is detected but the data is recoverable, then a ***soft error*** has occurred. Soft errors are generally handled by the on-board disk controller, and never seen by the OS.
- Once the disk is low-level formatted, the next step is to partition the drive into one or more separate partitions. This step must be completed even if the disk is to be used as a single large partition, so that the partition table can be written to the beginning of the disk.
- After partitioning, then the filesystems must be ***logically formatted,*** which involves laying down the master directory information (FAT table), initializing free lists, and creating at least the root directory of the filesystem. (Disk partitions which are to be used as raw devices are not logically formatted. This saves the overhead and disk space of the filesystem structure but requires that the application program manage its own disk storage requirements.)

Boot Block

- Computer ROM contains a ***bootstrap*** program (OS independent) with just enough code to find the first sector on the first hard drive on the first controller, load that sector into memory, and transfer control over to it. (The ROM bootstrap program may look in floppy and/or CD drives before accessing the hard drive, and is smart enough to recognize whether it has found valid boot code or not.)
- The first sector on the hard drive is known as the ***Master Boot Record, MBR,*** and contains a very small amount of code in addition to the ***partition table.*** The partition table documents how the disk is partitioned into logical disks, and indicates specifically which partition is the ***active*** or ***boot*** partition.

- The boot program then looks to the active partition to find an operating system, possibly loading up a slightly larger / more advanced boot program along the way.
- In a ***dual-boot*** (or larger multi-boot) system, the user may be given a choice of which operating system to boot, with a default action to be taken in the event of no response within some time frame.
- Once the kernel is found by the boot program, it is loaded into memory and then control is transferred over to the OS. The kernel will normally continue the boot process by initializing all important kernel data structures, launching important system services, and finally providing one or more login prompts. Boot options at this stage may include ***single-user*** a.k.a. ***maintenance*** or ***safe*** modes, in which very few system services are started - These modes are designed for system administrators to repair problems or otherwise maintain the system.

Bad Blocks

- No disk can be manufactured to 100% perfection, and all physical objects wear out over time. For these reasons all disks are shipped with a few bad blocks, and additional blocks can be expected to go bad slowly over time. If many blocks go bad then the entire disk will need to be replaced, but a few here and there can be handled through other means.
- In the old days, bad blocks had to be checked for manually. Formatting of the disk or running certain disk-analysis tools would identify bad blocks and attempt to read the data off them one last time through repeated tries. Then the bad blocks would be mapped out and taken out of future service. Sometimes the data could be recovered, and sometimes it was lost forever.
- Modern disk controllers make much better use of the error-correcting codes, so that bad blocks can be detected earlier, and the data usually recovered.
- Note that re-mapping of sectors from their normal linear progression can throw off the disk scheduling optimization of the OS, especially if the replacement sector is physically far away from the sector it is replacing. For this reason most disks normally keep a few spare sectors on each cylinder, as well as at least one spare cylinder. Whenever possible a bad sector will be mapped to another sector on the same cylinder, or at least a cylinder as close as possible. ***Sector slipping*** may also be performed, in which all sectors between the bad sector and the replacement sector are moved down by one, so that the linear progression of sector numbers can be maintained.
- If the data on a bad block cannot be recovered, then a ***hard error*** has occurred., which requires replacing the file(s) from backups, or rebuilding them from scratch.

Swap-Space Management

- Modern systems typically swap out pages as needed, rather than swapping out entire processes. Hence the swapping system is part of the virtual memory management system.
- Managing swap space is obviously an important task for modern OSes.

Swap-Space Use

- The amount of swap space needed by an OS varies greatly according to how it is used. Some systems require an amount equal to physical RAM; some want a multiple of that; some want an amount equal to the amount by which virtual memory exceeds physical RAM, and some systems use little or none!

- Some systems support multiple swap spaces on separate disks in order to speed up the virtual memory system.

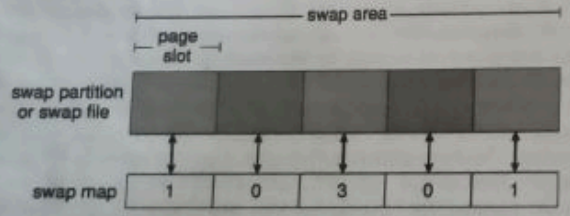
Swap-Space Location

Swap space can be physically located in one of two locations :

- As a large file which is part of the regular filesystem. This is easy to implement, but inefficient. Not only must the swap space be accessed through the directory system, the file is also subject to fragmentation issues. Caching the block location helps in finding the physical blocks, but that is not a complete fix.
- As a raw partition, possibly on a separate or little-used disk. This allows the OS more control over swap space management, which is usually faster and more efficient. Fragmentation of swap space is generally not a big issue, as the space is re-initialized every time the system is rebooted. The downside of keeping swap space on a raw partition is that it can only be grown by repartitioning the hard drive.

Swap-Space Management : An Example

- Historically OSes swapped out entire processes as needed. Modern systems swap out only individual pages, and only as needed. (For example process code blocks and other blocks that have not been changed since they were originally loaded are normally just freed from the virtual memory system rather than copying them to swap space, because it is faster to go find them again in the filesystem and read them back in from there than to write them out to swap space and then read them back.)
- In the mapping system shown below for Linux systems, a map of swap space is kept in memory, where each entry corresponds to a 4K block in the swap space. Zeros indicate free slots and non-zeros refer to how many processes have a mapping to that particular block (>1 for shared pages only.)



RAID Structure

- The general idea behind RAID is to employ a group of hard drives together with some form of duplication, either to increase reliability or to speed up operations, (or sometimes both.)
- ***RAID*** originally stood for ***Redundant Array of Inexpensive Disks,*** and was designed to use a bunch of cheap small disks in place of one or two larger more expensive ones. Today RAID systems employ large possibly expensive disks as their components, switching the definition to ***Independent*** disks.

Improvement of Reliability via Redundancy

- The more disks a system has, the greater the likelihood that one of them will go bad at any given time. Hence increasing disks on a system actually ***decreases*** the **Mean Time To Failure, MTTF** of the system.
- If, however, the same data was copied onto multiple disks, then the data would not be lost unless **both** copies of the data were damaged simultaneously, which is a **MUCH** lower probability than for a single disk going bad. More specifically, the second disk would have to go bad before the first disk was repaired, which brings the **Mean Time To Repair** into play. For example if two disks were involved, each with a MTTF of 100,000 hours and a MTTR of 10 hours, then the **Mean Time to Data Loss** would be 500 * 10^6 hours, or 57,000 years!
- This is the basic idea behind disk ***mirroring***, in which a system contains identical data on two or more disks.
  - Note that a power failure during a write operation could cause both disks to contain corrupt data, if both disks were writing simultaneously at the time of the power failure. One solution is to write to the two disks in series, so that they will not both become corrupted (at least not in the same way) by a power failure. And alternate solution involves non-volatile RAM as a write cache, which is not lost in the event of a power failure and which is protected by error-correcting codes.

RAID Levels

Mirroring provides reliability but is expensive; Striping improves performance, but does not improve reliability. Accordingly there are a number of different schemes that combine the principals of mirroring and striping in different ways, in order to balance reliability versus performance versus cost. These are described by different RAID levels, as follows: (In the diagram that follows, "C" indicates a copy, and "P" indicates parity, i.e. checksum bits.)

Raid Level 0 - This level includes striping only, with no mirroring.

Raid Level 1 - This level includes mirroring only, no striping.

Raid Level 2 - This level stores error-correcting codes on additional disks, allowing for any damaged data to be reconstructed by subtraction from the remaining undamaged data. Note that this scheme requires only three extra disks to protect 4 disks worth of data, as opposed to full mirroring. (The number of disks required is a function of the error-correcting algorithms, and the means by which the particular bad bit(s) is(are) identified.)

Raid Level 3 - This level is like level 2, except that it takes advantage of the fact that each disk is still doing its own error-detection, so that when an error occurs, there is no question about which disk in the array has the bad data. As a result a single parity bit is all that is needed to recover the lost data from an array of disks. Level 3 also includes striping, which improves performance. The downside with the parity approach is that every disk must take part in every disk access, and the parity bits must be constantly calculated and checked, reducing performance. Hardware-level parity calculations and NVRAM cache can help with both of those issues. In practice level 3 is greatly preferred over level 2.

Raid Level 4 - This level is like level 3, employing block-level striping instead of bit-level striping. The benefits are that multiple blocks can be read independently, and changes to a block only require writing two blocks (data and parity) rather than involving all disks. Note that new disks can be added seamlessly to the system provided they are initialized to all zeros, as this does not affect the parity results.

Raid Level 5 - This level is like level 4, except the parity blocks are distributed over all disks, thereby more evenly balancing the load on the system. For any given block on the disk(s), one of the disks will hold the parity information for that block and the other N-1 disks will hold the data. Note that the same disk

cannot hold both data and parity for the same block, as both would be lost in the event of a disk crash.

Raid Level 6 - This level extends raid level 5 by storing multiple bits of error recovery codes, (such as the Reed-Solomon codes), for each bit position of data, rather than a single parity bit. In the example shown below 2 bits of ECC are stored for every 4 bits of data, allowing data recovery in the face of up to two simultaneous disk failures. Note that this still involves only 50% increase in storage needs, as opposed to 100% for simple mirroring which could only tolerate a single disk failure.

(a) RAID 0: non-redundant striping.

(b) RAID 1: mirrored disks.

(c) RAID 2: memory-style error-correcting codes.

(d) RAID 3: bit-interleaved parity.

(e) RAID 4: block-interleaved parity.

(f) RAID 5: block-interleaved distributed parity.

(g) RAID 6: P + Q redundancy.

Stable-Storage Implementation

- The concept of stable storage involves a storage medium in which data is ***never*** lost, even in the face of equipment failure in the middle of a write operation.
- To implement this requires two (or more) copies of the data, with separate failure modes.

An attempted disk write results in one of three possible outcomes:

1. The data is successfully and completely written.
2. The data is partially written, but not completely. The last block written may be garbled.
3. No writing takes place at all.

- Whenever an equipment failure occurs during a write, the system must detect it, and return the system back to a consistent state. To do this requires two physical blocks for every logical block, and the following procedure :

1. Write the data to the first physical block.
2. After step 1 had completed, then write the data to the second physical block.
3. Declare the operation complete only after both physical writes have completed successfully.

- During recovery the pair of blocks is examined.
  - If both blocks are identical and there is no sign of damage, then no further action is necessary.
  - If one block contains a detectable error but the other does not, then the damaged block is replaced with the good copy.
  - If neither block shows damage but the data in the blocks differ, then replace the data in the first block with the data in the second block.
- Because the sequence of operations described above is slow, stable storage usually includes NVRAM as a cache, and declares a write operation complete once it has been written to the NVRAM.

FILE SYSTEM INTERFACE

File

A file is a named collection of related information that is recorded on secondary storage such as magnetic disks, magnetic tapes and optical disks. In general, a file is a sequence of bits, bytes, lines or records whose meaning is defined by the files creator and user.

File Attributes

- Different OSes keep track of different file attributes, including:
  - Name - Some systems give special significance to names, and particularly extensions (.exe, .txt, etc.), and some do not. Some extensions may be of significance to the OS (.exe), and others only to certain applications (.jpg)
  - Identifier
  - Type - Text, executable, other binary, etc.
  - Location - on the hard drive.
  - Size
  - Protection
  - Time & Date
  - User ID

File Operations

The file ADT supports many common operations:

Creating a file

Writing a file

Reading a file

Repositioning within a file

Deleting a file

Truncating a file.

Most OSes require that files be opened before access and closed after all access is complete. Normally the programmer must open and close files explicitly, but some rare systems open the file automatically at first access. Information about currently open files is stored in an open file table, containing for example:

File pointer - records the current position in the file, for the next read or write access.

File-open count - How many times has the current file been opened (simultaneously by different processes) and not yet closed? When this counter reaches zero the file can be removed from the table.

Some systems provide support for file locking.

A shared lock is for reading only.

A exclusive lock is for writing as well as reading.

An advisory lock is informational only, and not enforced. (A "Keep Out" sign, which may be ignored.)

A mandatory lock is enforced. (A truly locked door.)

UNIX used advisory locks, and Windows uses mandatory locks.

File Types

- **Windows (and some other systems) use special file extensions to indicate the type of each file:**

file type	usual extension	function
executable	exe, com, bin or none	ready-to-run machine-language program
object	obj, o	compiled, machine language, not linked
source code	c, cc, java, perl, asm	source code in various languages
batch	bat, sh	commands to the command interpreter
markup	xml, html, tex	textual data, documents
word processor	xml, rtf, docx	various word-processor formats
library	lib, a, so, dll	libraries of routines for programmers
print or view	gif, pdf, jpg	ASCII or binary file in a format for printing or viewing
archive	rar, zip, tar	related files grouped into one file, sometimes compressed, for archiving or storage
multimedia	mpeg, mov, mp3, mp4, avi	binary file containing audio or A/V information

File Structure

- Some files contain an internal structure, which may or may not be known to the OS.
- For the OS to support file formats increases the size and complexity of the OS.

- UNIX treats all files as sequences of bytes, with no further consideration of the internal structure. (With the exception of executable binary programs, which it must know how to load and find the first executable statement, etc.)
- Macintosh files have two *forks* - a *resource fork*, and a *data fork*. The resource fork contains information relating to the UI, such as icons and button images, and can be modified independently of the data fork, which contains the code or data as appropriate.

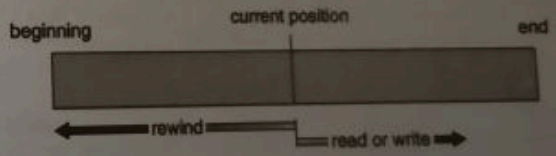
Internal File Structure

- Disk files are accessed in units of physical blocks, typically 512 bytes or some power-of-two multiple thereof. (Larger physical disks use larger block sizes, to keep the range of block numbers within the range of a 32-bit integer.)
- Internally files are organized in units of logical units, which may be as small as a single byte, or may be a larger size corresponding to some data record or structure size.
- The number of logical units which fit into one physical block determines its *packing*, and has an impact on the amount of internal fragmentation (wasted space) that occurs.
- As a rule, half a physical block is wasted for each file, and the larger the block sizes the more space is lost to internal fragmentation.

Access Methods

Sequential Access

- A sequential access file emulates magnetic tape operation, and generally supports a few operations:
  - read next - read a record and advance the tape to the next position.
  - write next - write a record and advance the tape to the next position.
  - rewind
  - skip n records - May or may not be supported. N may be limited to positive numbers, or may be limited to +/- 1.



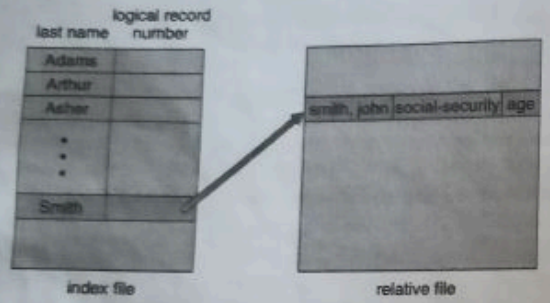
Direct Access

- Jump to any record and read that record. Operations supported include:
  - read n - read record number n. (Note an argument is now required.)
  - write n - write record number n. (Note an argument is now required.)
  - jump to record n - could be 0 or the end of file.
  - Query current record - used to return back to this record later.
  - Sequential access can be easily emulated using direct access. The inverse is complicated and inefficient.

sequential access	implementation for direct access
reset	cp = 0;
read_next	read cp; cp = cp + 1;
write_next	write cp; cp = cp + 1;

Other Access Methods

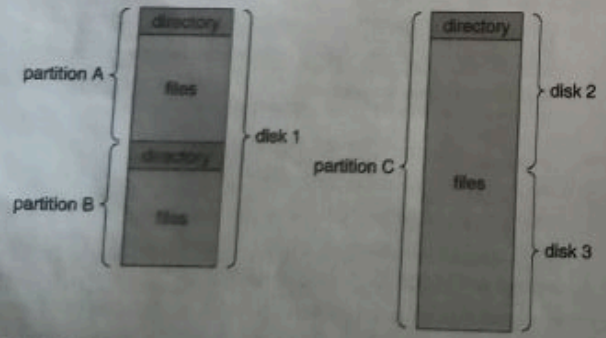
- An indexed access scheme can be easily built on top of a direct access system. Very large files may require a multi-tiered indexing scheme, i.e. indexes of indexes.



DIRECTORY STRUCTURE

Storage Structure

- A disk can be used in its entirety for a file system.
- Alternatively, a physical disk can be broken up into multiple *partitions, slices, or mini-disks*, each of which becomes a virtual disk and can have its own filesystem.
- Or, multiple physical disks can be combined into one *volume*, i.e. a larger virtual disk, with its own filesystem spanning the physical disks.



Single Level Directory

The simplest method is to have one big list of all the files on the disk. The entire system will contain only one directory which is supposed to mention all the files present in the file system. The directory contains one entry per each file present on the file system.

Single Level Directory

Advantages

1. Implementation is very simple.
2. If the sizes of the files are very small, then the searching becomes faster.
3. File creation, searching, deletion is very simple since we have only one directory.

Disadvantages

1. We cannot have two files with the same name.
2. The directory may be very big therefore searching for a file may take so much time.
3. Protection cannot be implemented for multiple users.
4. There are no ways to group same kind of files.
5. Choosing the unique name for every file is a bit complex and limits the number of files in the system because most of the Operating System limits the number of characters used to construct the file name.

Two-Level Directory

Each user gets their own directory space.

File names only need to be unique within a given user's directory.

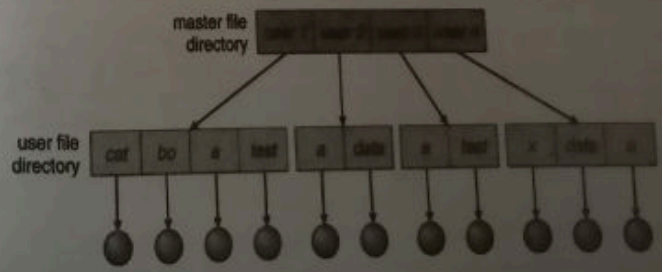
A master file directory is used to keep track of each users directory, and must be maintained when users are added to or removed from the system.

A separate directory is generally needed for system (executable) files.

Systems may or may not allow users to access other directories besides their own

If access to other directories is allowed, then provision must be made to specify the directory being accessed.

If access is denied, then special consideration must be made for users to run programs located in system directories. A search path is the list of directories in which to search for executable programs, and can be set uniquely for each user.



Tree-Structured Directories

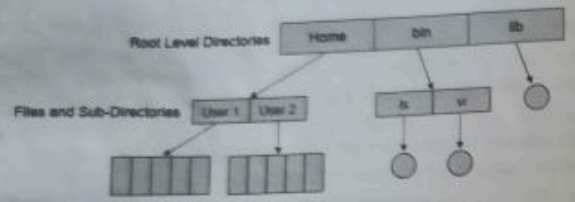
An obvious extension to the two-tiered directory structure, and the one with which we are all most familiar.

Each user / process has the concept of a current directory from which all (relative) searches take place.

Files may be accessed using either absolute pathnames (relative to the root of the tree) or relative pathnames (relative to the current directory.)

Directories are stored the same as any other file in the system, except there is a bit that identifies them as directories, and they have some special structure that the OS understands.

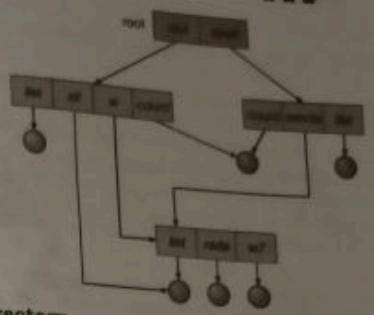
One question for consideration is whether to allow the removal of directories that are not empty - Windows requires that directories be emptied first, and UNIX provides an option for deleting entire sub-trees.



The Structured Directory System

Acyclic-Graph Directories

- When the same files need to be accessed in more than one place in the directory structure (e.g. because they are being shared by more than one user / process), it can be useful to provide an acyclic-graph structure. (Note the *directed* arcs from parent to child.)
- UNIX provides two types of *links* for implementing the acyclic-graph structure. (See "man ln" for more details.)
  - A *hard link* (usually just called a link) involves multiple directory entries that both refer to the same file. Hard links are only valid for ordinary files in the same filesystem.
  - A *symbolic link*, that involves a special file, containing information about where to find the linked file. Symbolic links may be used to link directories and/or files in other filesystems, as well as ordinary files in the current filesystem.
- Windows only supports symbolic links, termed *shortcuts*.
- Hard links require a *reference count*, or *link count* for each file, keeping track of how many directory entries are currently referring to this file. Whenever one of the references is removed the link count is reduced, and when it reaches zero, the disk space can be reclaimed.
- For symbolic links there is some question as to what to do with the symbolic links when the original file is moved or deleted :
  - One option is to find all the symbolic links and adjust them also.
  - Another is to leave the symbolic links dangling and discover that they are no longer valid the next time they are used.
  - What if the original file is removed, and replaced with another file having the same name before the symbolic link is next used?

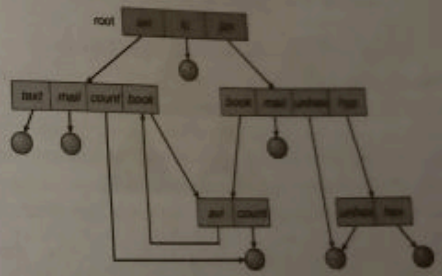


General Graph Directory

If cycles are allowed in the graphs, then several problems can arise:

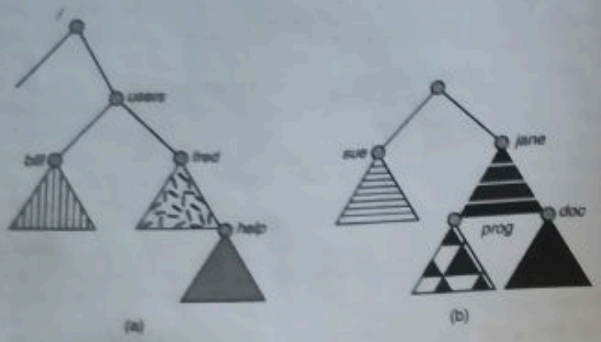
Search algorithms can go into infinite loops. One solution is to not follow links in search algorithms. (Or not to follow symbolic links, and to only allow symbolic links to refer to directories.)

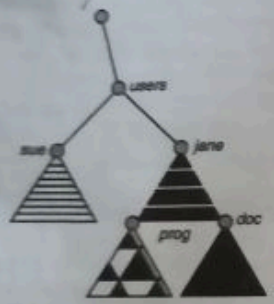
Sub-trees can become disconnected from the rest of the tree and still not have their reference counts reduced to zero. Periodic garbage collection is required to detect and resolve this problem.



File-System Mounting

- The basic idea behind mounting file systems is to combine multiple file systems into one large tree structure.
- The mount command is given a filesystem to mount and a **mount point** (directory) on which to attach it.
- Once a file system is mounted onto a mount point, any further references to that directory refer to the root of the mounted file system.
- Any files (or sub-directories) that had been stored in the mount point directory prior to mounting the new filesystem are now hidden by the mounted filesystem and are no longer available. For this reason, some systems only allow mounting onto empty directories.
- Filesystems can only be mounted by root, unless root has previously configured certain filesystems to be mountable onto certain pre-determined mount points. (E.g. root may allow users to mount floppy filesystems to /mnt or something like it) Anyone can run the mount command to see what filesystems are currently mounted.
- Filesystems may be mounted read-only, or have other restrictions imposed.





- The traditional Windows OS runs an extended two-tier directory structure, where the first tier of the structure separates volumes by drive letters, and a tree structure is implemented below that level.
- Macintosh runs a similar system, where each new volume that is found is automatically mounted and added to the desktop when it is found.
- More recent Windows systems allow filesystems to be mounted to any directory in the filesystem, much like UNIX.

File Sharing

Multiple Users

- On a multi-user system, more information needs to be stored for each file:
  - The owner (user) who owns the file, and who can control its access.
  - The group of other user IDs that may have some special access to the file.
  - What access rights are afforded to the owner (User), the Group, and to the rest of the world (the universe, a.k.a. Others.)
  - Some systems have more complicated access control, allowing or denying specific accesses to specifically named users or groups.

Remote File Systems

- The advent of the Internet introduces issues for accessing files stored on remote computers
  - The original method was ftp, allowing individual files to be transported across systems as needed. Ftp can be either account and password controlled, or ***anonymous***, not requiring any user name or password.
  - Various forms of ***distributed file systems*** allow remote file systems to be mounted onto a local directory structure, and accessed using normal file access commands. (The actual files are still transported across the network as needed, possibly using ftp as the underlying transport mechanism.)
  - The WWW has made it easy once again to access files on remote systems without mounting their filesystems, generally using (anonymous) ftp as the underlying file transport mechanism.

The Client-Server Model

- When one computer system remotely mounts a filesystem that is physically located on another system, the system which physically owns the files acts as a ***server***, and the system which mounts them is the ***client.***
- User IDs and group IDs must be consistent across both systems for the system to work properly.
- The same computer can be both a client and a server. (E.g. cross-linked file systems.)
- There are several security concerns involved in this model:
  - Servers commonly restrict mount permission to certain trusted systems only. Spoofing (a computer pretending to be a different computer) is a potential security risk.
  - Servers may restrict remote access to read-only.
  - Servers restrict which filesystems may be remotely mounted. Generally, the information within those subsystems is limited, relatively public, and protected by frequent backups.
- The NFS (Network File System) is a classic example of such a system.

Distributed Information Systems

- The ***Domain Name System, DNS,*** provides for a unique naming system across all the Internet.
- Domain names are maintained by the ***Network Information System, NIS,*** which unfortunately has several security issues. NIS+ is a more secure version but has not yet gained the same widespread acceptance as NIS.
- Microsoft's ***Common Internet File System, CIFS***, establishes a ***network login*** for each user on a networked system with shared file access. Older Windows systems used ***domains***, and newer systems (XP, 2000), use ***active directories.*** Usernames must match across the network for this system to be valid.
- A newer approach is the ***Lightweight Directory-Access Protocol, LDAP,*** which provides a ***secure single sign-on*** for all users to access all resources on a network. This is a secure system which is gaining in popularity, and which has the maintenance advantage of combining authorization information in one central location.

Failure Modes

- When a local disk file is unavailable, the result is generally known immediately, and is generally non-recoverable. The only reasonable response is for the response to fail.
- However, when a remote file is unavailable, there are many possible reasons, and whether it is unrecoverable is not readily apparent. Hence most remote access systems allow for blocking or delayed response, in the hopes that the remote system (or the network) will come back up eventually.

Protection

- Files must be kept safe for reliability (against accidental damage), and protection (against deliberate malicious access.) The former is usually managed with backup copies. This section discusses the latter.
- One simple protection scheme is to remove all access to a file. However this makes the file unusable, so some sort of controlled access must be arranged.

Types of Access

- The following low-level operations are often controlled:
  - Read - View the contents of the file
  - Write - Change the contents of the file.
  - Execute - Load the file onto the CPU and follow the instructions contained therein.
  - Append - Add to the end of an existing file.
  - Delete - Remove a file from the system.
  - List -View the name and other attributes of files on the system.
- Higher-level operations, such as copy, can generally be performed through combinations of the above.

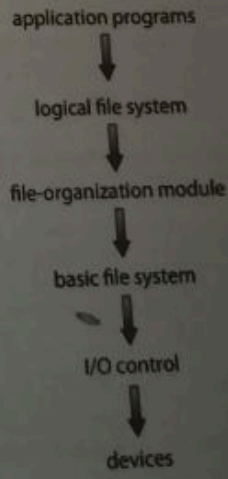
Access Control

- One approach is to have complicated ***Access Control Lists, ACL,*** which specify exactly what access is allowed or denied for specific users or groups.
  - The AFS uses this system for distributed access.
  - Control is very finely adjustable, but may be complicated, particularly when the specific users involved are unknown. (AFS allows some wild cards, so for example all users on a certain remote system may be trusted, or a given username may be trusted when accessing from any remote system.)
- UNIX uses a set of 9 access control bits, in three groups of three. These correspond to R, W, and X permissions for each of the Owner, Group, and Others. The RWX bits control the following privileges for ordinary files and directories:

File-System Structure

- Hard disks have two important properties that make them suitable for secondary storage of files in file systems: (1) Blocks of data can be rewritten in place, and (2) they are direct access, allowing any block of data to be accessed with only (relatively) minor movements of the disk heads and rotational latency.
- Disks are usually accessed in physical blocks, rather than a byte at a time. Block sizes may range from 512 bytes to 4K or larger.
- File systems organize storage on disk drives, and can be viewed as a layered design :

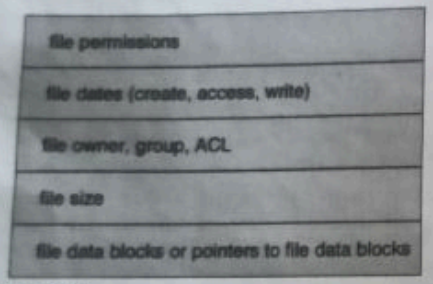
  - At the lowest layer are the physical devices, consisting of the magnetic media, motors & controls, and the electronics connected to them and controlling them. Modern disk put more and more of the electronic controls directly on the disk drive itself, leaving relatively little work for the disk controller card to perform.
  - ***I/O Control*** consists of ***device drivers***, special software programs (often written in assembly) which communicate with the devices by reading and writing special codes directly to and from memory addresses corresponding to the controller card's registers. Each controller card (device) on a system has a different set of addresses (registers, a.k.a. ***ports***) that it listens to, and a unique set of command codes and results codes that it understands.
  - The ***basic file system*** level works directly with the device drivers in terms of retrieving and storing raw blocks of data, without any consideration for what is in each block. Depending on the system, blocks may be referred to with a single block number, (e.g. block # 234234), or with head-sector-cylinder combinations.
  - The ***file organization module*** knows about files and their logical blocks, and how they map to physical blocks on the disk. In addition to translating from logical to physical blocks, the file organization module also maintains the list of free blocks, and allocates free blocks to files as needed.
  - The ***logical file system*** deals with all of the meta data associated with a file (UID, GID, mode, dates, etc), i.e. everything about the file except the data itself. This level manages the directory structure and the mapping of file names to ***file control blocks, FCBs***, which contain all of the meta data as well as block number information for finding the data on the disk.
- The layered approach to file systems means that much of the code can be used uniformly for a wide variety of different file systems, and only certain layers need to be filesystem specific. Common file systems in use include the UNIX file system, UFS, the Berkeley Fast File System, FFS, Windows systems FAT, FAT32, NTFS, CD-ROM systems ISO 9660, and for Linux the extended file systems ext2 and ext3 (among 40 others supported.)



File-System Implementation

Overview

- File systems store several important data structures on the disk:
  - A *boot-control block*, (per volume) a.k.a. the ***boot block*** in UNIX or the ***partition boot sector*** in Windows contains information about how to boot the system off of this disk. This will generally be the first sector of the volume if there is a bootable system loaded on that volume, or the block will be left vacant otherwise.
  - A ***volume control block,*** (per volume) a.k.a. the ***master file table*** in UNIX or the ***superblock*** in Windows, which contains information such as the partition table, number of blocks on each filesystem, and pointers to free blocks and free FCB blocks.
  - A directory structure (per file system), containing file names and pointers to corresponding FCBs. UNIX uses inode numbers, and NTFS uses a ***master file table.***
  - The ***File Control Block, FCB,*** (per file) containing details about ownership, size, permissions, dates, etc. UNIX stores this information in inodes, and NTFS in the master file table as a relational database structure.



A typical file-control block

- **There are also several key data structures stored in memory:**
  - An in-memory mount table.
  - An in-memory directory cache of recently accessed directory information.
  - *A system-wide open file table,* containing a copy of the FCB for every currently open file in the system, as well as some other related information.
  - *A per-process open file table,* containing a pointer to the system open file table as well as some other information. (For example the current file position pointer may be either here or in the system file table, depending on the implementation and whether the file is being shared or not.)
  - When a new file is created, a new FCB is allocated and filled out with important information regarding the new file. The appropriate directory is modified with the new file name and FCB information.
  - When a file is accessed during a program, the open( ) system call reads in the FCB information from disk, and stores it in the system-wide open file table. An entry is added to the per-process open file table referencing the system-wide table, and an index into the per-process table is returned by the open( ) system call. UNIX refers to this index as a *file descriptor*, and Windows refers to it as a *file handle*.

  - If another process already has a file open when a new request comes in for the same file, and it is sharable, then a counter in the system-wide table is incremented and the per-process table is adjusted to point to the existing entry in the system-wide table.
  - When a file is closed, the per-process table entry is freed, and the counter in the system-wide table is decremented. If that counter reaches zero, then the system wide table is also freed. Any data currently stored in memory cache for this file is written out to disk if necessary.

Partitions and Mounting

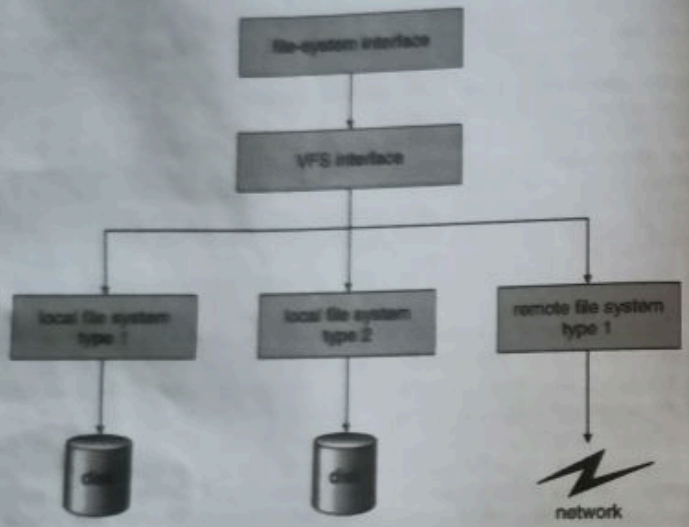
- Physical disks are commonly divided into smaller units called partitions. They can also be combined into larger units, but that is most commonly done for RAID installations.
- Partitions can either be used as raw devices (with no structure imposed upon them), or they can be formatted to hold a filesystem (i.e. populated with FCBs and initial directory structures as appropriate.) Raw partitions are generally used for swap space, and may also be used for certain programs such as databases that choose to manage their own disk storage system. Partitions containing fileaystems can generally only be accessed using the file system structure by ordinary users, but can often be accessed as a raw device also by root.
- The boot block is accessed as part of a raw partition, by the boot program prior to any operating system being loaded. Modern boot programs understand multiple OSes and filesystem formats, and can give the user a choice of which of several available systems to boot.
- The *root partition* contains the OS kernel and at least the key portions of the OS needed to complete the boot process. At boot time the root partition is mounted, and control is transferred from the boot program to the kernel found there. (Older systems required that the root partition lie completely within the first 1024 cylinders of the disk, because that was as far as the boot program could reach. Once the kernel had control, then it could access partitions beyond the 1024 cylinder boundary.)
- Continuing with the boot process, additional filesystems get mounted, adding their information into the appropriate mount table structure. As a part of the mounting process the file systems may be checked for errors or inconsistencies, either because they are flagged as not having been closed properly the last time they were used, or just for general principals. Filesystems may be mounted either automatically or manually. In UNIX a mount point is indicated by setting a flag in the in-memory copy of the inode, so all future references to that
- inode get re-directed to the root directory of the mounted filesystem.

Virtual File Systems

- *Virtual File Systems, VFS,* provide a common interface to multiple different filesystem types. In addition, it provides for a unique identifier (vnode) for files across the entire space, including across all filesystems of different types. (UNIX inodes are unique only across a single filesystem, and certainly do not carry across networked file systems.)
- The VFS in Linux is based upon four key object types.
  - The *inode* object, representing an individual file
  - The *file* object, representing an open file.

- The *superblock* object, representing a filesystem.
- The *dentry* object, representing a directory entry.

- Linux VFS provides a set of common functionalities for each filesystem, using function pointers accessed through a table. The same functionality is accessed through the same table position for all filesystem types, though the actual functions pointed to by the pointers may be filesystem specific. See /usr/include/linux/fs.h for full details. Common operations provided include open(), read( ), write( ), and mmap( ).



Directory Implementation

- Directories need to be fast to search, insert, and delete, with a minimum of wasted disk space.

Linear List

- A linear list is the simplest and easiest directory structure to set up, but it does have some drawbacks.
- Finding a file (or verifying one does not already exist upon creation) requires a linear search.
- Deletions can be done by moving all entries, flagging an entry as deleted, or by moving the last entry into the newly vacant position.
- Sorting the list makes searches faster, at the expense of more complex insertions and deletions.
- A linked list makes insertions and deletions into a sorted list easier, with overhead for the links.
- More complex data structures, such as B-trees, could also be considered.

Hash Table

- A hash table can also be used to speed up searches.
- Hash tables are generally implemented ***in addition to*** a linear or other structure

Allocation Methods

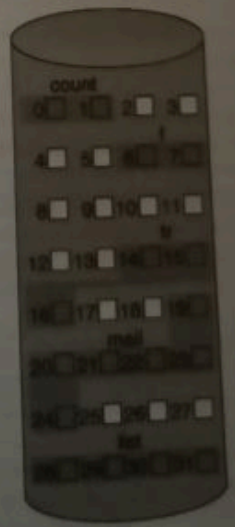
There are three major methods of storing files on disks: contiguous, linked, and indexed.

Contiguous Allocation

Contiguous Allocation requires that all blocks of a file be kept together contiguously.

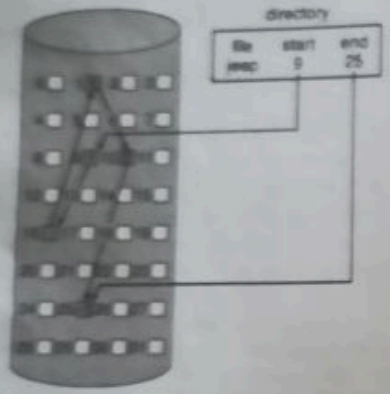
Performance is very fast, because reading successive blocks of the same file generally requires no movement of the disk heads, or at most one small step to the next adjacent cylinder.

- Storage allocation involves the same issues discussed earlier for the allocation of contiguous blocks of memory (first fit, best fit, fragmentation problems, etc.) The distinction is that the high time penalty required for moving the disk heads from spot to spot may now justify the benefits of keeping files contiguously when possible.
- (Even file systems that do not by default store files contiguously can benefit from certain utilities that compact the disk and make all files contiguous in the process.)
- Problems can arise when files grow, or if the exact size of a file is unknown at creation time:
  - Over-estimation of the file's final size increases external fragmentation and wastes disk space.
  - Under-estimation may require that a file be moved or a process aborted if the file grows beyond its originally allocated space.
  - If a file grows slowly over a long time period and the total final space must be allocated initially, then a lot of space becomes unusable before the file fills the space.
- A variation is to allocate file space in large contiguous chunks, called ***extents.*** When a file outgrows its original extent, then an additional one is allocated. For example an extent may be the size of a complete track or even cylinder, aligned on an appropriate track or cylinder boundary.) The high-performance files system Veritas uses extents to optimize performance.



Linked Allocation

- Disk files can be stored as linked lists, with the expense of the storage space consumed by each link. (E.g. a block may be 508 bytes instead of 512.)
- Linked allocation involves no external fragmentation, does not require pre-known file sizes, and allows files to grow dynamically at any time.
- Unfortunately linked allocation is only efficient for sequential access files, as random access requires starting at the beginning of the list for each new location access.
- Allocating *clusters* of blocks reduces the space wasted by pointers, at the cost of internal fragmentation.
- Another big problem with linked allocation is reliability if a pointer is lost or damaged. Doubly linked lists provide some protection, at the cost of additional overhead and wasted space.



Indexed Allocation

- *Indexed Allocation* combines all of the indexes for accessing each file into a common block (for that file), as opposed to spreading them all over the disk or storing them in a FAT table.

Some disk space is wasted (relative to linked lists or FAT tables) because an entire index block must be allocated for each file, regardless of how many data blocks the file contains. This leads to questions of how big the index block should be, and how it should be implemented. There are several approaches:

Linked Scheme - An index block is one disk block, which can be read and written in a single disk operation. The first index block contains some header information, the first *N* block addresses, and if necessary a pointer to additional linked index blocks.

Multi-Level Index - The first index block contains a set of pointers to secondary index blocks, which in turn contain pointers to the actual data blocks.

Combined Scheme - This is the scheme used in UNIX inodes, in which the first 12 or so data block pointers are stored directly in the inode, and then singly, doubly, and triply indirect pointers provide access to more data blocks as needed. The advantage of this scheme is that for small files (which many are), the data blocks are readily accessible (up to 48K with 4K block sizes); files up to about

4144K (using 4K blocks) are accessible with only a single indirect block (which can be cached), and huge files are still accessible using a relatively small number of disk accesses (larger in theory than can be addressed by a 32-bit address, which is why some systems have moved to 64-bit file pointers.)

Free-Space Management

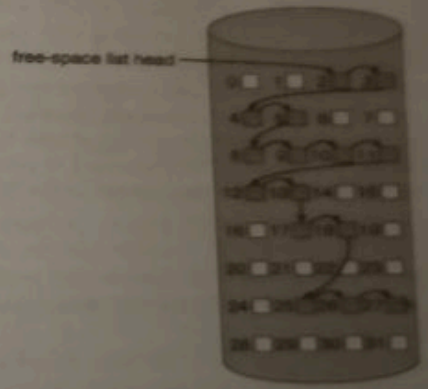
- Another important aspect of disk management is keeping track of and allocating free space.

Bit Vector

- One simple approach is to use a ***bit vector***, in which each bit represents a disk block, set to 1 if free or 0 if allocated.
- Fast algorithms exist for quickly finding contiguous blocks of a given size
- The down side is that a 40GB disk requires over 5MB just to store the bitmap. (For example.)

Linked List

- A linked list can also be used to keep track of all free blocks.
- Traversing the list and/or finding a contiguous block of a given size are not easy, but fortunately are not frequently needed operations. Generally the system just adds and removes single blocks from the beginning of the list.
- The FAT table keeps track of the free list as just one more linked list on the table.



Linked free-space list on disk.

Grouping

- A variation on linked list free lists is to use links of blocks of indices of free blocks. If a block holds up to N addresses, then the first block in the linked-list contains up to N-1 addresses of free blocks and a pointer to the next block of free addresses.

Counting

- When there are multiple contiguous blocks of free space then the system can keep track of the starting address of the group and the number of contiguous free blocks. As long as the average length of a contiguous group of free blocks is greater than two this offers a savings in space needed for the free list.

Space Maps

- Sun's ZFS file system was designed for HUGE numbers and sizes of files, directories, and even file systems.

- The resulting data structures could be VERY inefficient if not implemented carefully. For example, freeing up a 1 GB file on a 1 TB file system could involve updating thousands of blocks of free list bit maps if the file was spread across the disk.
- ZFS uses a combination of techniques, starting with dividing the disk up into (hundreds of) ***metaslabs*** of a manageable size, each having their own space map.
- Free blocks are managed using the counting technique, but rather than write the information to a table, it is recorded in a log-structured transaction record. Adjacent free blocks are also coalesced into a larger single free block.
- An in-memory space map is constructed using a balanced tree data structure, constructed from the log data.
- The combination of the in-memory tree and the on-disk log provide for very fast and efficient management of these very large files and free blocks.

NFS

- NFS stands for Network File System, a file system developed by Sun Microsystems, Inc. It is a client/server system that allows users to access files across a network and treat them as if they resided in a local file directory. For example, if you were using a computer linked to a second computer via NFS, you could access files on the second computer as if they resided in a directory on the first computer. This is accomplished through the processes of exporting (the process by which an NFS server provides remote clients with access to its files) and mounting (the process by which file systems are made available to the operating system and the user).
- The NFS protocol is designed to be independent of the computer, operating system, network architecture, and transport protocol. This means that systems using the NFS service may be manufactured by different vendors, use different operating systems, and be connected to networks with different architectures. These differences are transparent to the NFS application, and thus, the user.

The Mount Protocol

The NFS mount protocol is similar to the local mount protocol, establishing a connection between a specific local directory (the mount point) and a specific device from a remote system.

Each server maintains an export list of the local filesystems (directory sub-trees) which are exportable, who they are exportable to, and what restrictions apply (e.g. read-only access.)

The server also maintains a list of currently connected clients, so that they can be notified in the event of the server going down and for other reasons.

Automount and autounmount are supported.

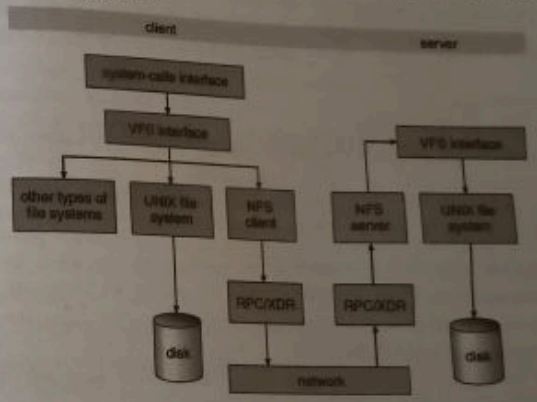
The NFS Protocol

- Implemented as a set of remote procedure calls (RPCs):
  - Searching for a file in a directory
  - Reading a set of directory entries
  - Manipulating links and directories
  - Accessing file attributes
  - Reading and writing files

These procedures can be invoked only after a file handle for the remotely mounted directory has been established. A prominent feature of NFS servers is that they are stateless. Servers do not maintain information about their clients from one access to another.

Three Major Layers of NFS Architecture

UNIX file-system interface (based on the open, read, write, and close calls, and file descriptors) v Virtual File System (VFS) layer – distinguishes local files from remote ones, and local files are further distinguished according to their file-system types λ The VFS activates file-system-specific operations to handle local requests according to their filesystem types λ Calls the NFS protocol procedures for remote requests v NFS service layer – bottom layer of the architecture λ Implements the NFS protocol



Path Name Translation : in NFS involves the parsing of a path name such as /usr/local/dir1/file. txt into separate directory entries, or components: (1) usr, (2) local, and (3) dir1. Path-name translation is done by breaking the path into component names and performing a separate NFS lookup call for every pair of component name and directory vnode. Once a n10unt point is crossed, every component lookup causes a separate RPC to the server

NFS Remote Operations v Nearly one-to-one correspondence between regular UNIX system calls and the NFS protocol RPCs (except opening and closing files) v NFS adheres to the remote-service paradigm, but employs buffering and caching techniques for the sake of performance v File-blocks cache – when a file is opened, the kernel checks with the remote server whether to fetch or revalidate the cached attributes λ Cached file blocks are used only if the corresponding cached attributes are up to date v File-attribute cache – the attribute cache is updated whenever new attributes arrive from the server v Clients do not free delayed-write blocks until the server confirms that the data have been written to disk.

QUESTIONS

1. List and explain different File attribute.
2. What different are the file types? Explain.
3. List and explain the various file operations?

4. Write a short note on access methods.
5. Explain the concept of file system mounting.
6. Explain file sharing.
7. Write a short note on different types of Directory.
8. Write a short note on Magnetic disks
9. Explain the concept of Disk formatting in detail.
10. Write a short note on Free-Space Management.
11. Explain Swapping.
12. Define Paging. Explain Page Fault.
13. Explain the structure of Page Table.
14. Write a short note of Thrashing.
15. Explain Paging.

Objective Questions

I. Multiple Choice Questions

1. Which of the following is the fastest means of memory access for CPU?
   a) Registers b) Cache
   c) Main memory d) Virtual Memory
2. CISC stands for _____
   a) Complex Information Sensed CPU
   b) Complex Instruction Set Computer
   c) Complex Intelligence Sensed CPU
   d) Complex Instruction Set CPU
3. Access in which records are accessed from and inserted into file, is classified as
   a) direct access
   b) sequential access
   c) random access
   d) duplicate access
4. To create a file
   a) allocate the space in file system
   b) make an entry for new file in directory
   c) allocate the space in file system & make an entry for new file in directory
   d) none of the mentioned
5. Mapping of file is managed by
   a) file metadata b) page table
   c) virtual memory d) file system
6. A file control block contains the information about
   a) file ownership
   b) file permissions
   c) location of file contents
   d) all of the mentioned

7. In the sequential access method, information in the file is processed
   a) one disk after the other, record access doesn't matter
   b) one record after the other
   c) one text document after the other
   d) none of the mentioned
8. A _____ is the basic element of data where individual field contains a single value, such as an employees last name, a data or the value of the sensor reading.
   a) field b) record
   c) file d) database
9. Some directory information is kept in main memory or cache to _____.
   a) fill up the cache
   b) increase free space in secondary storage
   c) decrease free space in secondary storage
   d) speed up access
10. Each set of operations for performing a specific task is a _____
    a) program b) code
    c) transaction d) all of the mentioned

[Ans.: (1 – a), (2 – b), (3 – b), (4 – c), (5 – a), (6 – d), (7 – b), (8 – a), (9 – d), (10 – c) **]**

II. True or False

1. Dynamic linking happens during execution time.
2. The logical and physical address generated while run-time address binding method are same.
3. The set of all physical address corresponding to the logical addresses in a Logical address in a Logical address space is called Physical Address Space –
4. Physical address is Computed by CPU.
5. Dynamic relocation is known as the memory which is changed and relocates by processes at the time of execution.
6. A process executes slower in contiguous memory location.
7. Paging is helping in faster data access.
8. The header and trailer contain information such as a sector number and an Error Correcting Code.
9. Direct access method allows file to be in order one record after the other.
10. Hash tables decreases directory search time.

[Ans.: True : 1, 3, 5, 7, 8, 10 **False :** 2, 4, 6, 9 **]**