LECTURE NOTES

ON

OPERATING SYSTEMS

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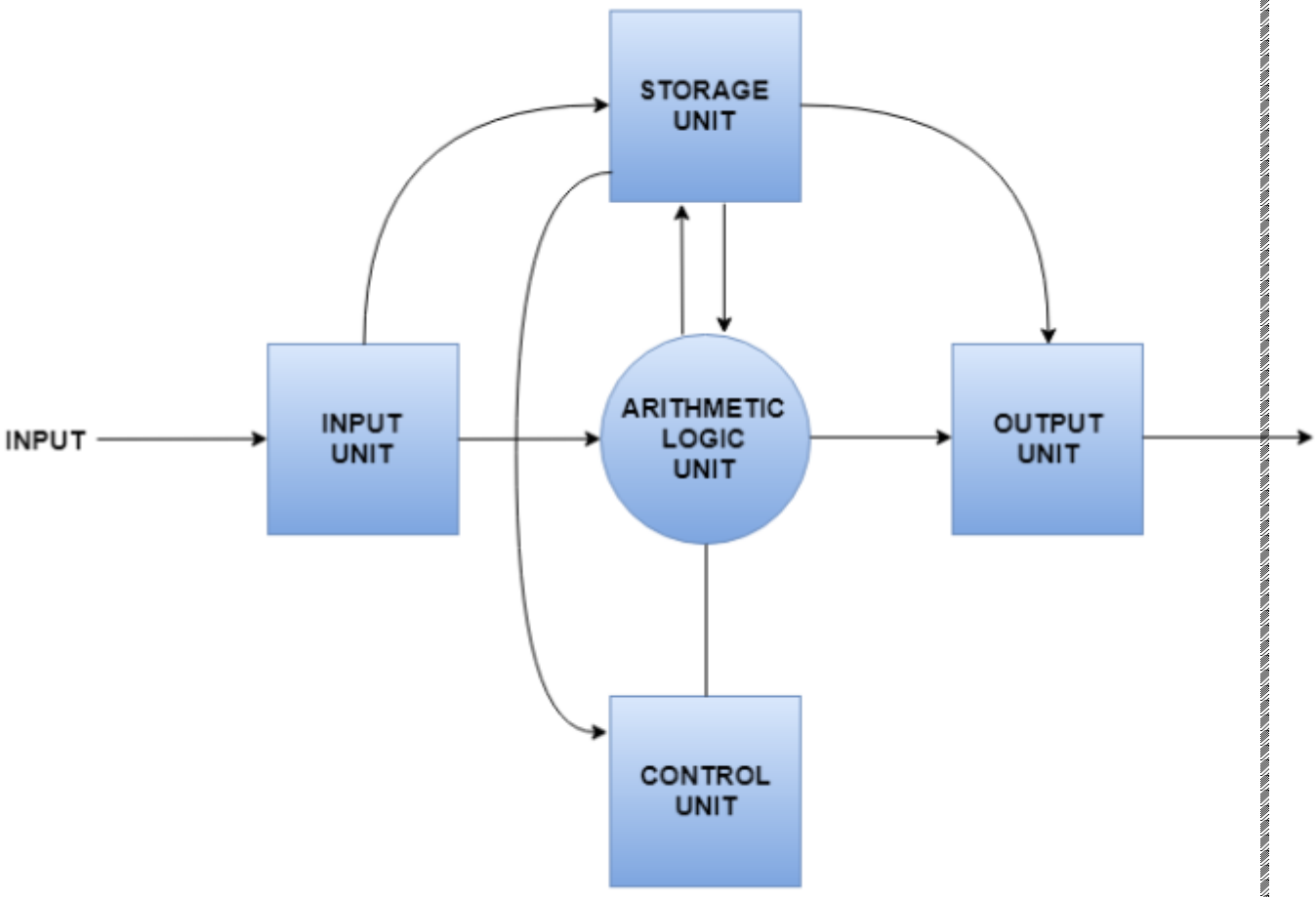
UNIT-1

OPERATING SYSTEM OVERVIEW

COMPUTER SYSTEM ARCHITECTURE:

A computer system is basically a machine that simplifies complicated tasks. It should maximize performance and reduce costs as well as power consumption.The different components in the Computer System Architecture are Input Unit, Output Unit, Storage Unit, Arithmetic Logic Unit, Control Unit etc.A diagram that shows the flow of data between these units is as follows:



The input data travels from input unit to ALU. Similarly, the computed data travels from ALU to output unit. The data constantly moves from storage unit to ALU and back again. This is because stored data is computed on before being stored again. The control unit controls all the other units as well as their data.

Details about all the computer units are:

1. **Input Unit**

   The input unit provides data to the computer system from the outside. So, basically it links the external environment with the computer. It takes data from the input devices, converts it into machine language and then loads it into the computer system. Keyboard, mouse etc. are the most commonly used input devices.

2. **Output Unit**

   The output unit provides the results of computer process to the users i.e it links the computer with the external environment. Most of the output data is the form of audio or video. The different output devices are monitors, printers, speakers, headphones etc.

3. **Storage Unit**

   Storage unit contains many computer components that are used to store data. It is traditionally divided into primary storage and secondary storage.Primary storage is also known as the main memory and is the memory directly accessible by the CPU. Secondary or external storage is not directly accessible by the CPU. The data from secondary storage needs to be brought into the primary storage before the CPU can use it. Secondary storage contains a large amount of data permanently.

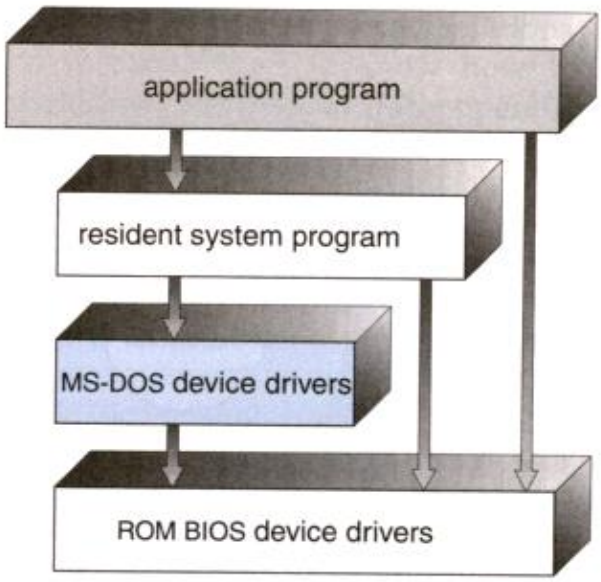
4. **Arithmetic Logic Unit**

   All the calculations related to the computer system are performed by the arithmetic logic unit. It can perform operations like addition, subtraction, multiplication, division etc. The control unit transfers data from storage unit to arithmetic logic unit when calculations need to be performed. The arithmetic logic unit and the control unit together form the central processing unit.

5. **Control Unit**

   This unit controls all the other units of the computer system and so is known as its central nervous system. It transfers data throughout the computer as required including from storage unit to central processing unit and vice versa. The control unit also dictates how the memory, input output devices, arithmetic logic unit etc. should behave.

Simple Structure

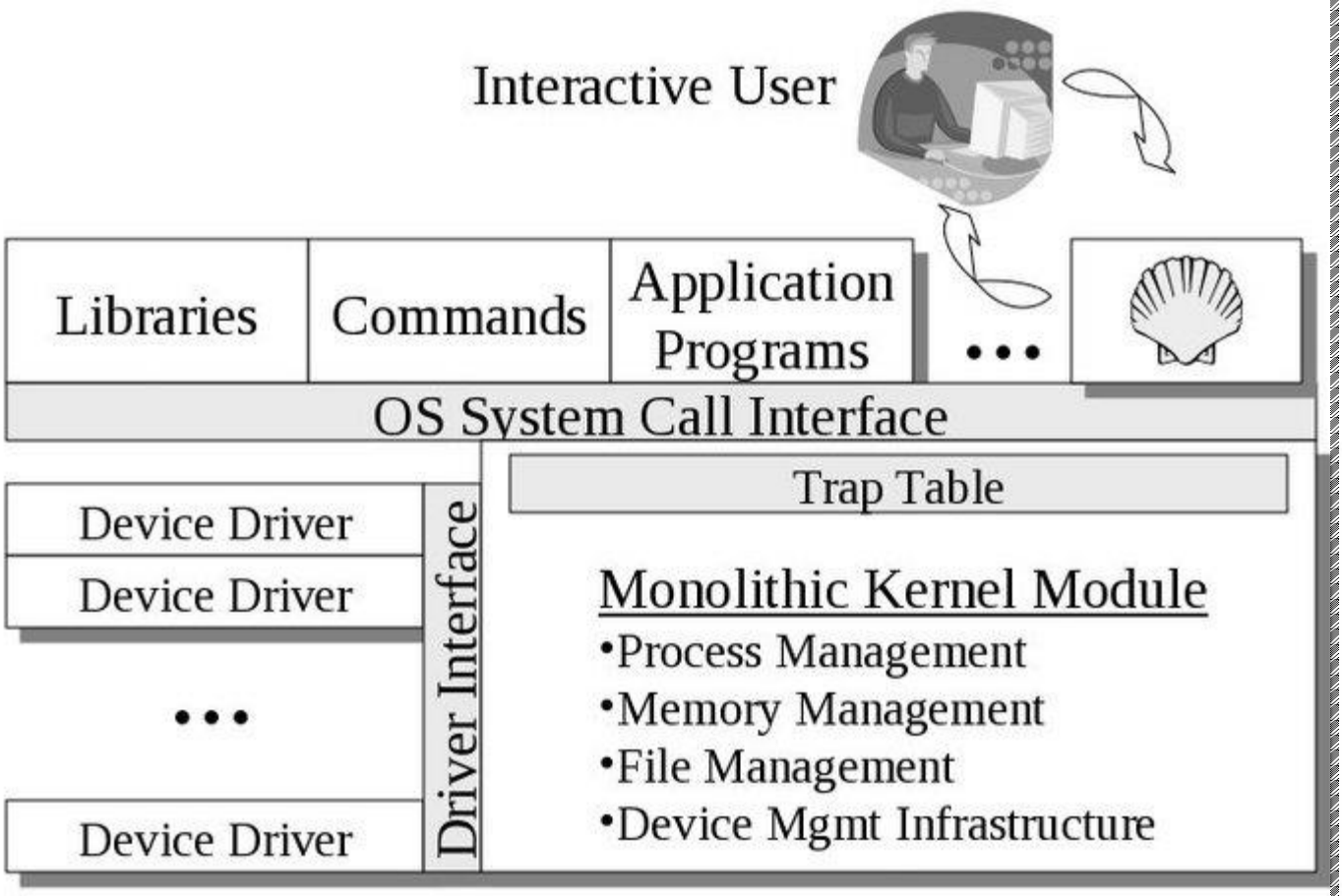


In MS-DOS, applications may bypass the operating system.

- Operating systems such as MS-DOS and the original UNIX did not have well-defined structures.
- There was no CPU Execution Mode (user and kernel), and so errors in applications could cause the whole system to crash.

Monolithic Approach

- Functionality of the OS is invoked with simple function calls within the kernel, which is one large program.
- Device drivers are loaded into the running kernel and become part of the kernel.

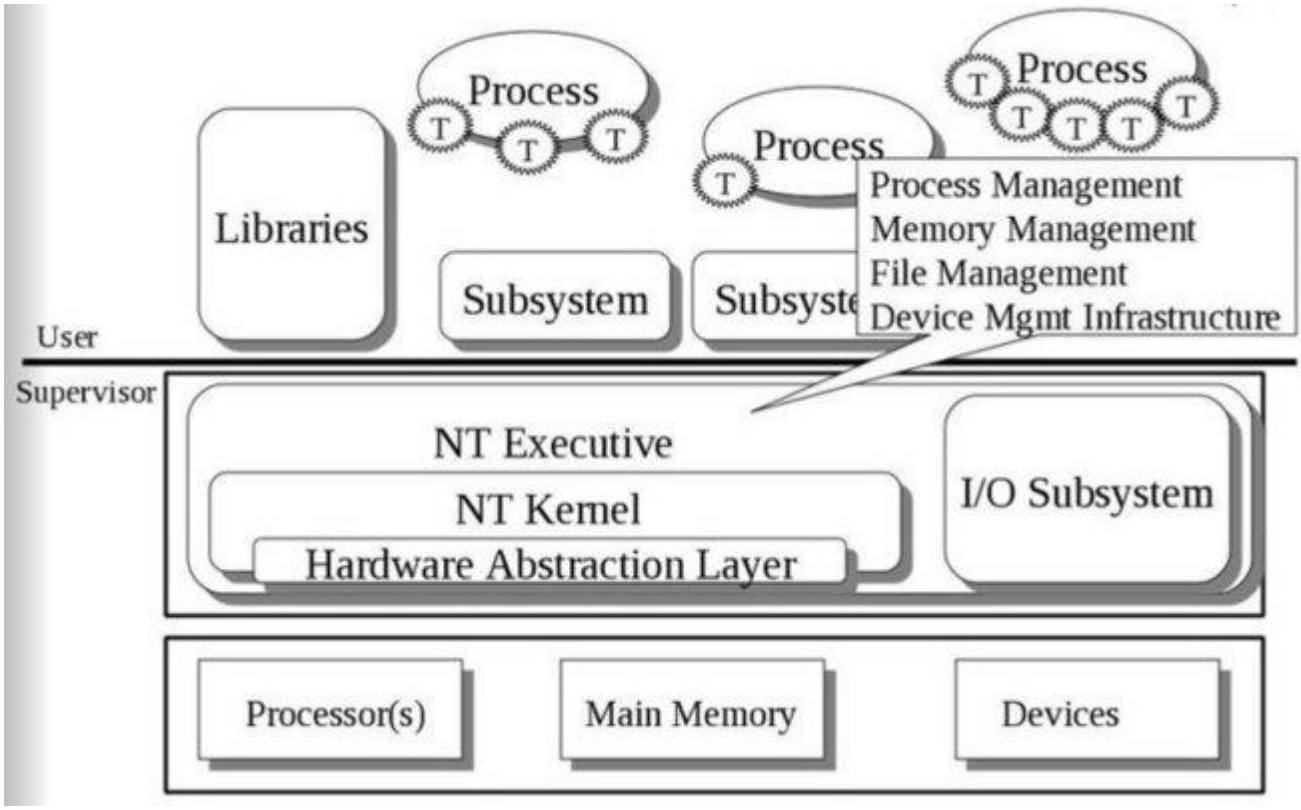


A monolithic kernel, such as Linux and other Unix systems.

Layered Approach

This approach breaks up the operating system into different layers.

- This allows implementers to change the inner workings, and increases modularity.
- As long as the external interface of the routines don't change, developers have more freedom to change the inner workings of the routines.
- With the layered approach, the bottom layer is the hardware, while the highest layer is the user interface.
    - The main *advantage* is simplicity of construction and debugging.
    - The main *difficulty* is defining the various layers.
    - The main *disadvantage* is that the OS tends to be less efficient than other implementations.



The Microsoft Windows NT Operating System. The lowest level is a monolithic kernel, but many OS components are at a higher level, but still part of the OS.

Microkernels

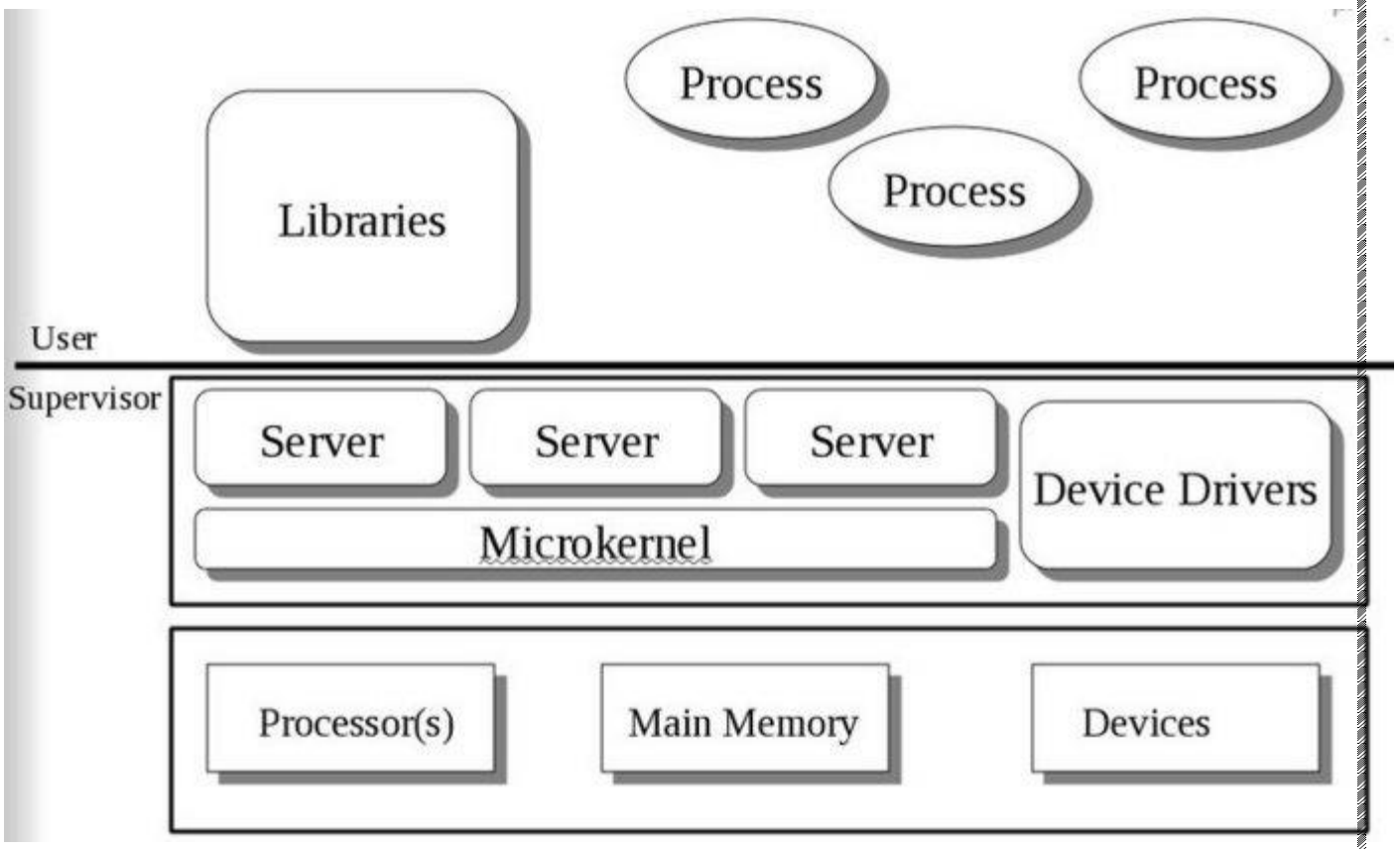
This structures the operating system by removing all nonessential portions of the kernel and implementing them as system and user level programs.

- Generally they provide minimal process and memory management, and a communications facility.
- Communication between components of the OS is provided by message passing.

The *benefits* of the microkernel are as follows:

- Extending the operating system becomes much easier.
- Any changes to the kernel tend to be fewer, since the kernel is smaller.
- The microkernel also provides more security and reliability.

Main *disadvantage* is poor performance due to increased system overhead from message passing.



A Microkernel architecture.

Operating – System Operations

Modern operating systems are interrupt driven.

- If there are no processes to execute,
- no I/O devices to service, and no users to whom to respond,

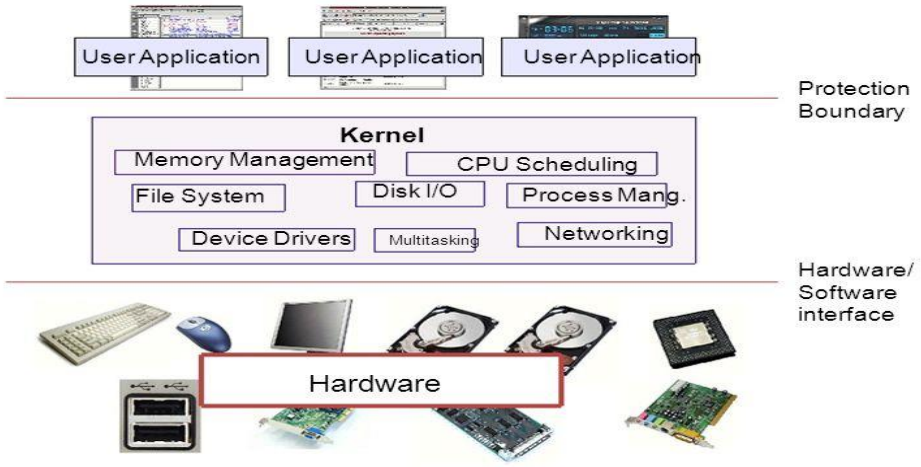
an operating system will sit quietly, waiting for something to happen. Events are almost always signaled by the occurrence of an **interrupt** or a **trap**.

Wondering!! what is trap ?

A trap (or an exception) is a software-generated interrupt caused either by an error (for example, division by zero or invalid memory access) or by a specific request from a user program that an operating-system service be performed.

- The interrupt-driven nature of an operating system defines that system's general structure. For each type of interrupt, separate segments of code in the operating system determine what action should be taken.
- An interrupt service routine is provided that is responsible for dealing with the interrupt. Since the operating system and the users share the hardware and software resources of the computer system, we need to make sure that an error in a user program could cause problems only for the one program that was running. With sharing, many processes could be adversely affected by a bug in one program. For example, if a process gets stuck in an infinite loop, this loop could prevent the correct operation of many other processes.
- More subtle errors can occur in a multiprogramming system, where one erroneous program might modify another program, the data of another program, or even the operating system itself. Without protection against these sorts of errors, either the computer must execute only one process at a time or all output must be suspect. A properly designed operating system must ensure that an incorrect (or malicious) program cannot cause other programs to execute incorrectly.

OS Operations a snapshot



Dual-Mode Operation

In order to ensure the proper execution of the operating system, we must be able to distinguish between the execution of operating-system code and user defined code. The approach taken by most computer systems is to provide hardware support that allows us to differentiate among various modes of execution. At the very least, we need two separate modes of operation: **user mode** and **kernel mode** (also called **supervisor mode**, **system mode**, or **privileged mode**). A bit, called the **mode bit**, is added to the hardware of the computer to indicate the current mode: kernel (0) or user (1). With the mode bit, we are able to distinguish between a task that is executed on behalf of the operating system and one that is executed on behalf of the user.

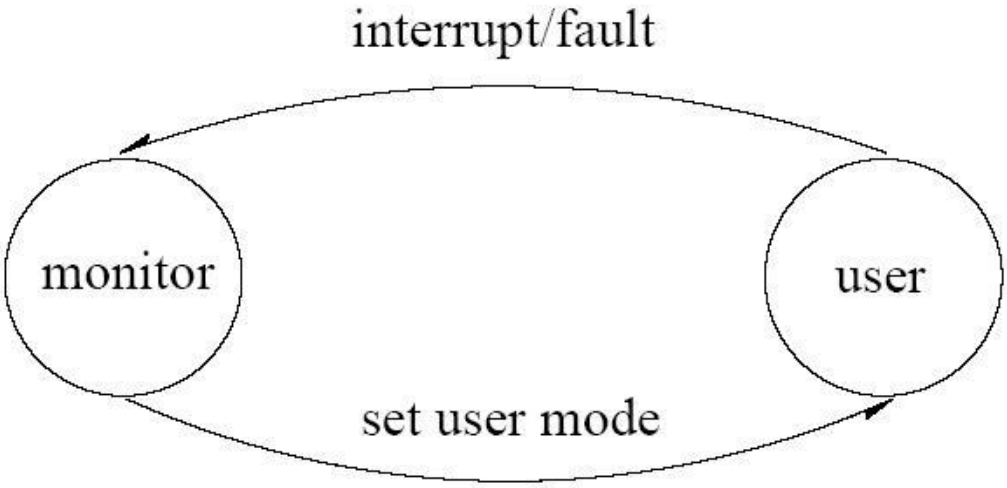
- When the computer system is executing on behalf of a user application, **the system is in user mode**.

- However, when a user application requests a service from the operating system (via a system call), it must **transition from user to kernel mode** to fulfill the request. As we shall see, this architectural enhancement is useful for many other aspects of system operation as well.
- At system boot time, the hardware starts in **kernel mode.**
- The operating system is then loaded and starts user applications in **user mode**.
- Whenever a trap or interrupt occurs, the hardware switches from **user mode to kernel mode** (that is, changes the state of the mode bit to 0).
- Thus, whenever the operating system gains control of the computer, it is in **kernel mode**.
- The system always **switches to user mode** (by setting the mode bit to 1) before passing control to a user program.

The dual mode of operation provides us with the means for protecting the operating system from errant users—and errant users from one another. We accomplish this protection by designating some of the machine instructions that may cause harm as privileged instructions. The hardware allows **privileged instructions** to be executed only in kernel mode. If an attempt is made to execute a privileged instruction in user mode, the hardware does not execute the instruction but rather treats it as illegal and traps it to the operating system. The instruction to switch to user mode is an example of a privileged instruction. Some other examples include I/O control, timer management, and interrupt management. As we shall see throughout the text, there are many additional privileged instructions.

We can now see the life cycle of instruction execution in a computer system. Initial control is within the operating system, where

instructions are executed in kernel mode. When control is given to a user application, the mode is set to user mode. Eventually, control is switched back to the operating system via an interrupt, a trap, or a system call. System calls provide the means for a user program to ask the operating system to perform tasks reserved for the operating system on the user program's behalf. A system call is invoked in a variety of ways, depending on the functionality provided by the underlying processor. In all forms, it is the method used by a process to request action by the operating system. A system call usually takes the form of a trap to a specific location in the interrupt vector. This trap can be executed by a generic trap instruction, although some systems (such as the MIPS R2000 family) have a specific syscall instruction.



When a system call is executed, it is treated by the hardware as a software interrupt. Control passes through the interrupt vector to a service routine in the operating system, and the mode bit is set to kernel mode. The system call service routine is a part of the operating system. The kernel examines the interrupting instruction to determine what system call has occurred; a parameter indicates what type of

service the user program is requesting. Additional information needed for the request may be passed in registers, on the stack, or in memory (with pointers to the memory locations passed in registers). The kernel verifies that the parameters are correct and legal, executes the request, and returns control to the instruction following the system call. The lack of a hardware-supported dual mode can cause serious shortcomings in an operating system.

For instance, MS-DOS was written for the Intel 8088 architecture, which has no mode bit and therefore no dual mode. A user program running awry can wipe out the operating system by writing over it with data; and multiple programs are able to write to a device at the same time, with possibly disastrous results. Recent versions of the Intel CPU, such is the Pentium, do provide dual-mode operation. Accordingly, most contemporary operating systems, such as Microsoft Windows 2000 and Windows XP, and Linux and Solaris for x86 systems, take advantage of this feature and provide greater protection for the operating system. Once hardware protection is in place, errors violating modes are detected by the hardware. These errors are normally handled by the operating system. If a user program fails in some way—such as by making an attempt either to execute an illegal instruction or to access memory that is not in the user's address space—then the hardware will trap to the operating system. The trap transfers control through the interrupt vector to the operating system, just as an interrupt does.

When a program error occurs, the operating system must terminate the program abnormally. This situation is handled by the same code as is a user-requested abnormal termination. An appropriate error message is given, and the memory of the program may be dumped. The memory dump is usually written to a file so that the user or

programmer can examine it and perhaps correct it and restart the program.

Timer

We must ensure that the operating system **maintains control over the CPU**. We must **prevent** a user program from **getting stuck in an infinite loop** or not calling system services and never returning control to the operating system. To accomplish this goal, we can use a timer. A timer can be set to interrupt the computer after a specified period. The period may be fixed (for example, 1/60 second) or variable (for example, from 1 millisecond to 1 second). A variable timer is generally implemented by a fixed-rate clock and a counter.

The operating system sets the counter. Every time the clock ticks, the counter is decremented. When the counter reaches 0, an interrupt occurs. For instance, a 10-bit counter with a 1-millisecond clock allows interrupts at intervals from 1 millisecond to 1,024 milliseconds, in steps of 1 millisecond. Before turning over control to the user, the operating system ensures that the timer is set to interrupt. If the timer interrupts, control transfers automatically to the operating system, which may treat the interrupt as a fatal error or may give the program more time. Clearly, instructions that modify the content of the timer are privileged. Thus, we can use the timer to prevent a user program from running too long. A simple technique is to initialize a counter with the amount of time that a program is allowed to run. A program with a 7-minute time limit, for example, would have its counter initialized to 420.

Every second, the timer interrupts and the counter is decremented by 1. As long as the counter is positive, control is returned to the user program. When the counter becomes negative, the operating system terminates the program for exceeding the assigned time limit.

Evolution of operating system:

Operating systems are there from the very first computer generation and they keep evolving with time. In this chapter, we will discuss some of the important types of operating systems which are most commonly used.

Batch operating system

The users of a batch operating system do not interact with the computer directly. Each user prepares his job on an off-line device like punch cards and submits it to the computer operator. To speed up processing, jobs with similar needs are batched together and run as a group. The programmers leave their programs with the operator and the operator then sorts the programs with similar requirements into batches.

The problems with Batch Systems are as follows –

- Lack of interaction between the user and the job.
- CPU is often idle, because the speed of the mechanical I/O devices is slower than the CPU.
- Difficult to provide the desired priority.

Time-sharing operating systems

Time-sharing is a technique which enables many people, located at various terminals, to use a particular computer system at the same time. Time-sharing or multitasking is a logical extension of multiprogramming. Processor's time which is shared among multiple users simultaneously is termed as time-sharing.

The main difference between Multiprogrammed Batch Systems and Time-Sharing Systems is that in case of Multiprogrammed batch systems, the

objective is to maximize processor use, whereas in Time-Sharing Systems, the objective is to minimize response time.

Multiple jobs are executed by the CPU by switching between them, but the switches occur so frequently. Thus, the user can receive an immediate response. For example, in a transaction processing, the processor executes each user program in a short burst or quantum of computation. That is, if **n**users are present, then each user can get a time quantum. When the user submits the command, the response time is in few seconds at most.

The operating system uses CPU scheduling and multiprogramming to provide each user with a small portion of a time. Computer systems that were designed primarily as batch systems have been modified to time-sharing systems.

Advantages of Timesharing operating systems are as follows –

- Provides the advantage of quick response.
- Avoids duplication of software.
- Reduces CPU idle time.

Disadvantages of Time-sharing operating systems are as follows –

- Problem of reliability.
- Question of security and integrity of user programs and data.
- Problem of data communication.

Distributed operating System

Distributed systems use multiple central processors to serve multiple real-time applications and multiple users. Data processing jobs are distributed among the processors accordingly.

The processors communicate with one another through various communication lines (such as high-speed buses or telephone lines). These

are referred as **loosely coupled systems** or distributed systems. Processors in a distributed system may vary in size and function. These processors are referred as sites, nodes, computers, and so on.

The advantages of distributed systems are as follows –

- With resource sharing facility, a user at one site may be able to use the resources available at another.
- Speedup the exchange of data with one another via electronic mail.
- If one site fails in a distributed system, the remaining sites can potentially continue operating.
- Better service to the customers.
- Reduction of the load on the host computer.
- Reduction of delays in data processing.

Network operating System

A Network Operating System runs on a server and provides the server the capability to manage data, users, groups, security, applications, and other networking functions. The primary purpose of the network operating system is to allow shared file and printer access among multiple computers in a network, typically a local area network (LAN), a private network or to other networks.

Examples of network operating systems include Microsoft Windows Server 2003, Microsoft Windows Server 2008, UNIX, Linux, Mac OS X, Novell NetWare, and BSD.

The advantages of network operating systems are as follows –

- Centralized servers are highly stable.
- Security is server managed.

- Upgrades to new technologies and hardware can be easily integrated into the system.
- Remote access to servers is possible from different locations and types of systems.

The disadvantages of network operating systems are as follows –

- High cost of buying and running a server.
- Dependency on a central location for most operations.
- Regular maintenance and updates are required.

Real Time operating System

A real-time system is defined as a data processing system in which the time interval required to process and respond to inputs is so small that it controls the environment. The time taken by the system to respond to an input and display of required updated information is termed as the **response time**. So in this method, the response time is very less as compared to online processing.

Real-time systems are used when there are rigid time requirements on the operation of a processor or the flow of data and real-time systems can be used as a control device in a dedicated application. A real-time operating system must have well-defined, fixed time constraints, otherwise the system will fail. For example, Scientific experiments, medical imaging systems, industrial control systems, weapon systems, robots, air traffic control systems, etc.

There are two types of real-time operating systems.

Hard real-time systems

Hard real-time systems guarantee that critical tasks complete on time. In hard real-time systems, secondary storage is limited or missing and the

data is stored in ROM. In these systems, virtual memory is almost never found.

Soft real-time systems

Soft real-time systems are less restrictive. A critical real-time task gets priority over other tasks and retains the priority until it completes. Soft real-time systems have limited utility than hard real-time systems. For example, multimedia, virtual reality, Advanced Scientific Projects like undersea exploration and planetary rovers, etc.

n Operating System provides services to both the users and to the programs.

- It provides programs an environment to execute.
- It provides users the services to execute the programs in a convenient manner.

Following are a few common services provided by an operating system –

- Program execution
- I/O operations
- File System manipulation
- Communication
- Error Detection
- Resource Allocation
- Protection

Program execution

Operating systems handle many kinds of activities from user programs to system programs like printer spooler, name servers, file server, etc. Each of these activities is encapsulated as a process.

A process includes the complete execution context (code to execute, data to manipulate, registers, OS resources in use). Following are the major activities of an operating system with respect to program management –

- Loads a program into memory.
- Executes the program.
- Handles program's execution.
- Provides a mechanism for process synchronization.
- Provides a mechanism for process communication.
- Provides a mechanism for deadlock handling.

I/O Operation

An I/O subsystem comprises of I/O devices and their corresponding driver software. Drivers hide the peculiarities of specific hardware devices from the users.

An Operating System manages the communication between user and device drivers.

- I/O operation means read or write operation with any file or any specific I/O device.
- Operating system provides the access to the required I/O device when required.

File system manipulation

A file represents a collection of related information. Computers can store files on the disk (secondary storage), for long-term storage purpose. Examples of storage media include magnetic tape, magnetic disk and

optical disk drives like CD, DVD. Each of these media has its own properties like speed, capacity, data transfer rate and data access methods.

A file system is normally organized into directories for easy navigation and usage. These directories may contain files and other directions. Following are the major activities of an operating system with respect to file management –

- Program needs to read a file or write a file.
- The operating system gives the permission to the program for operation on file.
- Permission varies from read-only, read-write, denied and so on.
- Operating System provides an interface to the user to create/delete files.
- Operating System provides an interface to the user to create/delete directories.
- Operating System provides an interface to create the backup of file system.

Communication

In case of distributed systems which are a collection of processors that do not share memory, peripheral devices, or a clock, the operating system manages communications between all the processes. Multiple processes communicate with one another through communication lines in the network.

The OS handles routing and connection strategies, and the problems of contention and security. Following are the major activities of an operating system with respect to communication –

- Two processes often require data to be transferred between them

- Both the processes can be on one computer or on different computers, but are connected through a computer network.
- Communication may be implemented by two methods, either by Shared Memory or by Message Passing.

Error handling

Errors can occur anytime and anywhere. An error may occur in CPU, in I/O devices or in the memory hardware. Following are the major activities of an operating system with respect to error handling –

- The OS constantly checks for possible errors.
- The OS takes an appropriate action to ensure correct and consistent computing.

Resource Management

In case of multi-user or multi-tasking environment, resources such as main memory, CPU cycles and files storage are to be allocated to each user or job. Following are the major activities of an operating system with respect to resource management –

- The OS manages all kinds of resources using schedulers.
- CPU scheduling algorithms are used for better utilization of CPU.

Protection

Considering a computer system having multiple users and concurrent execution of multiple processes, the various processes must be protected from each other's activities.

Protection refers to a mechanism or a way to control the access of programs, processes, or users to the resources defined by a computer system. Following are the major activities of an operating system with respect to protection –

- The OS ensures that all access to system resources is controlled.
- The OS ensures that external I/O devices are protected from invalid access attempts.
- The OS provides authentication features for each user by means of passwords.

User Operating System Interface -CLI

Command Line Interface (CLI) or command interpreter allows direct command entry
Sometimes implemented in kernel, sometimes by systems program
Sometimes multiple flavors implemented –shells
Primarily fetches a command from user and executes it
Sometimes commands built-in, sometimes just names of programs

User Operating System Interface -Gui

User-friendly desktop metaphor interface
Usually mouse, keyboard, and monitor
Iconsrepresent files, programs, actions, etc
Various mouse buttons over objects in the interface cause various actions (provide information, options, execute function, open directory (known as a folder)
Invented at Xerox PARC

Many systems now include both CLI and GUI interfaces

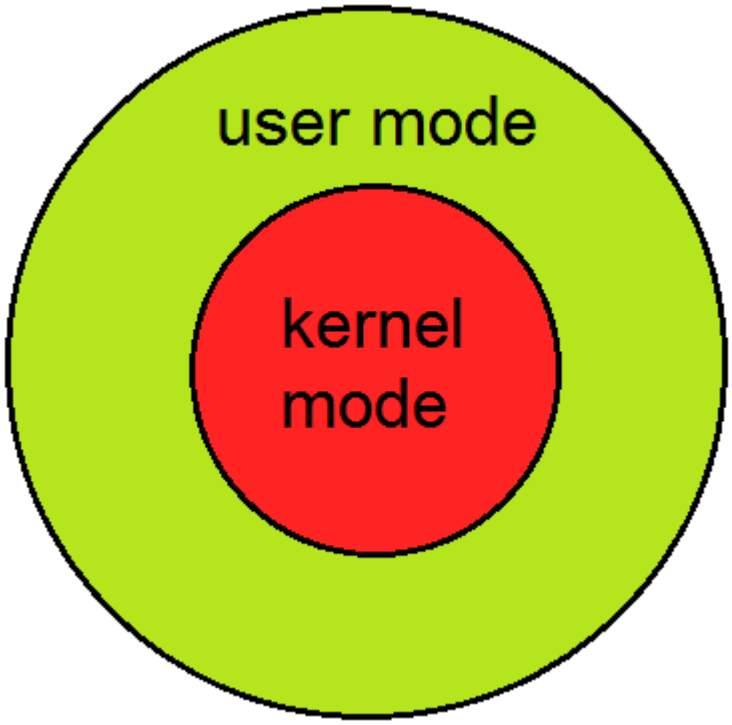
Microsoft Windows is GUI with CLI —commandǁ shell
Apple Mac OS X as —Aquaǁ GUI interface with UNIX kernel underneath and shells

available

Solaris is CLI with optional GUI interfaces (Java Desktop, KDE)

System calls:

o understand system calls, first one needs to understand the difference between **kernel mode** and **user mode** of a CPU. Every modern operating system supports these two modes.



Modes supported by the operating system

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.

System Call

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.

In a typical UNIX system, there are around 300 system calls. Some of them which are important ones in this context, are described below.

Fork()

The `fork()` system call is used to create processes. When a process (a program in execution) makes a `fork()` call, an exact copy of the process is created. Now there are two processes, one being the **parent** process and the other being the **child** process.

The process which called the `fork()` call is the **parent** process and the process which is created newly is called the **child** process. The child process will be exactly the same as the parent. Note that the process state of the parent i.e., the address space, variables, open files etc. is copied into the child process. This means that the parent and child processes have identical but physically different address spaces. The change of values in parent process doesn't affect the child and vice versa is true too.

Both processes start execution from the next line of code i.e., the line after the `fork()` call. Let's look at an example:

```
// example.c
#include <stdio.h>
void main()
{
    int val;
    val = fork();   // line A
    printf("%d", val);  // line B
}
```

When the above example code is executed, when **line A** is executed, a child process is created. Now both processes start execution from **line B**. To differentiate between the child process and the parent process, we need to look at the value returned by the `fork()` call.

The difference is that, in the parent process, fork() returns a value which represents the **process ID** of the child process. But in the child process, `fork()` returns the value 0.

This means that according to the above program, the output of parent process will be the **process ID**of the child process and the output of the child process will be 0.

Exec()

The `exec()` system call is also used to create processes. But there is one big difference between `fork()` and `exec()` calls. The `fork()` call creates a new process while preserving the parent process. But, an `exec()` call replaces the address space, text segment, data segment etc. of the current process with the new process.

It means, after an `exec()` call, only the new process exists. The process which made the system call, wouldn't exist.

There are many flavors of `exec()` in UNIX, one being `exec1()` which is shown below as an example:

```
// example2.c
#include <stdio.h>
void main()
{
    execl("/bin/ls", "ls", 0);      // line A
    printf("This text won't be printed unless an error occurs in exec().");
}
```

As shown above, the first parameter to the execl() function is the address of the program which needs to be executed, in this case, the address of the **ls** utility in UNIX. Then it is followed by the name of the program which is **ls** in this case and followed by optional arguments. Then the list should be terminated by a NULL pointer (0).

When the above example is executed, at line A, the **ls** program is called and executed and the current process is halted. Hence the `printf()` function is never called since the process has already been halted. The only exception to

this is that, if the **execl()** function causes an error, then the `printf()`function is executed.

Types of system calls:

There are 5 different categories of system calls:

process control, file manipulation, device manipulation, information maintenance and communication.

. Process Control

A running program needs to be able to stop execution either normally or abnormally. When execution is stopped abnormally, often a dump of memory is taken and can be examined with a debugger.

. File Management

Some common system calls are *create*, *delete*, *read*, *write*, *reposition*, or *close*. Also, there is a need to determine the file attributes – *get* and *set* file attribute. Many times the OS provides an API to make these system calls.

Device Management

Process usually require several resources to execute, if these resources are available, they will be granted and control returned to the user process. These resources are also thought of as devices. Some are physical, such as a video card, and others are abstract, such as a file.

User programs *request* the device, and when finished they *release* the device. Similar to files, we can *read*, *write*, and *reposition* the device.

Information Management

Some system calls exist purely for transferring information between the user program and the operating system. An example of this is *time*, or *date*.

The OS also keeps information about all its processes and provides system calls to report this information.

Communication

There are two models of interprocess communication, the message-passing model and the shared memory model.

- Message-passing uses a common mailbox to pass messages between processes.
- Shared memory use certain system calls to create and gain access to create and gain access to regions of memory owned by other processes. The two processes exchange information by reading and writing in the shared data.

System programs:

hese programs are not usually part of the OS kernel, but are part of the overall operating system.

File management

These programs create, delete, copy, rename, print, dump, list, and generally manipulate files and directories.

Status information

Some programs simply request the date and time, and other simple requests. Others provide detailed performance, logging, and debugging information. The output of these files is often sent to a terminal window or GUI window

File modification

Programs such as text editors are used to create, and modify files.

Communications

These programs provide the mechanism for creating a virtual connect among processes, users, and other computers. Email and web browsers are a couple examples.

Protection and security :

Protection and security requires that computer resources such as CPU, softwares, memory etc. are protected. This extends to the operating system as well as the data in the system. This can be done by ensuring integrity, confidentiality and availability in the operating system. The system must be protect against unauthorized access, viruses, worms etc.

Threats to Protection and Security

A threat is a program that is malicious in nature and leads to harmful effects for the system. Some of the common threats that occur in a system are:

Virus

Viruses are generally small snippets of code embedded in a system. They are very dangerous and can corrupt files, destroy data, crash systems etc. They can also spread further by replicating themselves as required.

Trojan Horse

A trojan horse can secretly access the login details of a system. Then a malicious user can use these to enter the system as a harmless being and wreak havoc.

Trap Door

A trap door is a security breach that may be present in a system without the knowledge of the users. It can be exploited to harm the data or files in a system by malicious people.

Worm

A worm can destroy a system by using its resources to extreme levels. It can generate multiple copies which claim all the resources and don't allow any other processes to access them. A worm can shut down a whole network in this way.

Denial of Service

These type of attacks do not allow the legitimate users to access a system. It overwhelms the system with requests so it is overwhelmed and cannot work properly for other user.

Protection and Security Methods

The different methods that may provide protect and security for different computer systems are:

Authentication

This deals with identifying each user in the system and making sure they are who they claim to be. The operating system makes sure that all the users are authenticated before they access the system. The different ways to make sure that the users are authentic are:

- **Username/ Password**

  Each user has a distinct username and password combination and they need to enter it correctly before they can access the system.

- **User Key/ User Card**

  The users need to punch a card into the card slot or use they individual key on a keypad to access the system.

- **User Attribute Identification**

  Different user attribute identifications that can be used are fingerprint, eye retina etc. These are unique for each user and are compared with the existing samples in the database. The user can only access the system if there is a match.

One Time Password

These passwords provide a lot of security for authentication purposes. A one time password can be generated exclusively for a login every time a user wants to enter the system. It cannot be used more than once. The various ways a one time password can be implemented are:

- **Random Numbers**

The system can ask for numbers that correspond to alphabets that are pre arranged. This combination can be changed each time a login is required.

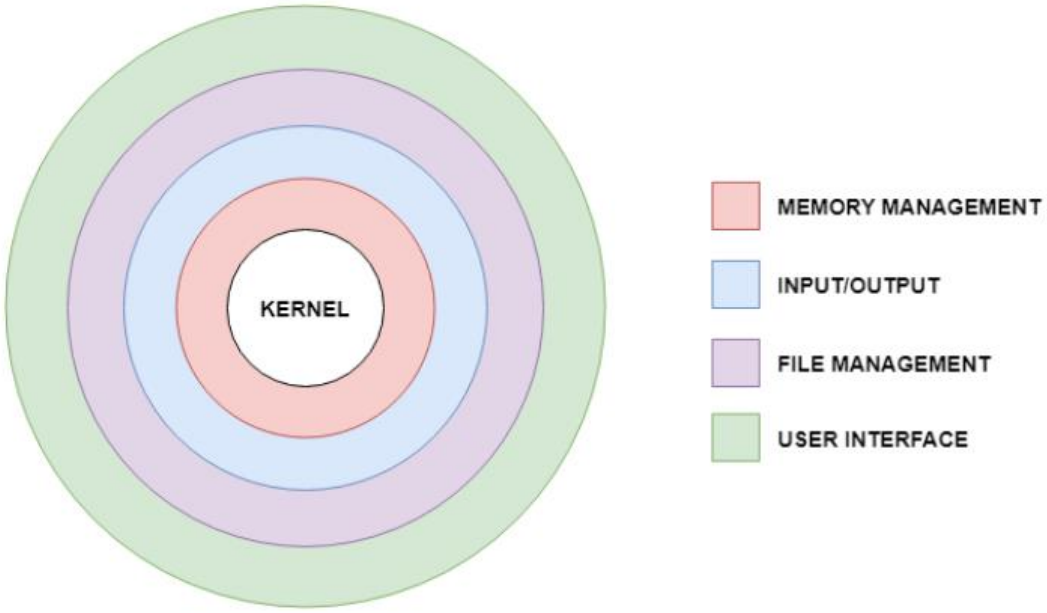
- **Secret Key**

  A hardware device can create a secret key related to the user id for login. This key can change each time.

Operating system design and implementation

operating system is a construct that allows the user application programs to interact with the system hardware. Operating system by itself does not provide any function but it provides an atmosphere in which different applications and programs can do useful work.

There are many problems that can occur while designing and implementing an operating system. These are covered in operating system design and implementation.



Layered Operating System Design

Operating System Design Goals

It is quite complicated to define all the goals and specifications of the operating system while designing it.The design changes depending on the type of the operating system i.e if it is batch system, time shared system, single user system, multi user system, distributed system etc.

There are basically two types of goals while designing an operating system. These are:

User Goals

The operating system should be convenient, easy to use, reliable, safe and fast according to the users. However, these specifications are not very useful as there is no set method to achieve these goals.

System Goals

The operating system should be easy to design, implement and maintain. These are specifications required by those who create, maintain and operate the operating system. But there is not specific method to achieve these goals as well.

Operating System Mechanisms and Policies

There is no specific way to design an operating system as it is a highly creative task. However, there are general software principles that are applicable to all operating systems.

A subtle difference between mechanism and policy is that mechanism shows how to do something and policy shows what to do. Policies may change over time and this would lead to changes in mechanism. So, it is better to have a general mechanism that would require few changes even when a policy change occurs.

For example - If the mechanism and policy are independent, then few changes are required in mechanism if policy changes. If a policy favours I/O intensive processes over CPU intensive processes, then a policy change to preference of CPU intensive processes will not change the mechanism.

Operating System Implementation

The operating system needs to be implemented after it is designed. Earlier they were written in assembly language but now higher level languages are used. The first system not written in assembly language was the Master Control Program (MCP) for Burroughs Computers.

Advantages of Higher Level Language

There are multiple advantages to implementing an operating system using a higher level language such as: the code is written more fast, it is compact and also easier to debug and understand. Also, the operating system can be easily moved from one hardware to another if it is written in a high level language.

Disadvantages of Higher Level Language

Using high level language for implementing an operating system leads to a loss in speed and increase in storage requirements. However in modern systems only a small amount of code is needed for high performance, such as the CPU scheduler and memory manager. Also, the bottleneck routines in the system can be replaced by assembly language equivalents if required.

Virtual machine:

A virtual machine is a software computer that, like a physical computer, runs an operating system and applications. The virtual machine is comprised of a set of specification and configuration files and is backed by the physical resources of a host. Every virtual machine has virtual devices that provide the same functionality as physical hardware and have additional benefits in terms of portability, manageability, and security.

A virtual machine consists of several types of files that you store on a supported storage device. The key files that make up a virtual machine are the configuration file, virtual disk file, NVRAM setting file, and the log file. You configure virtual machine settings through the vSphere Web Client or the vSphere Client. You do not need to touch the key files.

A virtual machine can have more files if one or more snapshots exist or if you add Raw Device Mappings (RDMs).

Unit -2:

Process concepts:

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

Process memory is divided into four sections for efficient working :

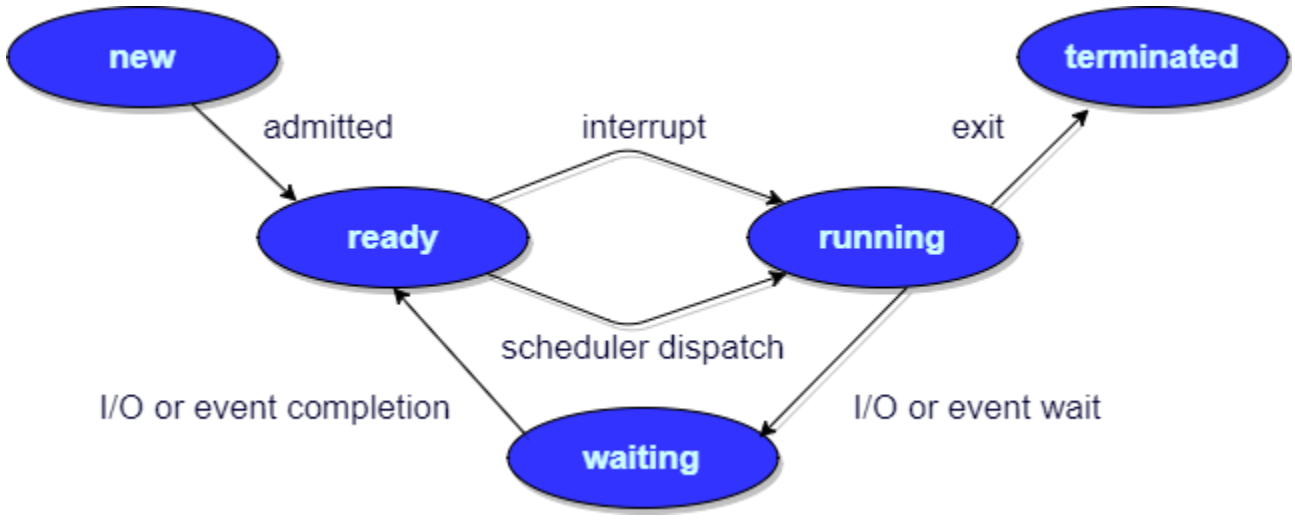
- The **Text section** is made up of the compiled program code, read in from non-volatile storage when the program is launched.

- The **Data section** is made up the global and static variables, allocated and initialized prior to executing the main.
- The **Heap** is used for the dynamic memory allocation, and is managed via calls to new, delete, malloc, free, etc.
- The **Stack** is used for local variables. Space on the stack is reserved for local variables when they are declared.

Different Process States

Processes in the operating system can be in any of the following states:

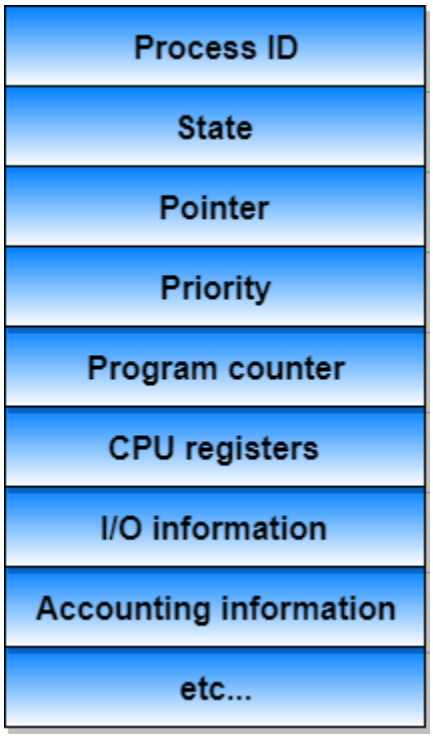
- `NEW`- The process is being created.
- `READY`- The process is waiting to be assigned to a processor.
- `RUNNING`- Instructions are being executed.
- `WAITING`- The process is waiting for some event to occur(such as an I/O completion or reception of a signal).
- `TERMINATED`- The process has finished execution.



Process Control Block

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

- **Process State**: It can be running, waiting etc.
- **Process ID** and the **parent process ID**.
- CPU registers and Program Counter. **Program Counter** holds the address of the next instruction to be executed for that process.
- **CPU Scheduling** information: Such as priority information and pointers to scheduling queues.
- **Memory Management information**: For example, page tables or segment tables.
- **Accounting information**: The User and kernel CPU time consumed, account numbers, limits, etc.
- **I/O Status information**: Devices allocated, open file tables, etc.



Process scheduling:

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

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

Scheduling fell into one of the two general categories:

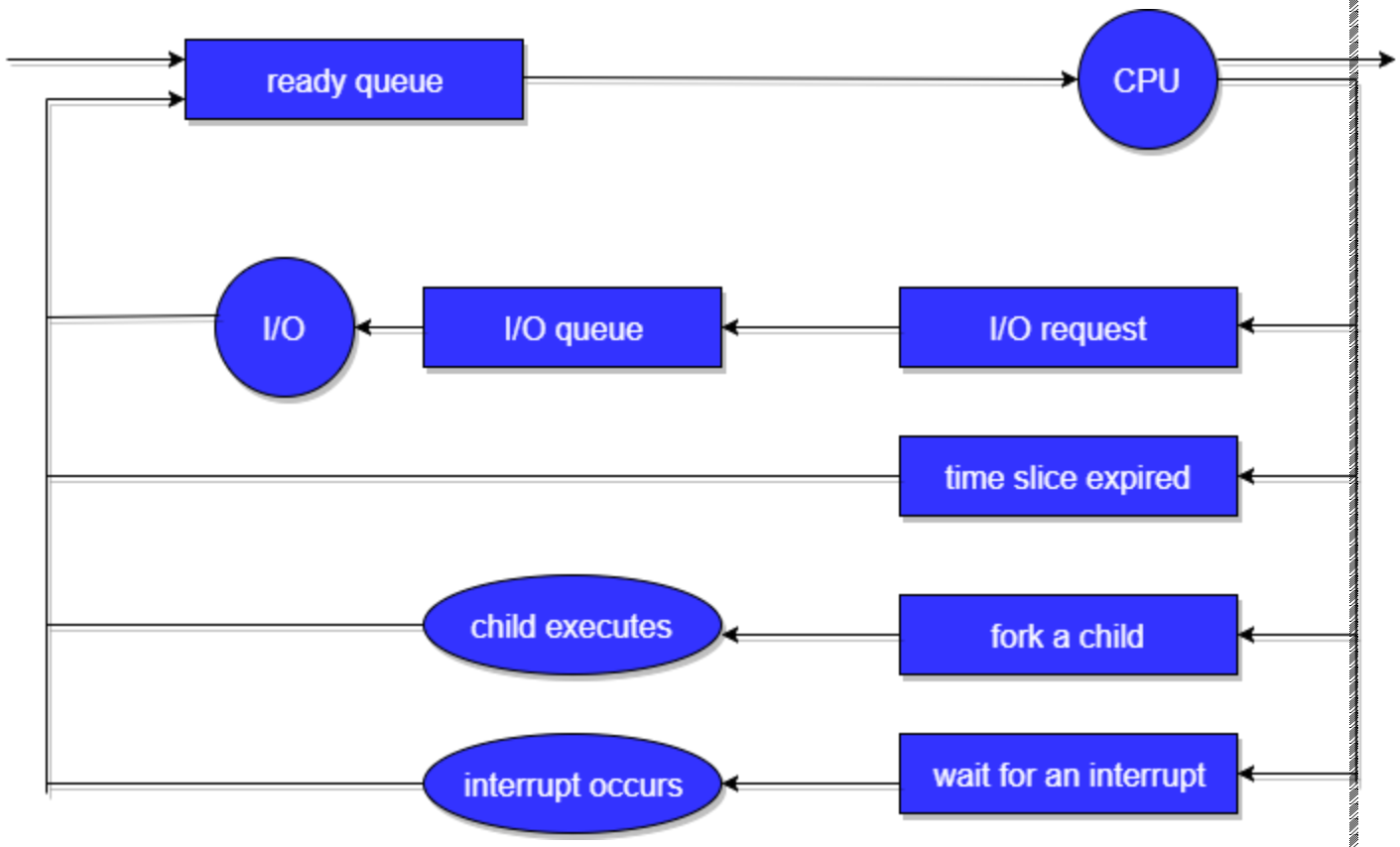
- **Non Pre-emptive Scheduling:** When the currently executing process gives up the CPU voluntarily.
- **Pre-emptive Scheduling:** When the operating system decides to favour another process, pre-empting the currently executing process.

Scheduling Queues

- All processes, upon entering into the system, are stored in the **Job Queue**.
- Processes in the `Ready` state are placed in the **Ready Queue**.
- Processes waiting for a device to become available are placed in **Device Queues**. There are unique device queues available for each I/O device.

A new process is initially put in the **Ready queue**. It waits in the ready queue until it is selected for execution(or dispatched). Once the process is assigned to the CPU and is executing, one of the following several events can occur:

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



In the first two cases, the process eventually switches from the waiting state to the ready state, and is then put back in the ready queue. A process continues this cycle until it terminates, at which time it is removed from all queues and has its PCB and resources deallocated.

Types of Schedulers

There are three types of schedulers available:

1. Long Term Scheduler
2. Short Term Scheduler
3. Medium Term Scheduler

Let's discuss about all the different types of Schedulers in detail:

Long Term Scheduler

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

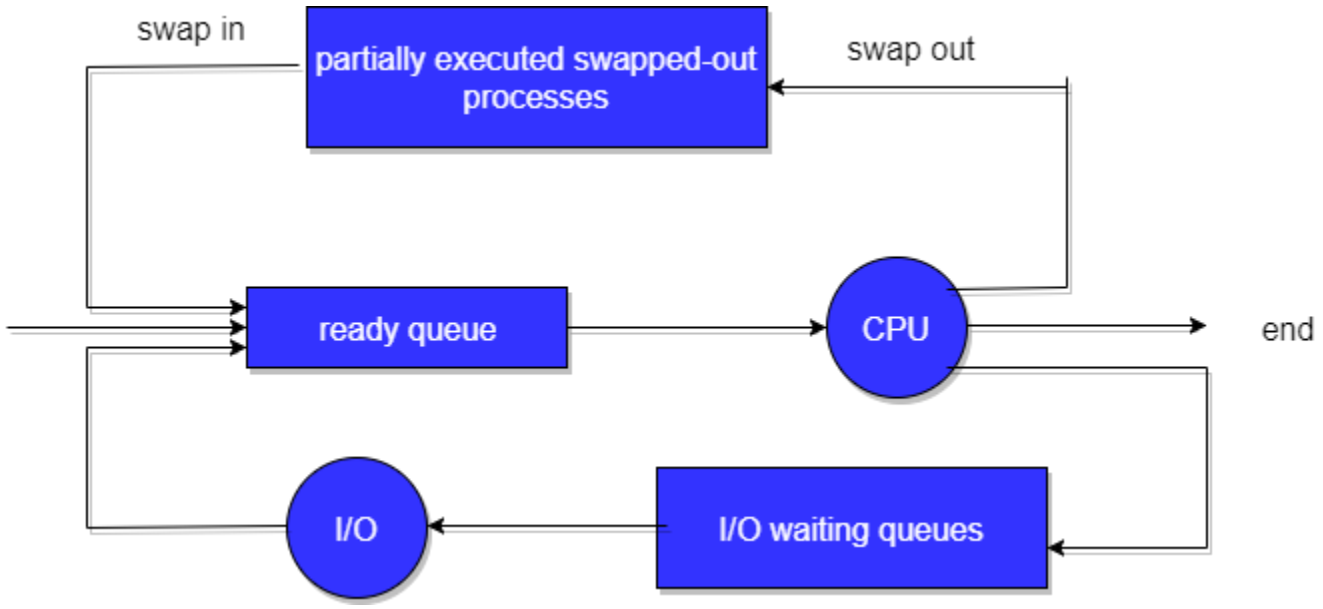
Short Term Scheduler

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

Medium Term Scheduler

This scheduler removes the processes from memory (and from active contention for the CPU), and thus reduces the degree of multiprogramming. At some later time, the process can be reintroduced into memory and its execution van be continued where it left off. This scheme is called **swapping**. The process is swapped out, and is later swapped in, by the medium term scheduler.

Swapping may be necessary to improve the process mix, or because a change in memory requirements has overcommitted available memory, requiring memory to be freed up. This complete process is descripted in the below diagram:



Addition of Medium-term scheduling to the queueing diagram.

Context switch:

1. Switching the CPU to another process requires **saving** the state of the old process and **loading**the saved state for the new process. This task is known as a **Context Switch**.
2. The **context** of a process is represented in the **Process Control Block(PCB)** of a process; it includes the value of the CPU registers, the process state and memory-management information. When a context switch occurs, the Kernel saves the context of the old process in its PCB and loads the saved context of the new process scheduled to run.
3. Context switch time is **pure overhead**, because the **system does no useful work while switching**. Its speed varies from machine to machine, depending on the memory speed, the number of registers that must be copied, and the existence of special instructions(such as a single instruction to load or store all registers). Typical speeds range from 1 to 1000 microseconds.
4. Context Switching has become such a performance **bottleneck** that programmers are using new structures(threads) to avoid it whenever and wherever possible.

Operations on Process

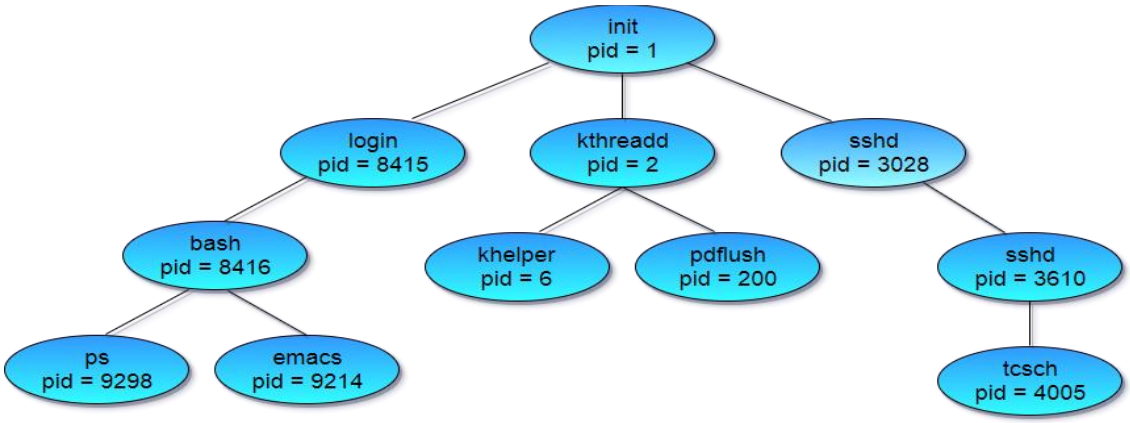
Below we have discussed the two major operation **Process Creation** and **Process Termination**.

Process Creation

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

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

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



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

Types of CPU Scheduling

CPU scheduling decisions may take place under the following four circumstances:

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

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

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

Non-Preemptive Scheduling

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

This scheduling method is used by the Microsoft Windows 3.1 and by the Apple Macintosh operating systems.

It is the only method that can be used on certain hardware platforms, because It does not require the special hardware(for example: a timer) needed for preemptive scheduling.

Preemptive Scheduling

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

CPU Scheduling: Scheduling Criteria

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

CPU Utilization

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

Throughput

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

Turnaround Time

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

Waiting Time

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

Load Average

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

Response Time

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

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

Scheduling Algorithms

To decide which process to execute first and which process to execute last to achieve maximum CPU utilisation, computer scientists have defined some algorithms, they are:

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

First Come First Serve Scheduling

In the "First come first serve" scheduling algorithm, as the name suggests, the process which arrives first, gets executed first, or we can say that the process which requests the CPU first, gets the CPU allocated first.

- First Come First Serve, is just like **FIFO**(First in First out) Queue data structure, where the data element which is added to the queue first, is the one who leaves the queue first.

- This is used in Batch Systems.
- It's **easy to understand and implement** programmatically, using a Queue data structure, where a new process enters through the **tail** of the queue, and the scheduler selects process from the **head** of the queue.
- A perfect real life example of FCFS scheduling is **buying tickets at ticket counter**.

Calculating Average Waiting Time

For every scheduling algorithm, **Average waiting time** is a crucial parameter to judge it's performance.

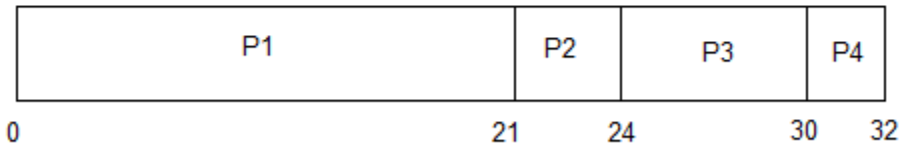
AWT or Average waiting time is the average of the waiting times of the processes in the queue, waiting for the scheduler to pick them for execution.

Lower the Average Waiting Time, better the scheduling algorithm.

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

PROCESS	BURST TIME
P1	21
P2	3
P3	6
P4	2

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



This is the GANTT chart for the above processes

The average waiting time will be `18.75 ms`

For the above given proccesses, first **P1** will be provided with the CPU resources,

- Hence, waiting time for **P1** will be `0`
- **P1** requires `21 ms` for completion, hence waiting time for **P2** will be `21 ms`
- Similarly, waiting time for process **P3** will be execution time of **P1** + execution time for **P2**, which will be `(21 + 3) ms` = `24 ms`.
- For process **P4** it will be the sum of execution times of **P1**, **P2** and **P3**.

The **GANTT chart** above perfectly represents the waiting time for each process.

Problems with FCFS Scheduling

Below we have a few shortcomings or problems with the FCFS scheduling algorithm:

1. It is **Non Pre-emptive** algorithm, which means the **process priority** doesn't matter.

   If a process with very least priority is being executed, more like **daily routine backup** process, which takes more time, and all of a sudden some other high priority process arrives, like **interrupt to avoid system crash**, the high priority process will have to wait, and hence in this case, the system will crash, just because of improper process scheduling.

2. Not optimal Average Waiting Time.
3. Resources utilization in parallel is not possible, which leads to **Convoy Effect**, and hence poor resource(CPU, I/O etc) utilization.

What is Convoy Effect?

Convoy Effect is a situation where many processes, who need to use a resource for short time are blocked by one process holding that resource for a long time.

This essentially leads to poort utilization of resources and hence poor performance.

Program for FCFS Scheduling

Here we have a simple C++ program for processes with **arrival time** as `0`.

In the program, we will be calculating the **Average waiting time** and **Average turn around time** for a given `array` of **Burst times** for the list of processes.

```
/* Simple C++ program for implementation
of FCFS scheduling */

#include<iostream>

using namespace std;

// function to find the waiting time for all processes
void findWaitingTime(int processes[], int n, int bt[], int wt[])
{
    // waiting time for first process will be 0
    wt[0] = 0;

    // calculating waiting time
    for (int i = 1; i < n ; i++)
    {
        wt[i] =  bt[i-1] + wt[i-1];
    }
}

// function to calculate turn around time
void findTurnAroundTime( int processes[], int n, int bt[], int wt[], int tat[])
{
    // calculating turnaround time by adding
    // bt[i] + wt[i]
    for (int i = 0; i < n ; i++)
    {
        tat[i] = bt[i] + wt[i];
```

```
    }
}

// function to calculate average time
void findAverageTime( int processes[], int n, int bt[])
{
    int wt[n], tat[n], total_wt = 0, total_tat = 0;

    // function to find waiting time of all processes
    findWaitingTime(processes, n, bt, wt);

    // function to find turn around time for all processes
    findTurnAroundTime(processes, n, bt, wt, tat);

    // display processes along with all details
    cout << "Processes  "<< " Burst time  "<< " Waiting time  " << " Turn around time\n";

    // calculate total waiting time and total turn around time
    for (int i = 0; i < n; i++)
    {
        total_wt = total_wt + wt[i];
        total_tat = total_tat + tat[i];
        cout << "   " << i+1 << "\t\t" << bt[i] <<"\t    "<< wt[i] <<"\t\t  " << tat[i] <<endl;
    }

    cout << "Average waiting time = "<< (float)total_wt / (float)n;
    cout << "\nAverage turn around time = "<< (float)total_tat / (float)n;
}

// main function
int main()
{
    // process ids
    int processes[] = { 1, 2, 3, 4};
    int n = sizeof processes / sizeof processes[0];
```

```
    // burst time of all processes
    int  burst_time[] = {21, 3, 6, 2};

    findAverageTime(processes, n,  burst_time);

    return 0;
}
```

```
Processes Burst time Waiting time Turn around time
1 21 0 21
2 3 21 24
3 6 24 30
4 2 30 32
Average waiting time = 18.75
Average turn around time = 26.75
```

Here we have simple formulae for calculating various times for given processes:

Completion Time: Time taken for the execution to complete, starting from arrival time.

Turn Around Time: Time taken to complete after arrival. In simple words, it is the difference between the Completion time and the Arrival time.

Waiting Time: Total time the process has to wait before it's execution begins. It is the difference between the Turn Around time and the Burst time of the process.

For the program above, we have considered the **arrival time** to be `0` for all the processes, try to implement a program with variable arrival times.

Shortest Job First(SJF) Scheduling

Shortest Job First scheduling works on the process with the shortest **burst time** or **duration** first.

- This is the best approach to minimize waiting time.
- This is used in Batch Systems.
- It is of two types:
  1. Non Pre-emptive
  2. Pre-emptive
- To successfully implement it, the burst time/duration time of the processes should be known to the processor in advance, which is practically not feasible all the time.
- This scheduling algorithm is optimal if all the jobs/processes are available at the same time. (either Arrival time is `0` for all, or Arrival time is same for all)

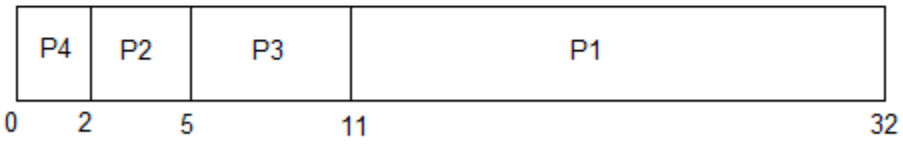
Non Pre-emptive Shortest Job First

Consider the below processes available in the ready queue for execution, with **arrival time** as `0` for all and given **burst times**.

PROCESS	BURST TIME
P1	21
P2	3
P3	6
P4	2

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

Hence the GANTT chart will be following :



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

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

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

Problem with Non Pre-emptive SJF

If the **arrival time** for processes are different, which means all the processes are not available in the ready queue at time `0`, and some jobs arrive after some time, in such situation, sometimes process with short burst time have to wait for the current process's execution to finish, because in Non Pre-emptive SJF, on arrival of a process with short duration, the existing job/process's execution is not halted/stopped to execute the short job first.

This leads to the problem of **Starvation**, where a shorter process has to wait for a long time until the current longer process gets executed. This happens if shorter jobs keep coming, but this can be solved using the concept of **aging**.

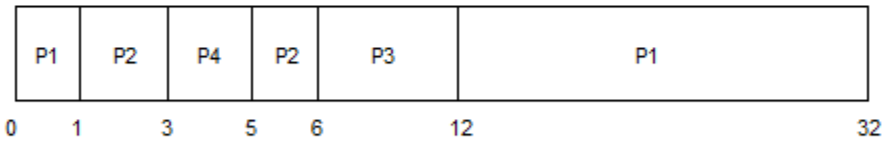
Pre-emptive Shortest Job First

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

removed from execution, and the shorter job is executed first.

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

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



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

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

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

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

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

The Pre-emptive SJF is also known as **Shortest Remaining Time First**, because at any given point of time, the job with the shortest remaining time is executed first.

Program for SJF Scheduling

In the below program, we consider the **arrival time** of all the jobs to be `0`.

Also, in the program, we will **sort** all the jobs based on their **burst time** and then execute them one by one, just like we did in FCFS scheduling program.

```
// c++ program to implement Shortest Job first

#include<bits/stdc++.h>

using namespace std;

struct Process
{
   int pid;     // process ID
   int bt;      // burst Time
};

/*
    this function is used for sorting all
    processes in increasing order of burst time
*/
bool comparison(Process a, Process b)
{
    return (a.bt < b.bt);
}

// function to find the waiting time for all processes
void findWaitingTime(Process proc[], int n, int wt[])
{
    // waiting time for first process is 0
    wt[0] = 0;

    // calculating waiting time
    for (int i = 1; i < n ; i++)
    {
        wt[i] = proc[i-1].bt + wt[i-1] ;
    }
}
```

```
// function to calculate turn around time
void findTurnAroundTime(Process proc[], int n, int wt[], int tat[])
{
    // calculating turnaround time by adding bt[i] + wt[i]
    for (int i = 0; i < n ; i++)
    {
        tat[i] = proc[i].bt + wt[i];
    }
}

// function to calculate average time
void findAverageTime(Process proc[], int n)
{
    int wt[n], tat[n], total_wt = 0, total_tat = 0;

    // function to find waiting time of all processes
    findWaitingTime(proc, n, wt);

    // function to find turn around time for all processes
    findTurnAroundTime(proc, n, wt, tat);

    // display processes along with all details
    cout << "\nProcesses "<< " Burst time "
         << " Waiting time " << " Turn around time\n";

    // calculate total waiting time and total turn around time
    for (int i = 0; i < n; i++)
    {
        total_wt = total_wt + wt[i];
        total_tat = total_tat + tat[i];
        cout << " " << proc[i].pid << "\t\t"
             << proc[i].bt << "\t " << wt[i]
             << "\t\t " << tat[i] <<endl;
    }
```

```
    cout << "Average waiting time = "
         << (float)total_wt / (float)n;
    cout << "\nAverage turn around time = "
         << (float)total_tat / (float)n;
}

// main function
int main()
{
    Process proc[] = {{1, 21}, {2, 3}, {3, 6}, {4, 2}};
    int n = sizeof proc / sizeof proc[0];

    // sorting processes by burst time.
    sort(proc, proc + n, comparison);

    cout << "Order in which process gets executed\n";
    for (int i = 0 ; i < n; i++)
    {
        cout << proc[i].pid <<" ";
    }

    findAverageTime(proc, n);

    return 0;
}
```

```
Order in which process gets executed
4 2 3 1
Processes Burst time Waiting time Turn around time
4 2 0 2
2 3 2 5
3 6 5 11
1 21 11 32
Average waiting time = 4.5
Average turn around time = 12.5
```

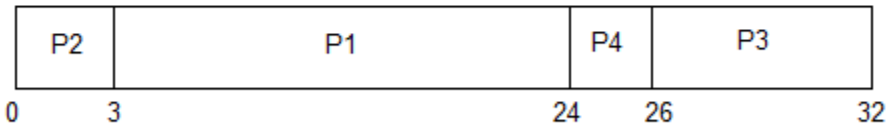
Try implementing the program for SJF with variable **arrival time** for different jobs, yourself.

Priority Scheduling

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

PROCESS	BURST TIME	PRIORITY
P1	21	2
P2	3	1
P3	6	4
P4	2	3

The GANTT chart for following processes based on Priority scheduling will be,



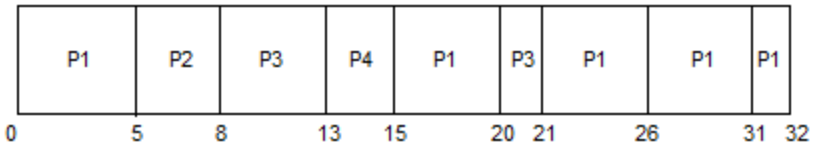
The average waiting time will be, (0 + 3 + 24 + 26)/4 = 13.25 ms

Round Robin Scheduling

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

PROCESS	BURST TIME
P1	21
P2	3
P3	6
P4	2

The GANTT chart for round robin scheduling will be,



The average waiting time will be, 11 ms.

Multiple process Scheduling

Another class of scheduling algorithms has been created for situations in which processes are easily classified into different groups.

For example: A common division is made between foreground(or interactive) processes and background (or batch) processes. These two types of processes have different response-time requirements, and so might have different scheduling needs. In addition, foreground processes may have priority over background processes.

A multi-level queue scheduling algorithm partitions the ready queue into several separate queues. The processes are permanently assigned to one queue, generally based on some property of the process, such as memory size, process priority, or process type. Each queue has its own scheduling algorithm.

For example: separate queues might be used for foreground and background processes. The foreground queue might be scheduled by Round Robin algorithm, while the background queue is scheduled by an FCFS algorithm.

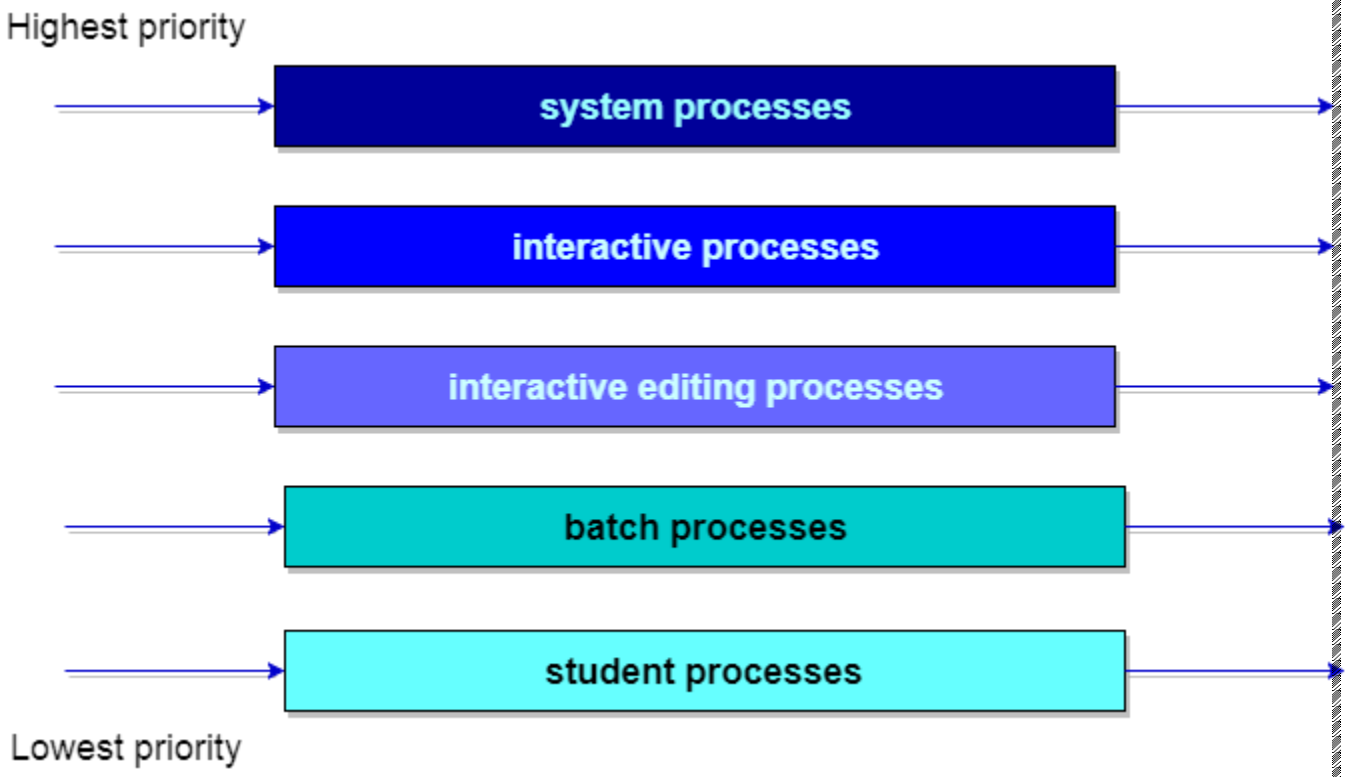
In addition, there must be scheduling among the queues, which is commonly implemented as fixed-priority preemptive scheduling.

For example: The foreground queue may have absolute priority over the background queue.

Let us consider an example of a multilevel queue-scheduling algorithm with five queues:

1. System Processes
2. Interactive Processes
3. Interactive Editing Processes
4. Batch Processes
5. Student Processes

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



Real time scheduling

Real Time Scheduling

Introduction

Priority based scheduling enables us to give better service to certain processes. In our discussion of multi-queue scheduling, priority was adjusted based on whether a task was more interactive or compute intensive. But most schedulers enable us to give any process any desired priority. Isn't that good enough?

Priority scheduling is inherently a *best effort* approach. If our task is competing with other high priority tasks, it may not get as much time as it requires. Sometimes best effort isn't good enough:

- During reentry, the space shuttle is aerodynamically unstable. It is not actually being kept under control by the quick reflexes of the well-trained pilots, but rather by guidance computers that are collecting attitude and acceleration input and adjusting numerous spoilers hundreds of times per second.
- Scientific and military satellites may receive precious and irreplaceable sensor data at extremely high speeds. If it takes us too long to receive, process, and store one data frame, the next data frame may be lost.
- More mundanely, but also important, many manufacturing processes are run by computers nowadays. An assembly line needs to move at a particular speed, with each step being performed at a particular time. Performing the action too late results in a flawed or useless product.
- Even more commonly, playing media, like video or audio, has real time requirements. Sound must be produced at a certain rate and frames must be displayed frequently enough or the media becomes uncomfortable to deal with.

There are many computer controlled applications where delays in critical processing can have undesirable, or even disastrous consequences.

What are Real-Time Systems

A real-time system is one whose correctness depends on timing as well as functionality.

When we discussed more traditional scheduling algorithms, the metrics we looked at were *turn-around time* (or throughput), *fairness*, and mean *response time*. But real-time systems have very different requirements, characterized by different metrics:

- *timeliness* ... how closely does it meet its timing requirements (e.g. ms/day of accumulated tardiness)
- *predictability* ... how much deviation is there in delivered timeliness

And we introduce a few new concepts:

- *feasibility* ... whether or not it is possible to meet the requirements for a particular task set
- *hard real-time* ... there are strong requirements that specified tasks be run a specified intervals (or within a specified response time). Failure to meet this requirement (perhaps by as little as a fraction of a micro-second) may result in system failure.
- *soft real-time* ... we may want to provide very good (e.g. microseconds) response time, the only consequences of missing a deadline are degraded performance or recoverable failures.

It sounds like real-time scheduling is more critical and difficult than traditional time-sharing, and in many ways it is. But real-time systems may have a few characteristics that make scheduling easier:

- We may actually know how long each task will take to run. This enables much more intelligent scheduling.
- *Starvation* (of low priority tasks) may be acceptable. The space shuttle absolutely must sense attitude and acceleration and adjust spolier positions once per millisecond. But it probably doesn't matter if we update the navigational display once per millisecond or once every ten seconds. Telemetry transmission is probably somewhere in-between. Understanding the relative criticality of each task gives us the freedom to intelligently shed less critical work in times of high demand.
- The work-load may be relatively fixed. Normally high utilization implies long queuing delays, as bursty traffic creates long lines. But if the incoming traffic rate is relatively constant, it is possible to simultaneously achieve high utilization and good response time.

Real-Time Scheduling Algorithms

In the simplest real-time systems, where the tasks and their execution times are all known, there might not even be a scheduler. One task might simply call (or yield to) the next. This model makes a great deal of sense in a system where the tasks form a

producer/consumer pipeline (e.g. MPEG frame receipt, protocol decoding, image decompression, display).

In more complex real-time system, with a larger (but still fixed) number of tasks that do not function in a strictly pipeline fashion, it may be possible to *static* scheduling. Based on the list of tasks to be run, and the expected completion time for each, we can define (at design or build time) a fixed schedule that will ensure timely execution of all tasks.

But for many real-time systems, the work-load changes from moment to moment, based on external events. These require *dynamic* scheduling. For *dynamic* scheduling algorithms, there are two key questions:

1. how they choose the next (ready) task to run
    - shortest job first
    - static priority ... highest priority ready task
    - soonest start-time deadline first (ASAP)
    - soonest completion-time deadline first (slack time)
2. how they handle overload (infeasible requirements)
    - best effort
    - periodicity adjustments ... run lower priority tasks less often.
    - work shedding ... stop running lower priority tasks entirely.

Preemption may also be a different issue in real-time systems. In ordinary time-sharing, preemption is a means of improving mean response time by breaking up the execution of long-running, compute-intensive tasks. A second advantage of preemptive scheduling, particularly important in a general purpose timesharing system, is that it prevents a buggy (infinite loop) program from taking over the CPU. The trade-off, between improved response time and increased overhead (for the added context switches), almost always favors preemptive scheduling. This may not be true for real-time systems:

- preempting a running task will almost surely cause it to miss its completion deadline.
- since we so often know what the expected execution time for a task will be, we can schedule accordingly and should have little need for preemption.
- embedded and real-time systems run fewer and simpler tasks than general purpose time systems, and the code is often much better tested ... so infinite loop bugs are extremely rare.

For the least demanding real time tasks, a sufficiently lightly loaded system might be reasonably successful in meeting its deadlines. However, this is achieved simply because the frequency at which the task is run happens to be high enough to meet its real time requirements, not because the scheduler is aware of such requirements. A lightly loaded machine running a traditional scheduler can often display a video to a user's satisfaction, not because the scheduler "knows" that a frame must be rendered by a certain deadline, but simply because the machine has enough cycles and a low enough work load to render the frame before the deadline has arrived.

Thread scheduling:

Thread is an execution unit which consists of its own program counter, a stack, and a set of registers. Threads are also known as Lightweight processes. Threads are popular way to improve application through parallelism. The CPU switches rapidly back and forth among the threads giving illusion that the threads are running in parallel.

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

Types of Thread

There are two types of threads:

1. User Threads
2. Kernel Threads

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

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

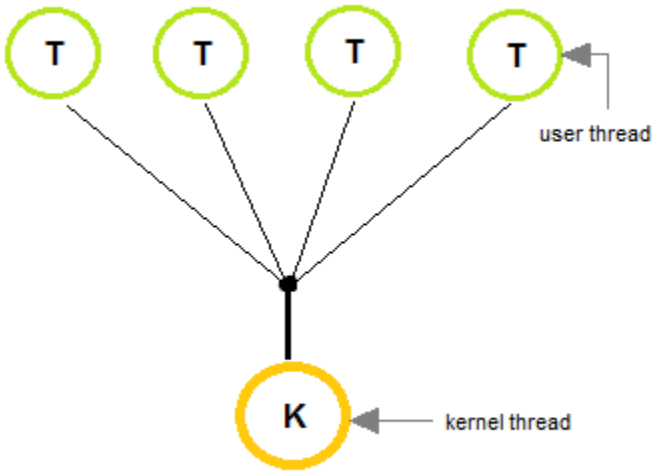
Multithreading Models

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

- Many to One Model
- One to One Model
- Many to Many Model

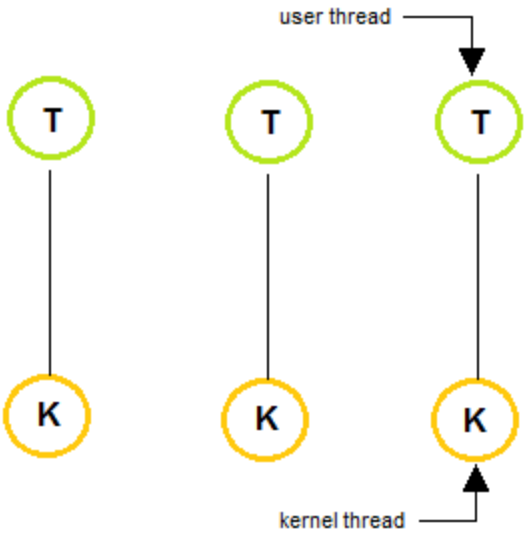
Many to One Model

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



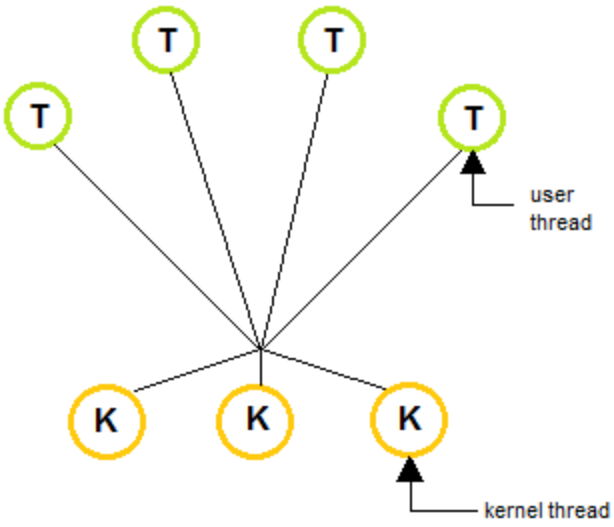
One to One Model

- The **one to one** model creates a separate kernel thread to handle each and every user thread.
- Most implementations of this model place a limit on how many threads can be created.
- Linux and Windows from 95 to XP implement the one-to-one model for threads.



Many to Many Model

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


T
T
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user
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kernel thread

Unit -3

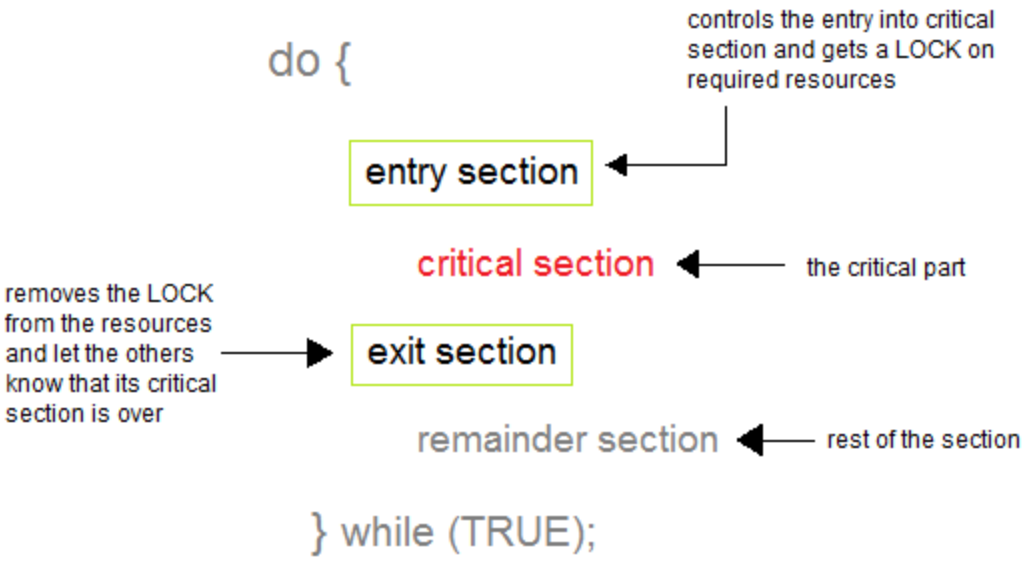
Process synchronization:

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

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

Critical Section Problem

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



Solution to Critical Section Problem

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

---

1. Mutual Exclusion

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

2. Progress

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

3. Bounded Waiting

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

Synchronization Hardware

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

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

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

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

Mutex Locks

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

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

Introduction to Semaphores

In 1965, Dijkstra proposed a new and very significant technique for managing concurrent processes by using the value of a simple integer variable to synchronize the progress of interacting processes. This integer variable is called **semaphore**. So it is basically a synchronizing tool and is accessed only through two low standard atomic operations, **wait** and **signal** designated by `P(S)` and `V(S)`respectively.

In very simple words, **semaphore** is a variable which can hold only a non-negative Integer value, shared between all the threads, with operations **wait** and **signal**, which work as follow:

```
P(S): if S ≥ 1 then S := S - 1
      else <block and enqueue the process>;

V(S): if <some process is blocked on the queue>
        then <unblock a process>
      else S := S + 1;
```

The classical definitions of **wait** and **signal** are:

- **Wait**: Decrements the value of its argument `S`, as soon as it would become non-negative(greater than or equal to `1`).

- **Signal**: Increments the value of its argument `S`, as there is no more process blocked on the queue.

Properties of Semaphores

1. It's simple and always have a non-negative Integer value.
2. Works with many processes.
3. Can have many different critical sections with different semaphores.
4. Each critical section has unique access semaphores.
5. Can permit multiple processes into the critical section at once, if desirable.

Types of Semaphores

Semaphores are mainly of two types:

1. **Binary Semaphore:**

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

2. **Counting Semaphores:**

   These are used to implement bounded concurrency.

Example of Use

Here is a simple step wise implementation involving declaration and usage of semaphore.

```
Shared var mutex: semaphore = 1;
Process i
    begin
    .
    .
    P(mutex);
    execute CS;
    V(mutex);
    .
    .
    End;
```

Limitations of Semaphores

1. **Priority Inversion** is a big limitation of semaphores.
2. Their use is not enforced, but is by convention only.
3. With improper use, a process may block indefinitely. Such a situation is called **Deadlock**. We will be studying deadlocks in details in coming lessons.

Classical Problems of Synchronization

In this tutorial we will discuss about various classic problem of synchronization.

Semaphore can be used in other synchronization problems besides Mutual Exclusion.

Below are some of the classical problem depicting flaws of process synchronaization in systems where cooperating processes are present.

We will discuss the following three problems:

1. Bounded Buffer (Producer-Consumer) Problem
2. The Readers Writers Problem
3. Dining Philosophers Problem

Bounded Buffer Problem

- This problem is generalised in terms of the **Producer Consumer problem**, where a **finite** buffer pool is used to exchange messages between producer and consumer processes.

  Because the buffer pool has a maximum size, this problem is often called the **Bounded buffer problem**.

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

The Readers Writers Problem

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

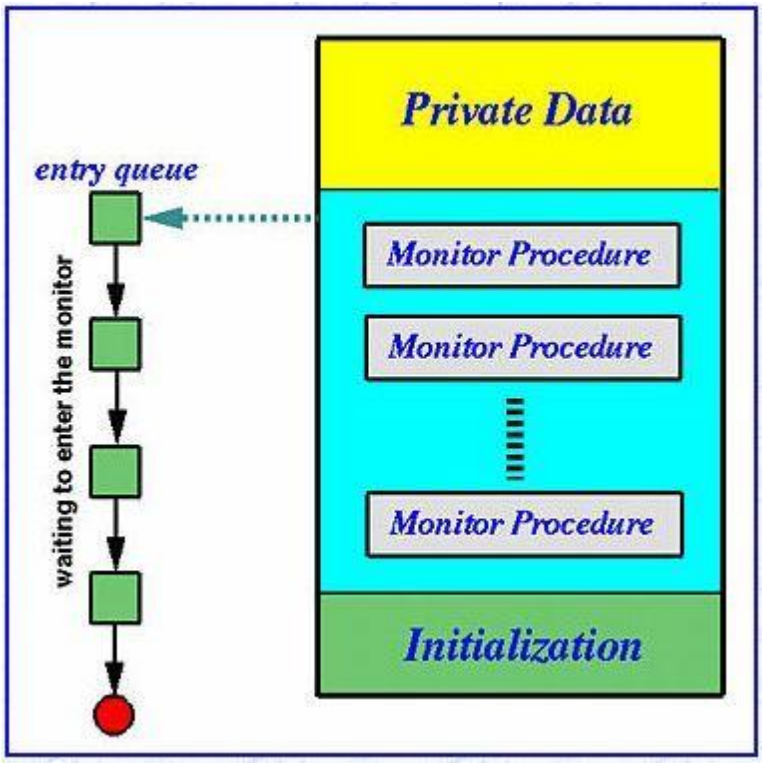
Dining Philosophers Problem

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

Monitor:

monitor is a **set of multiple** routines which are protected by a mutual exclusion lock. None of the routines in the monitor can be executed by a thread until that thread acquires the lock. This means that only ONE thread can execute within the monitor at a time. Any other threads must wait for the thread that's currently executing to give up control of the lock.

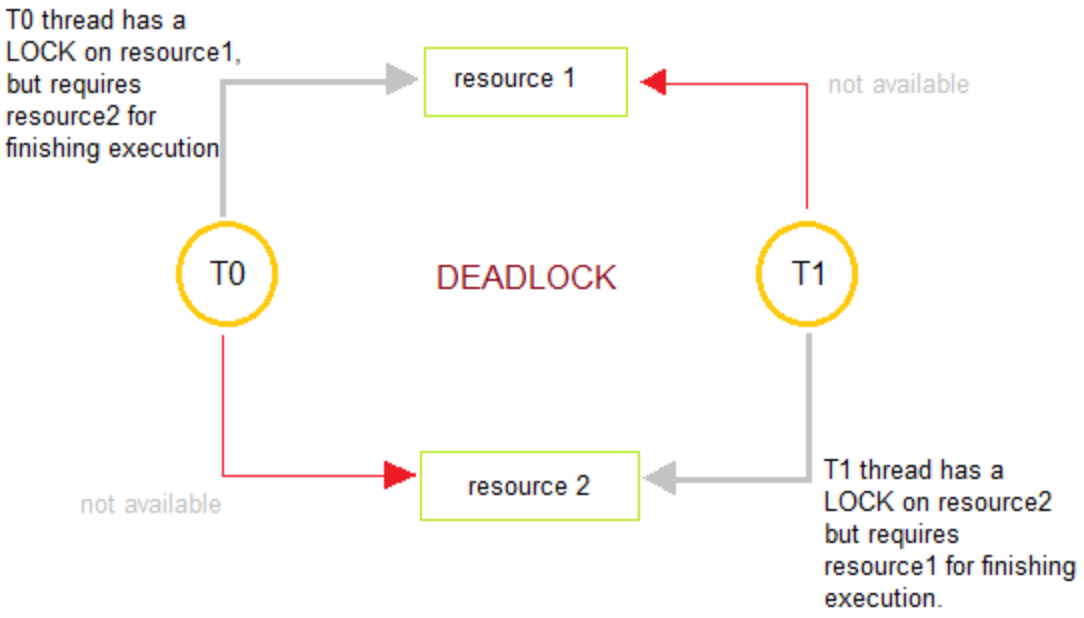
A monitor has ***four*** components as shown below: initialization, private data, monitor procedures, and monitor entry queue. The ***initialization*** component contains the code that is used exactly once when the monitor is created, The ***private data*** section contains all private data, including private procedures, that can only be used *within*the monitor. Thus, these private items are not visible from outside of the monitor. The ***monitor procedures*** are procedures that can be called from outside of the monitor. The ***monitor entry queue*** contains all threads that called monitor procedures but have not been granted permissions.



Monitors are supposed to be used in a multithreaded or multiprocess environment in which multiple threads/processes may call the monitor procedures at the same time asking for service. Thus, a monitor guarantees that ***at any moment at most one thread can be executing in a monitor***! If a thread calls a monitor procedure, this thread will be blocked if there is another thread executing in the monitor. Those threads that were not granted the entering permission will be queued to a monitor ***entry queue***outside of the monitor. When the monitor becomes empty (*i.e.*, no thread is executing in it), one of the threads in the entry queue will be released and granted the permission to execute the called monitor procedure.

What is a Deadlock?

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



How to avoid Deadlocks

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

1. **Mutual Exclusion**

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

2. **Hold and Wait**

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

3. **No Preemption**

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

4. **Circular Wait**

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

Handling Deadlock

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

1. **Preemption**

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

2. **Rollback**

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

3. **Kill one or more processes**

   This is the simplest way, but it works.

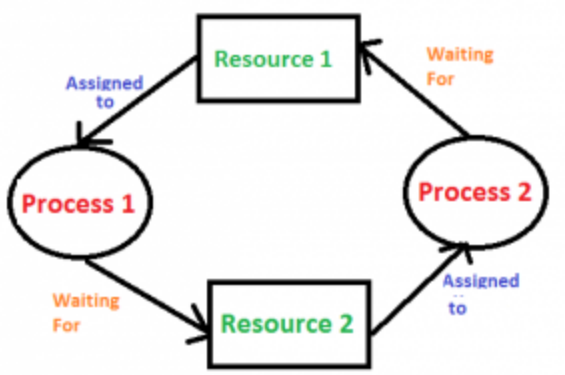
What is a Livelock?

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

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

Deadlock Detection
1. If resources have single instance:
In this case for Deadlock detection we can run an algorithm to check for cycle in the Resource Allocation Graph. Presence of cycle in the graph is

the sufficient condition for deadlock.



In the above diagram, resource 1 and resource 2 have single instances. There is a cycle R1–>P1–>R2–>P2. So Deadlock is Confirmed.

2. If there are multiple instances of resources:
Detection of cycle is necessary but not sufficient condition for deadlock detection, in this case system may or may not be in deadlock varies according to different situations.

Deadlock Recovery

Traditional operating system such as Windows doesn't deal with deadlock recovery as it is time and space consuming process. Real time operating systems use Deadlock recovery.

Recovery method

1. Killing the process.

```
killing all the process involved in deadlock.


Killing process one by one. After killing each
process check for deadlock again keep repeating
process till system recover from deadlock.
```

3. Resource Preemption
   Resources are preempted from the processes involved in deadlock, preempted resources are allocated to other processes, so that their is a possibility of recovering the system from deadlock. In this case system go into starvation.

Logical and physical address space:

Physical Address Space

Physical address space in a system can be defined as the size of the main memory. It is really important to compare the process size with the physical address space. The process size must be less than the physical address space.

Physical Address Space = Size of the Main Memory

If, physical address space = 64 KB = 2 ^ 6 KB = 2 ^ 6 X 2 ^ 10 Bytes = 2 ^ 16 bytes

Let us consider,
word size = 8 Bytes = 2 ^ 3 Bytes

Hence,
Physical address space (in words) = (2 ^ 16) / (2 ^ 3) = 2 ^ 13 Words

Therefore,
Physical Address = 13 bits

In General,
If, Physical Address Space = N Words

then, Physical Address = $\log_2 N$

Logical Address Space

Logical address space can be defined as the size of the process. The size of the process should be less enough so that it can reside in the main memory.

Let's say,

Logical Address Space = 128 MB = (2 ^ 7 X 2 ^ 20) Bytes = 2 ^ 27 Bytes
Word size = 4 Bytes = 2 ^ 2 Bytes

Logical Address Space (in words) = (2 ^ 27) / (2 ^ 2) = 2 ^ 25 Words
Logical Address = 25 Bits

In general,

If, logical address space = L words
Then, Logical Address = Log_2L bits

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 and every memory location, regardless of 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.

This tutorial will teach you basic concepts related to Memory Management.

Process Address Space

The process address space is the set of logical addresses that a process references in its code. For example, when 32-bit addressing is in use, addresses can range from 0 to 0x7fffffff; that is, 2^31 possible numbers, for a total theoretical size of 2 gigabytes.

The operating system takes care of mapping the logical addresses to physical addresses at the time of memory allocation to the program. There are three types of addresses used in a program before and after memory is allocated −

S.N.	Memory Addresses & Description
1	**Symbolic addresses** The addresses used in a source code. The variable names, constants, and instruction labels are the basic elements of the symbolic address space.

2	**Relative addresses** At the time of compilation, a compiler converts symbolic addresses into relative addresses.
3	**Physical addresses** The loader generates these addresses at the time when a program is loaded into main memory.

Virtual and physical addresses are the same in compile-time and load-time address-binding schemes. Virtual and physical addresses differ in execution-time address-binding scheme.

The set of all logical addresses generated by a program is referred to as a **logical address space**. The set of all physical addresses corresponding to these logical addresses is referred to as a **physical address space.**

The runtime mapping from virtual to physical address is done by the memory management unit (MMU) which is a hardware device. MMU uses following mechanism to convert virtual address to physical address.

- The value in the base register is added to every address generated by a user process, which is treated as offset at the time it is sent to memory. For example, if the base register value is 10000, then an attempt by the user to use address location 100 will be dynamically reallocated to location 10100.
- The user program deals with virtual addresses; it never sees the real physical addresses.

Static vs Dynamic Loading

The choice between Static or Dynamic Loading is to be made at the time of computer program being developed. If you have to load your program

statically, then at the time of compilation, the complete programs will be compiled and linked without leaving any external program or module dependency. The linker combines the object program with other necessary object modules into an absolute program, which also includes logical addresses.

If you are writing a Dynamically loaded program, then your compiler will compile the program and for all the modules which you want to include dynamically, only references will be provided and rest of the work will be done at the time of execution.

At the time of loading, with **static loading**, the absolute program (and data) is loaded into memory in order for execution to start.

If you are using **dynamic loading**, dynamic routines of the library are stored on a disk in relocatable form and are loaded into memory only when they are needed by the program.

Static vs Dynamic Linking

As explained above, when static linking is used, the linker combines all other modules needed by a program into a single executable program to avoid any runtime dependency.

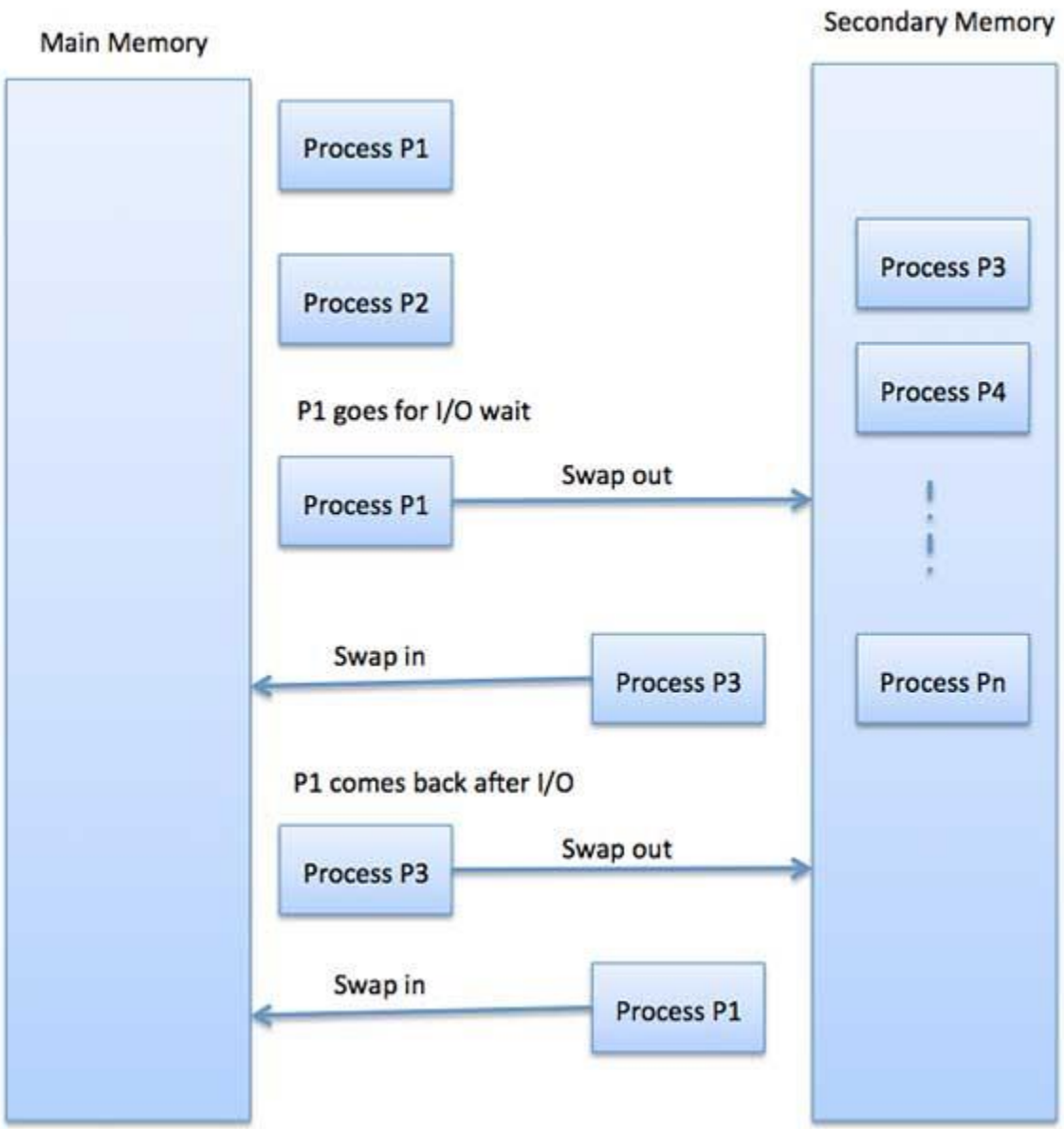
When dynamic linking is used, it is not required to link the actual module or library with the program, rather a reference to the dynamic module is provided at the time of compilation and linking. Dynamic Link Libraries (DLL) in Windows and Shared Objects in Unix are good examples of dynamic libraries.

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 to regain main memory.

Let us assume that the user process is of size 2048KB and on a standard hard disk where swapping will take place has a data transfer rate around 1 MB per second. The actual transfer of the 1000K process to or from memory will take

```
2048KB / 1024KB per second
= 2 seconds
= 2000 milliseconds
```

Now considering in and out time, it will take complete 4000 milliseconds plus other overhead where the process competes to regain main memory.

Memory Allocation

Main memory usually has two partitions –

- **Low Memory** – Operating system resides in this memory.
- **High Memory** – User processes are held in high memory.

Operating system uses the following memory allocation mechanism.

S.N.	Memory Allocation & Description
1	**Single-partition allocation** In this type of allocation, relocation-register scheme is used to protect user processes from each other, and from changing operating-system code and data. Relocation register contains value of smallest physical address whereas limit register contains range of logical addresses. Each logical address must be less than the limit register.

2	**Multiple-partition allocation** In this type of allocation, main memory is divided into a number of 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.

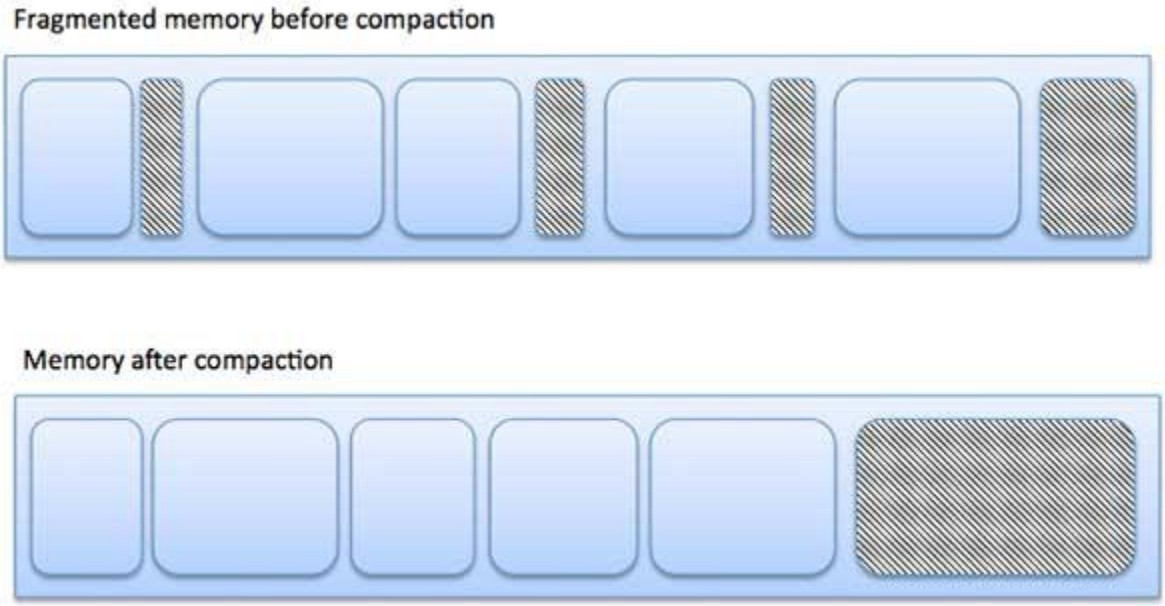
Fragmentation

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

Fragmentation is of two types –

S.N.	Fragmentation & Description
1	**External fragmentation** Total memory space is enough to satisfy a request or to reside a process in it, but it is not contiguous, so it cannot be used.
2	**Internal fragmentation** Memory block assigned to process is bigger. Some portion of memory is left unused, as it cannot be used by another process.

The following diagram shows how fragmentation can cause waste of memory and a compaction technique can be used to create more free memory out of fragmented memory –



External fragmentation can be reduced by compaction or shuffle memory contents to place all free memory together in one large block. To make compaction feasible, relocation should be dynamic.

The internal fragmentation can be reduced by effectively assigning the smallest partition but large enough for the process.

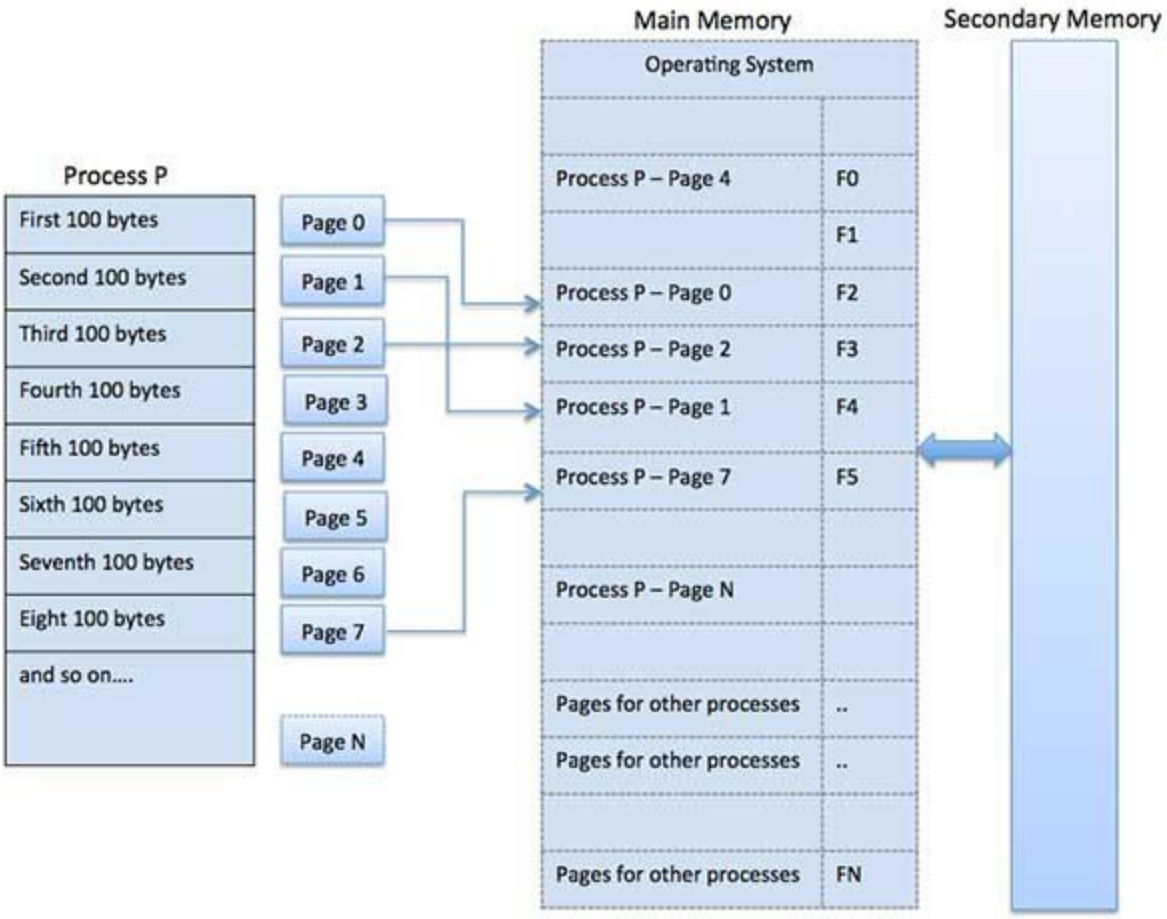
Paging

A computer can address more memory than the amount physically installed on the system. This extra memory is actually called virtual memory and it is a section of a hard that's set up to emulate the computer's RAM. Paging technique plays an important role in implementing virtual memory.

Paging is a memory management technique in which process address space is broken into blocks of the same size called **pages** (size is power of 2, between 512 bytes and 8192 bytes). The size of the process is measured in the number of pages.

Similarly, main memory is divided into small fixed-sized blocks of (physical) memory called **frames** and the size of a frame is kept the same as that of a

page to have optimum utilization of the main memory and to avoid external fragmentation.



Address Translation

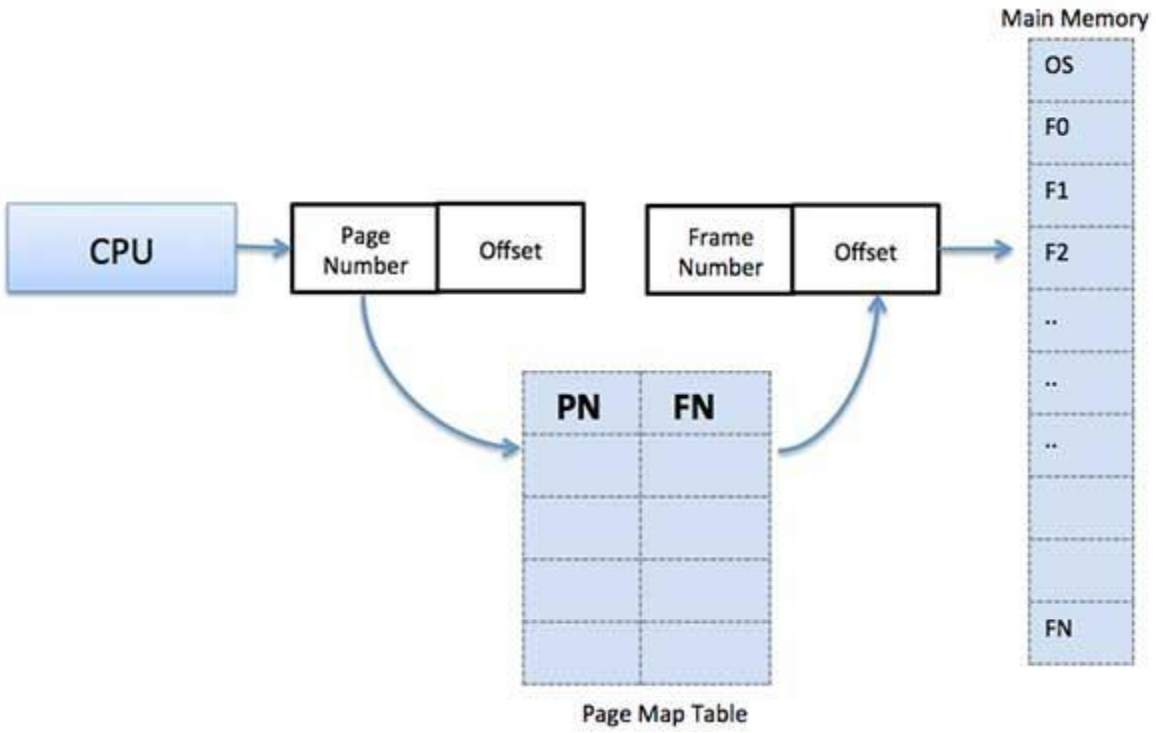
Page address is called **logical address** and represented by **page number**and the **offset**.

```
Logical Address = Page number + page offset
```

Frame address is called **physical address** and represented by a **frame number** and the **offset**.

```
Physical Address = Frame number + page offset
```

A data structure called **page map table** is used to keep track of the relation between a page of a process to a frame in physical memory.



When the system allocates a frame to any page, it translates this logical address into a physical address and create entry into the page table to be used throughout execution of the program.

When a process is to be executed, its corresponding pages are loaded into any available memory frames. Suppose you have a program of 8Kb but your memory can accommodate only 5Kb at a given point in time, then the paging concept will come into picture. When a computer runs out of RAM, the operating system (OS) will move idle or unwanted pages of memory to secondary memory to free up RAM for other processes and brings them back when needed by the program.

This process continues during the whole execution of the program where the OS keeps removing idle pages from the main memory and write them onto the secondary memory and bring them back when required by the program.

Advantages and Disadvantages of Paging

Here is a list of advantages and disadvantages of paging –

- Paging reduces external fragmentation, but still suffer from internal fragmentation.
- Paging 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.

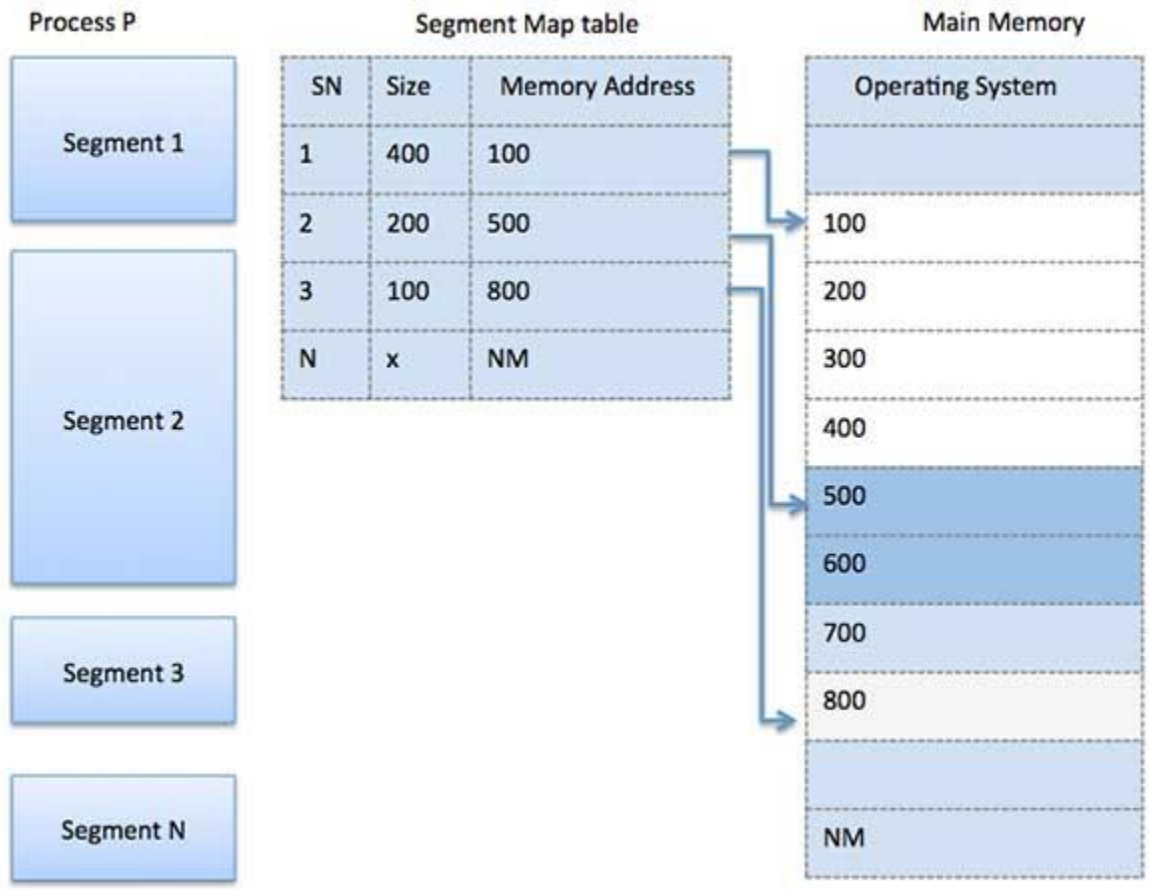
Segmentation

Segmentation is a memory management technique in which each job is divided into several segments of different sizes, one for each module that contains pieces that perform related functions. Each segment is actually a different logical address space of the program.

When a process is to be executed, its corresponding segmentation are loaded into non-contiguous memory though every segment is loaded into a contiguous block of available memory.

Segmentation memory management works very similar to paging but here segments are of variable-length where as in paging pages are of fixed size.

A program segment contains the program's main function, utility functions, data structures, and so on. The operating system maintains a **segment map table** for every process and a list of free memory blocks along with segment numbers, their size and corresponding memory locations in main memory. For each segment, the table stores the starting address of the segment and the length of the segment. A reference to a memory location includes a value that identifies a segment and an offset.


Process P
Segment Map table
Main Memory
Segment 1
Segment 2
Segment 3
Segment N
SN
Size
Memory Address
1
400
100
2
200
500
3
100
800
N
x
NM
Operating System
100
200
300
400
500
600
700
800
NM

\

Unit -4:

Virtual memory:

A computer can address more memory than the amount physically installed on the system. This extra memory is actually called **virtual memory** and it is a section of a hard disk that's set up to emulate the computer's RAM.

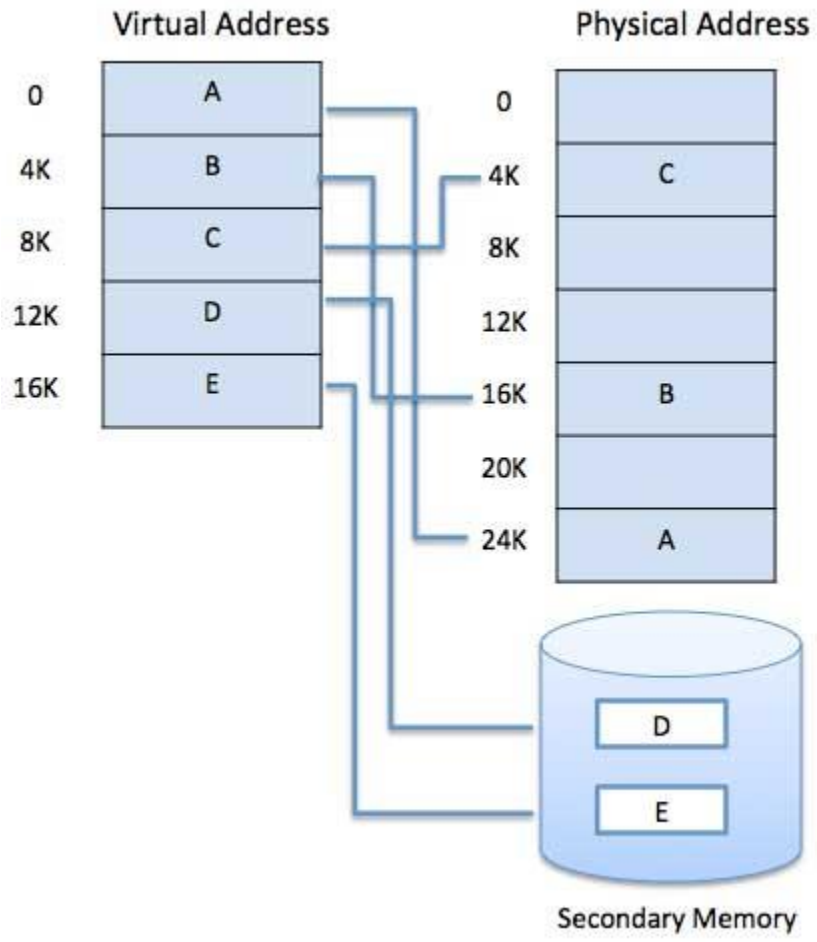
The main visible advantage of this scheme is that programs can be larger than physical memory. Virtual memory serves two purposes. First, it allows us to extend the use of physical memory by using disk. Second, it allows us to have memory protection, because each virtual address is translated to a physical address.

Following are the situations, when entire program is not required to be loaded fully in main memory.

- User written error handling routines are used only when an error occurred in the data or computation.
- Certain options and features of a program may be used rarely.
- Many tables are assigned a fixed amount of address space even though only a small amount of the table is actually used.
- The ability to execute a program that is only partially in memory would counter many benefits.
- Less number of I/O would be needed to load or swap each user program into memory.
- A program would no longer be constrained by the amount of physical memory that is available.

- Each user program could take less physical memory, more programs could be run the same time, with a corresponding increase in CPU utilization and throughput.

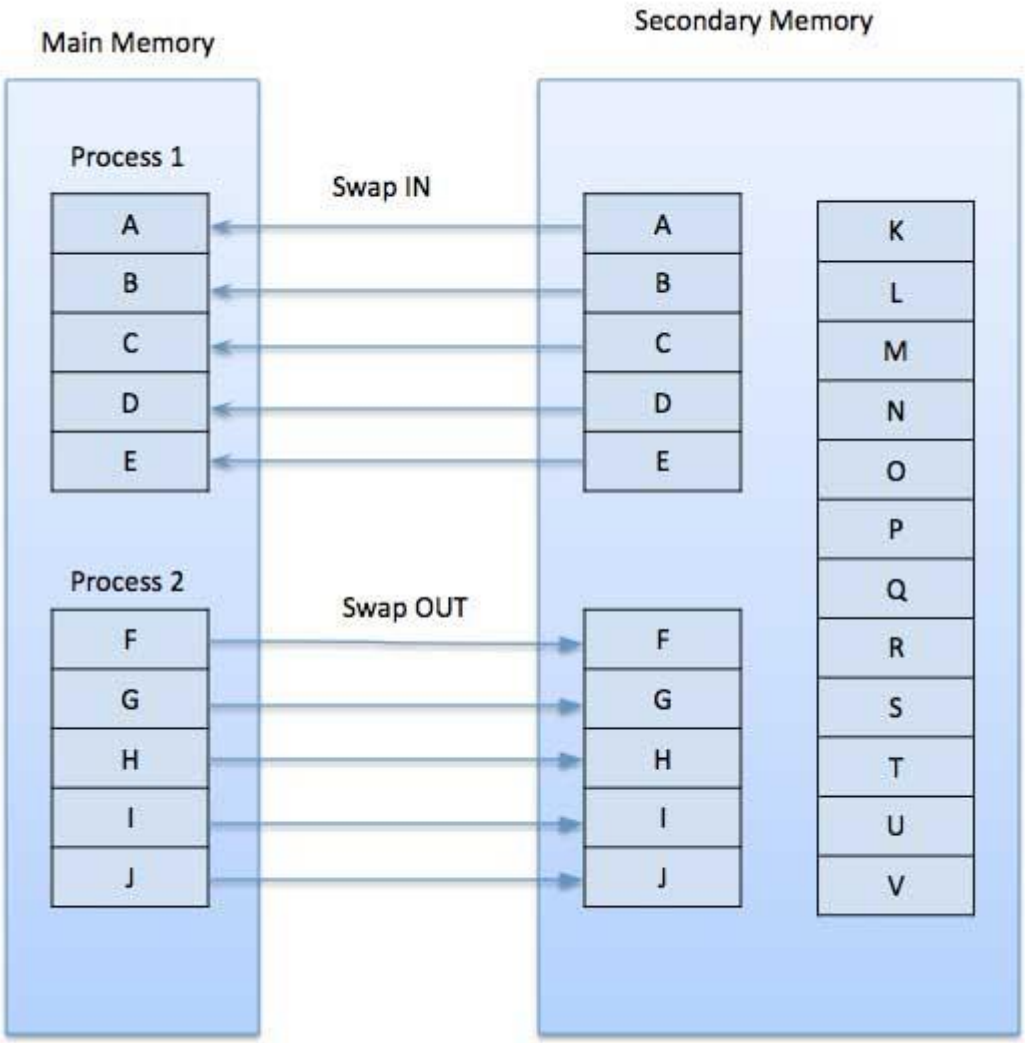
Modern microprocessors intended for general-purpose use, a memory management unit, or MMU, is built into the hardware. The MMU's job is to translate virtual addresses into physical addresses. A basic example is given below –



Virtual memory is commonly implemented by demand paging. It can also be implemented in a segmentation system. Demand segmentation can also be used to provide virtual memory.

Demand Paging

A demand paging system is quite similar to a paging system with swapping where processes reside in secondary memory and pages are loaded only on demand, not in advance. When a context switch occurs, the operating system does not copy any of the old program's pages out to the disk or any of the new program's pages into the main memory Instead, it just begins executing the new program after loading the first page and fetches that program's pages as they are referenced.



While executing a program, if the program references a page which is not available in the main memory because it was swapped out a little ago, the processor treats this invalid memory reference as a **page fault** and

transfers control from the program to the operating system to demand the page back into the memory.

Advantages

Following are the advantages of Demand Paging –

- Large virtual memory.
- More efficient use of memory.
- There is no limit on degree of multiprogramming.

Disadvantages

- Number of tables and the amount of processor overhead for handling page interrupts are greater than in the case of the simple paged management techniques.

Page Replacement Algorithm

Page replacement algorithms are the techniques using which an Operating System decides which memory pages to swap out, write to disk when a page of memory needs to be allocated. Paging happens whenever a page fault occurs and a free page cannot be used for allocation purpose accounting to reason that pages are not available or the number of free pages is lower than required pages.

When the page that was selected for replacement and was paged out, is referenced again, it has to read in from disk, and this requires for I/O completion. This process determines the quality of the page replacement algorithm: the lesser the time waiting for page-ins, the better is the algorithm.

A page replacement algorithm looks at the limited information about accessing the pages provided by hardware, and tries to select which pages should be replaced to minimize the total number of page misses, while balancing it with the costs of primary storage and processor time of the

algorithm itself. There are many different page replacement algorithms. We evaluate an algorithm by running it on a particular string of memory reference and computing the number of page faults,

Reference String

The string of memory references is called reference string. Reference strings are generated artificially or by tracing a given system and recording the address of each memory reference. The latter choice produces a large number of data, where we note two things.

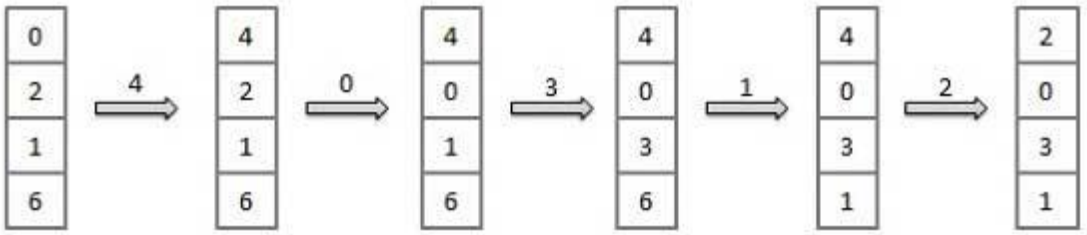
- For a given page size, we need to consider only the page number, not the entire address.
- If we have a reference to a page **p**, then any immediately following references to page **p** will never cause a page fault. Page p will be in memory after the first reference; the immediately following references will not fault.
- For example, consider the following sequence of addresses – 123,215,600,1234,76,96
- If page size is 100, then the reference string is 1,2,6,12,0,0

First In First Out (FIFO) algorithm

- Oldest page in main memory is the one which will be selected for replacement.
- Easy to implement, keep a list, replace pages from the tail and add new pages at the head.

Reference String : 0, 2, 1, 6, 4, 0, 1, 0, 3, 1, 2, 1

Misses : x x x x x x x x x



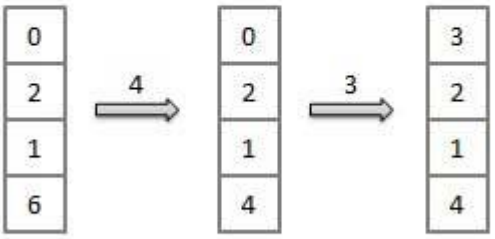
Fault Rate = 9 / 12 = 0.75

Optimal Page algorithm

- An optimal page-replacement algorithm has the lowest page-fault rate of all algorithms. An optimal page-replacement algorithm exists, and has been called OPT or MIN.
- Replace the page that will not be used for the longest period of time. Use the time when a page is to be used.

Reference String : 0, 2, 1, 6, 4, 0, 1, 0, 3, 1, 2, 1

Misses : x x x x x x



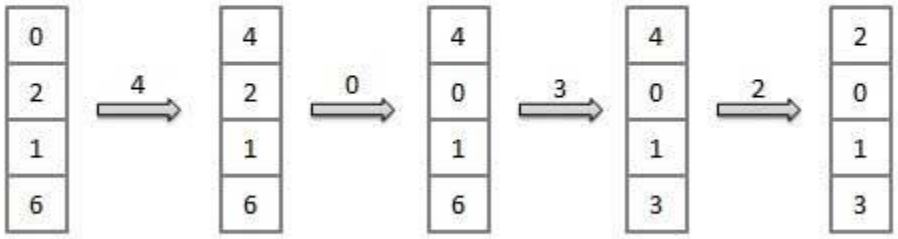
Fault Rate = 6 / 12 = 0.50

Least Recently Used (LRU) algorithm

- Page which has not been used for the longest time in main memory is the one which will be selected for replacement.
- Easy to implement, keep a list, replace pages by looking back into time.

Reference String : 0, 2, 1, 6, 4, 0, 1, 0, 3, 1, 2, 1

Misses : x x x x x x x x



Fault Rate = 8 / 12 = 0.67

Page Buffering algorithm

- To get a process start quickly, keep a pool of free frames.
- On page fault, select a page to be replaced.
- Write the new page in the frame of free pool, mark the page table and restart the process.
- Now write the dirty page out of disk and place the frame holding replaced page in free pool.

Least frequently Used(LFU) algorithm

- The page with the smallest count is the one which will be selected for replacement.

-
- This algorithm suffers from the situation in which a page is used heavily during the initial phase of a process, but then is never used again.

Most frequently Used(MFU) algorithm

- This algorithm is based on the argument that the page with the smallest count was probably just brought in and has yet to be used.

Allocation of frames

An important aspect of operating systems, virtual memory is implemented using demand paging. Demand paging necessitates the development of a page-replacement algorithmand a **frame allocation algorithm**. Frame allocation algorithms are used if you have multiple processes; it helps decide how many frames to allocate to each process.
There are various constraints to the strategies for the allocation of frames:

- You cannot allocate more than the total number of available frames.
- At least a minimum number of frames should be allocated to each process. This constraint is supported by two reasons. The first reason is, as less number of frames are allocated, there is an increase in the page fault ratio, decreasing the performance of the execution of the process. Secondly, there should be enough frames to hold all the different pages that any single instruction can reference.

Frame allocation algorithms –
The two algorithms commonly used to allocate frames to a process are:

1. **Equal allocation:** In a system with x frames and y processes, each process gets equal number of frames, i.e. x/y. For instance, if the system has 48 frames and 9 processes, each process will get 5 frames. The three frames which are not allocated to any process can be used as a free-frame buffer pool.
    - **Disadvantage:** In systems with processes of varying sizes, it does not make much sense to give each process equal frames. Allocation of a large number of frames to a small process will

eventually lead to the wastage of a large number of allocated unused frames.

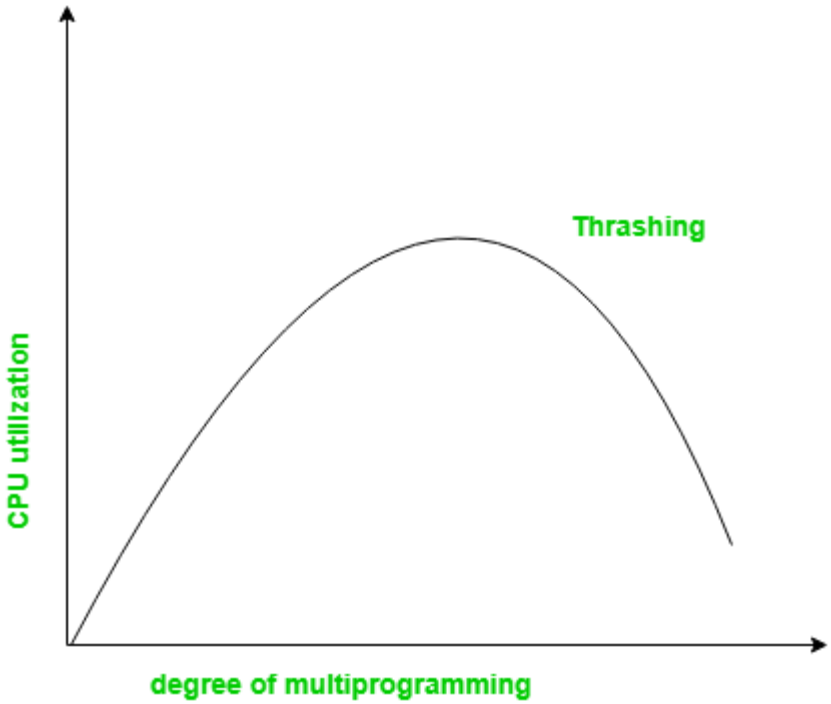
2. **Proportional allocation:** Frames are allocated to each process according to the process size.
   For a process p_i of size s_i, the number of allocated frames is $\mathbf{a_i = (s_i/S)*m}$, where S is the sum of the sizes of all the processes and m is the number of frames in the system. For instance, in a system with 62 frames, if there is a process of 10KB and another process of 127KB, then the first process will be allocated (10/137)*62 = 4 frames and the other process will get (127/137)*62 = 57 frames.
   - **Advantage:** All the processes share the available frames according to their needs, rather than equally.

Global vs Local Allocation –
The number of frames allocated to a process can also dynamically change depending on whether you have used **global replacement** or **local replacement** for replacing pages in case of a page fault.

1. **Local replacement:** When a process needs a page which is not in the memory, it can bring in the new page and allocate it a frame from its own set of allocated frames only.
   - **Advantage:** The pages in memory for a particular process and the page fault ratio is affected by the paging behavior of only that process.
   - **Disadvantage:** A low priority process may hinder a high priority process by not making available to the high priority process its frames.
2. **Global replacement:** When a process needs a page which is not in the memory, it can bring in the new page and allocate it a frame from the set of all frames, even if that frame is currently allocated to some other process; that is, one process can take a frame from another.
   - **Advantage:** Does not hinder the performance of processes and hence results in greater system throughput.
   - **Disadvantage:** The page fault ratio of a process can not be solely controlled by the process itself. The pages in memory for a process depends on the paging behavior of other processes as well.

Thrashing :

Thrashing is a condition or a situation when the system is spending a major portion of its time in servicing the page faults, but the actual processing done is very negligible.



The basic concept involved is that if a process is allocated too few frames, then there will be too many and too frequent page faults. As a result, no useful work would be done by the CPU and the CPU utilisation would fall drastically. The long-term scheduler would then try to improve the CPU utilisation by loading some more processes into the memory thereby increasing the degree of multiprogramming. This would result in a further decrease in the CPU utilization triggering a chained reaction of higher page faults followed by an increase in the degree of multiprogramming, called Thrashing.

Locality Model –

A locality is a set of pages that are actively used together. The locality model states that as a process executes, it moves from one locality to another. A program is generally composed of several different localities which may overlap.

For example when a function is called, it defines a new locality where memory references are made to the instructions of the function call, it's local and global variables, etc. Similarly, when the function is exited, the process leaves this locality.

Techniques to handle:

1. **Working Set Model –**
   This model is based on the above-stated concept of the Locality Model.
   The basic principle states that if we allocate enough frames to a process to accommodate its current locality, it will only fault whenever it moves to some new locality. But if the allocated frames are lesser than the size of the current locality, the process is bound to thrash.

   According to this model, based on a parameter A, the working set is defined as the set of pages in the most recent 'A' page references. Hence, all the actively used pages would always end up being a part of the working set.

   The accuracy of the working set is dependant on the value of parameter A. If A is too large, then working sets may overlap. On the other hand, for smaller values of A, the locality might not be covered entirely.

   If D is the total demand for frames and is the working set size for a process i,

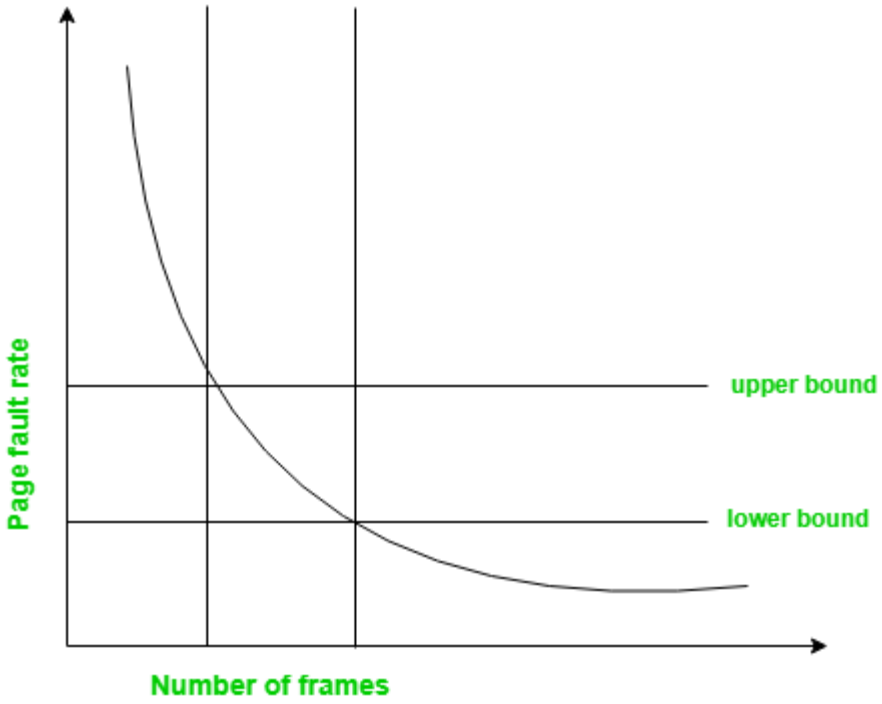
   Now, if 'm' is the number of frames available in the memory, there are 2 possibilities:

   - (i) D>m i.e. total demand exceeds the number of frames, then thrashing will occur as some processes would not get enough frames.
   - (ii) D<=m, then there would be no thrashing.

   If there are enough extra frames, then some more processes can be loaded in the memory. On the other hand, if the summation of working set sizes exceeds the availability of frames, then some of the processes have to be suspended(swapped out of memory).

This technique prevents thrashing along with ensuring the highest degree of multiprogramming possible. Thus, it optimizes CPU utilisation.

2. **Page Fault Frequency –**
   A more direct approach to handle thrashing is the one that uses Page-Fault Frequency concept.



File Concept

10.1.1 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** (e.g. inode number)
  - **Type** - Text, executable, other binary, etc.
  - **Location** - on the hard drive.

- **Size**
- **Protection**
- **Time & Date**
- **User ID**

10.1.2 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.
  - **Disk location of the file.**
  - **Access rights**
- 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.

10.1.3 File Types

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

- Macintosh stores a creator attribute for each file, according to the program that first created it with the create( ) system call.
- UNIX stores magic numbers at the beginning of certain files. (Experiment with the "file" command, especially in directories such as /bin and /dev)

10.1.4 File Structure

- Some files contain an internal structure, which may or may not be known to the OS.
- For the OS to support particular 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.

10.1.5 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 general rule, half a physical block is wasted for each file, and the larger the block sizes the more space is lost to internal fragmentation.

10.2 Access Methods

10.2.1 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.

10.2.2 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.

10.2.3 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.

10.3 Directory Structure

10.3.1 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 be used for raw storage, swap space, etc.)
- Or, multiple physical disks can be combined into one ***volume***, i.e. a larger virtual disk, with its own filesystem spanning the physical disks.

10.3.2 Directory Overview

- Directory operations to be supported include:
    - Search for a file
    - Create a file - add to the directory

- Delete a file - erase from the directory
- List a directory - possibly ordered in different ways.
- Rename a file - may change sorting order
- Traverse the file system.

10.3.3. Single-Level Directory

- Simple to implement, but each file must have a unique name.

10.3.4 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.

10.3.5 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 or not 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.

10.3.6 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?

10.3.7 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. (chkdsk in DOS and fsck in UNIX search for these problems, among others, even though cycles are not supposed to be allowed in either system. Disconnected disk blocks that are not marked as free are added back to the file systems with made-up file names, and can usually be safely deleted.)

10.4 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 actually 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.

10.5 File Sharing

10.5.1 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 (**U**ser), the **G**roup, and to the rest of the world (the universe, a.k.a. **O**thers.)
  - Some systems have more complicated access control, allowing or denying specific accesses to specifically named users or groups.

10.5.2 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.

10.5.2.1 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. (I.e. this is most applicable across multiple computers managed by the same organization, shared by a common group of users.)
- The same computer can be both a client and a server. (E.g. cross-linked file systems.)
- There are a number of 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.

10.5.2.2 Distributed Information Systems

- The ***Domain Name System, DNS,*** provides for a unique naming system across all of 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.*** User names 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.

10.5.2.3 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 or not 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.

10.5.3 Consistency Semantics

- ***Consistency Semantics*** deals with the consistency between the views of shared files on a networked system. When one user changes the file, when do other users see the changes?
- At first glance this appears to have all of the synchronization issues discussed in Chapter 6. Unfortunately the long delays involved in network operations prohibit the use of atomic operations as discussed in that chapter.

10.5.3.1 UNIX Semantics

- The UNIX file system uses the following semantics:
  - Writes to an open file are immediately visible to any other user who has the file open.
  - One implementation uses a shared location pointer, which is adjusted for all sharing users.
- The file is associated with a single exclusive physical resource, which may delay some accesses.

10.5.3.2 Session Semantics

- The Andrew File System, AFS uses the following semantics:
  - Writes to an open file are not immediately visible to other users.
  - When a file is closed, any changes made become available only to users who open the file at a later time.
- According to these semantics, a file can be associated with multiple (possibly different) views. Almost no constraints are imposed on scheduling accesses. No user is delayed in reading or writing their personal copy of the file.
- AFS file systems may be accessible by systems around the world. Access control is maintained through (somewhat) complicated access control lists, which may grant access to the entire world (literally) or to specifically named users accessing the files from specifically named remote environments.

10.5.3.3 Immutable-Shared-Files Semantics

- Under this system, when a file is declared as ***shared*** by its creator, it becomes immutable and the name cannot be re-used for any other resource. Hence it becomes read-only, and shared access is simple.

10.6 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.

10.6.1 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.

10.6.2 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.)

bit	Files	Directories
R	Read (view) file contents.	Read directory contents. Required to get a listing of the directory.
W	Write (change) file	Change directory contents. Required to create or delete files.

	contents.	
X	Execute file contents as a program.	Access detailed directory information. Required to get a long listing, or to access any specific file in the directory. Note that if a user has X but not R permissions on a directory, they can still access specific files, but only if they already know the name of the file they are trying to access.

- 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. (See "man chmod" for full details.) The RWX bits control the following privileges for ordinary files and directories:

- In addition there are some special bits that can also be applied:
    - The set user ID (SUID) bit and/or the set group ID (SGID) bits applied to executable files temporarily change the identity of whoever runs the program to match that of the owner / group of the executable program. This allows users running specific programs to have access to files (***while running that program***) to which they would normally be unable to access. Setting of these two bits is usually restricted to root, and must be done with caution, as it introduces a potential security leak.
    - The sticky bit on a directory modifies write permission, allowing users to only delete files for which they are the owner. This allows everyone to create files in /tmp, for example, but to only delete files which they have created, and not anyone else's.
    - The SUID, SGID, and sticky bits are indicated with an S, S, and T in the positions for execute permission for the user, group, and others, respectively. If the letter is lower case, (s, s, t), then the corresponding execute permission is not also given. If it is upper case, (S, S, T), then the coresponding execute permission IS given.
    - The numeric form of chmod is needed to set these advanced bits.

- Windows adjusts files access through a simple GUI:

10.6.3 Other Protection Approaches and Issues

- Some systems can apply passwords, either to individual files, or to specific sub-directories, or to the entire system. There is a trade-off between the number of passwords that must be maintained (and remembered by the users) and the amount of information that is vulnerable to a lost or forgotten password.
- Older systems which did not originally have multi-user file access permissions (DOS and older versions of Mac) must now be ***retrofitted*** if they are to share files on a network.
- Access to a file requires access to all the files along its path as well. In a cyclic directory structure, users may have different access to the same file accessed through different paths.
- Sometimes just the knowledge of the existence of a file of a certain name is a security (or privacy) concern. Hence the distinction between the R and X bits on UNIX directorie

Allocation methods:

Files are allocated disk spaces by operating system. Operating systems deploy following three main ways to allocate disk space to files.

- Contiguous Allocation
- Linked Allocation
- Indexed Allocation

Contiguous Allocation

- Each file occupies a contiguous address space on disk.
- Assigned disk address is in linear order.
- Easy to implement.

- External fragmentation is a major issue with this type of allocation technique.

Linked Allocation

- Each file carries a list of links to disk blocks.
- Directory contains link / pointer to first block of a file.
- No external fragmentation
- Effectively used in sequential access file.
- Inefficient in case of direct access file.

Indexed Allocation

- Provides solutions to problems of contiguous and linked allocation.
- A index block is created having all pointers to files.
- Each file has its own index block which stores the addresses of disk space occupied by the file.
- Directory contains the addresses of index blocks of files.

Freespace management

The system keeps tracks of the free disk blocks for allocating space to files when they are created. Also, to reuse the space released from deleting the files, free space management becomes crucial. The system maintains a free space list which keeps track of the disk blocks that are not allocated to some file or directory. The free space list can be implemented mainly as:

1. **Bitmap or Bit vector –**
   A Bitmap or Bit Vector is series or collection of bits where each bit corresponds to a disk block. The bit can take two values: 0 and 1: *0 indicates that the block is allocated* and 1 indicates a free block. The given instance of disk blocks on the disk in *Figure 1* (where green

blocks are allocated) can be represented by a bitmap of 16 bits as: **0000111000000110**.

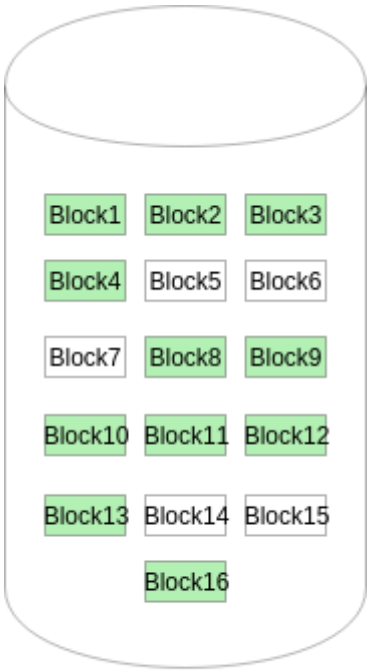


Figure - 1

Advantages –

- Simple to understand.
- Finding the first free block is efficient. It requires scanning the words (a group of 8 bits) in a bitmap for a non-zero word. (A 0-valued word has all bits 0). The first free block is then found by scanning for the first 1 bit in the non-zero word.

The block number can be calculated as: *(number of bits per word) *(number of 0-values words) + offset of bit first bit 1 in the non-zero word* .

For the *Figure-1*, we scan the bitmap sequentially for the first non-zero word.

The first group of 8 bits (00001110) constitute a non-zero word since all bits are not 0. After the non-0 word is found, we look for the first 1 bit. This is the 5th bit of the non-zero word. So, offset = 5. Therefore, the first free block number = 8*0+5 = 5.

2. **Linked List –**

In this approach, the free disk blocks are linked together i.e. a free block contains a pointer to the next free block. The block number of

the very first disk block is stored at a separate location on disk and is also cached in memory.

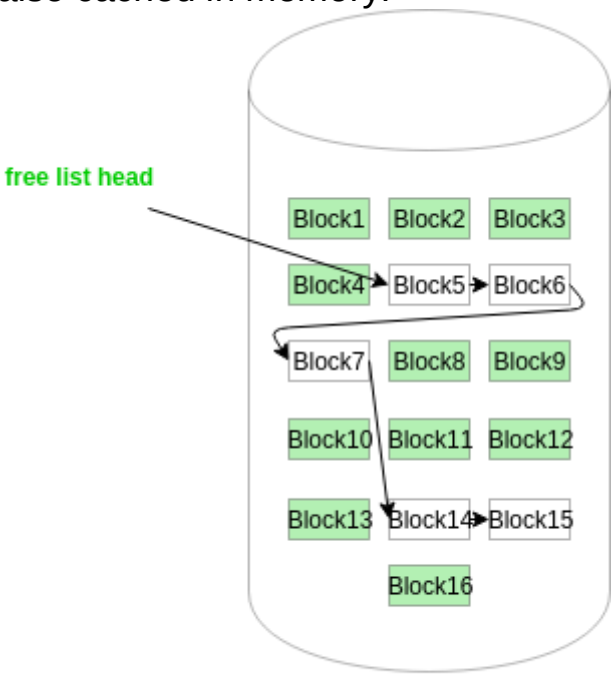


Figure - 2

In *Figure-2*, the free space list head points to Block 5 which points to Block 6, the next free block and so on. The last free block would contain a null pointer indicating the end of free list.
A drawback of this method is the I/O required for free space list traversal.

3. **Grouping** –
   This approach stores the address of the free blocks in the first free block. The first free block stores the address of some, say n free blocks. Out of these n blocks, the first n-1 blocks are actually free and the last block contains the address of next free n blocks.
   An **advantage** of this approach is that the addresses of a group of free disk blocks can be found easily.
4. **Counting** –
   This approach stores the address of the first free disk block and a number n of free contiguous disk blocks that follow the first block. Every entry in the list would contain:
   1. Address of first free disk block
   2. A number n

For example, *in Figure-1*, the first entry of the free space list would be: ([Address of Block 5], 2), because 2 contiguous free blocks follow block 5.

Directory Implementation

There is the number of algorithms by using which, the directories can be implemented. However, the selection of an appropriate directory implementation algorithm may significantly affect the performance of the system.

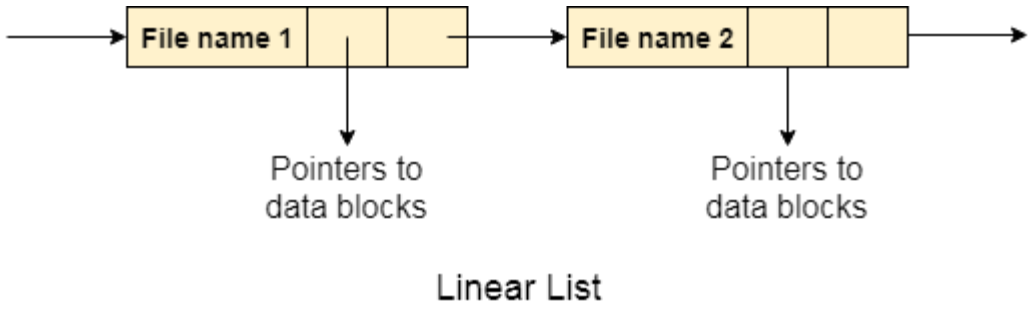
The directory implementation algorithms are classified according to the data structure they are using. There are mainly two algorithms which are used in these days.

1. Linear List

In this algorithm, all the files in a directory are maintained as singly lined list. Each file contains the pointers to the data blocks which are assigned to it and the next file in the directory.

Characteristics

1. When a new file is created, then the entire list is checked whether the new file name is matching to a existing file name or not. In case, it doesn't exist, the file can be created at the beginning or at the end. Therefore, searching for a unique name is a big concern because traversing the whole list takes time.
2. The list needs to be traversed in case of every operation (creation, deletion, updating, etc) on the files therefore the systems become inefficient.



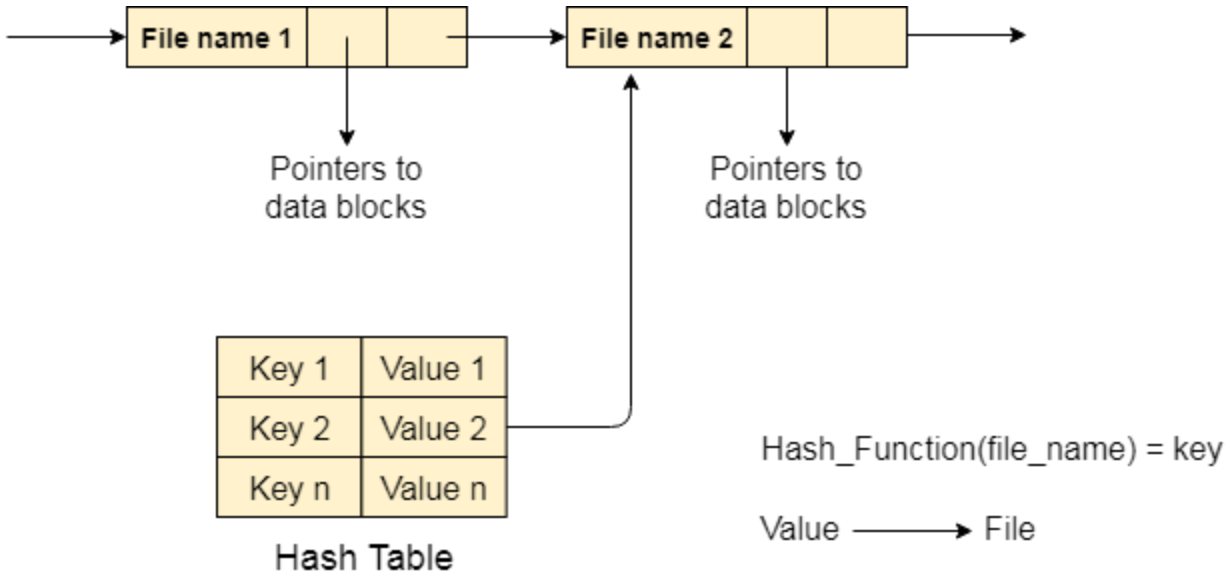
Linear List

2. Hash Table

To overcome the drawbacks of singly linked list implementation of directories, there is an alternative approach that is hash table. This approach suggests to use hash table along with the linked lists.

A key-value pair for each file in the directory gets generated and stored in the hash table. The key can be determined by applying the hash function on the file name while the key points to the corresponding file stored in the directory.

Now, searching becomes efficient due to the fact that now, entire list will not be searched on every operating. Only hash table entries are checked using the key and if an entry found then the corresponding file will be fetched using the value.



Hash Table

Efficiency and Performance

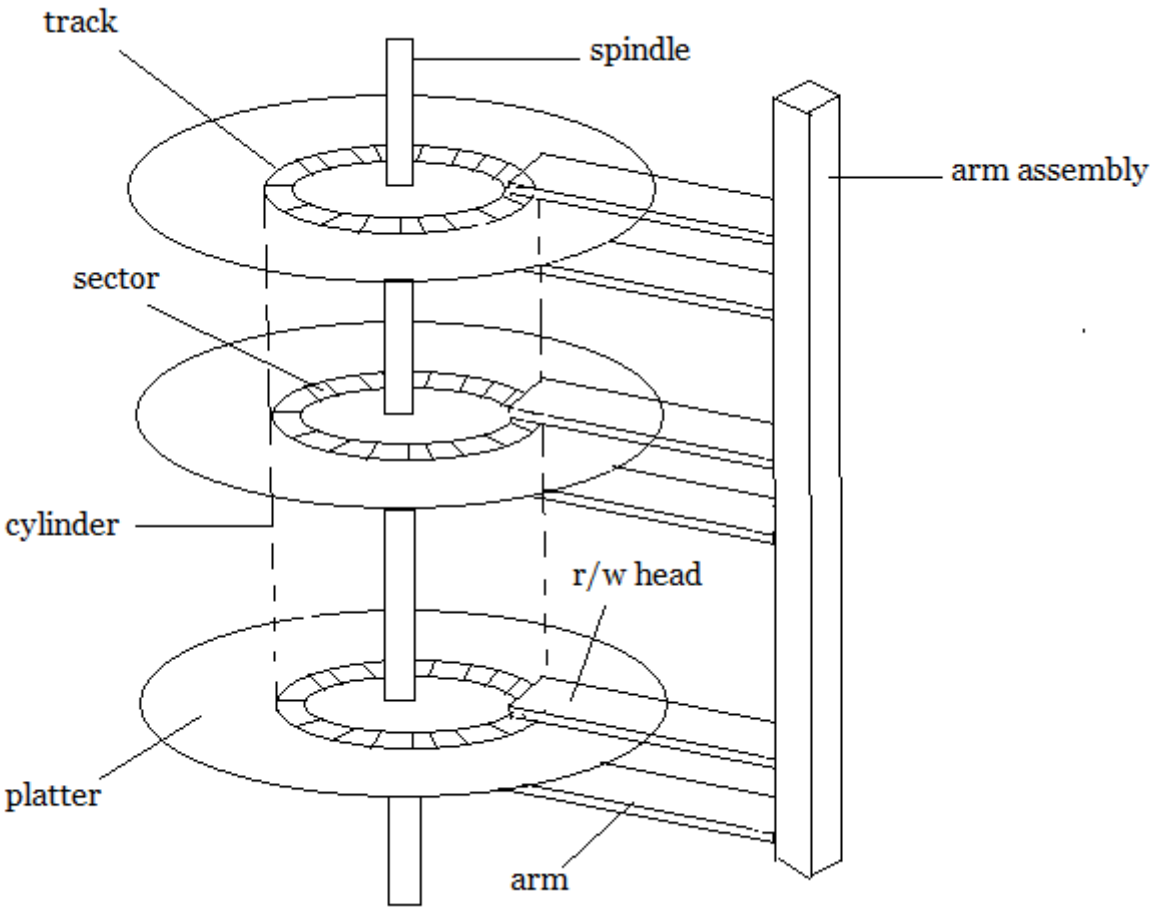
- Efficiency dependent on:
  - disk allocation and directory algorithms
  - types of data kept in file's directory entry
- Performance
  - disk cache – separate section of main memory for frequently used blocks
  - free-behind and read-ahead – techniques to optimize sequential access
  - improve PC performance by dedicating section of memory as virtual disk, or RAM disk.

Unit -5:

Overview of mass storage structure:

Disk Structure

In modern computers, most of the secondary storage is in the form of magnetic disks. Hence, knowing the structure of a magnetic disk is necessary to understand how the data in the disk is accessed by the computer.



Structure of a magnetic disk

A magnetic disk contains several **platters**. Each platter is divided into circular shaped **tracks**. The length of the tracks near the centre is less than the length of the tracks farther from the centre. Each track is further divided into **sectors**, as shown in the figure.

Tracks of the same distance from centre form a cylinder. A read-write head is used to read data from a sector of the magnetic disk.

The speed of the disk is measured as two parts:

- **Transfer rate:** This is the rate at which the data moves from disk to the computer.
- **Random access time:** It is the sum of the seek time and rotational latency.

Seek time is the time taken by the arm to move to the required track. **Rotational latency** is defined as the time taken by the arm to reach the required sector in the track.

Even though the disk is arranged as sectors and tracks physically, the data is logically arranged and addressed as an array of blocks of fixed size. The size of a block can be **512** or **1024** bytes. Each logical block is mapped with a sector on the disk, sequentially. In this way, each sector in the disk will have a logical address.

Disk Attachment

Disk drives can be attached either directly to a particular host (a local disk) or to a network.

Host-Attached Storage

- Local disks are accessed through I/O Ports as described earlier.
- The most common interfaces are IDE or ATA, each of which allow up to two drives per host controller.
- SATA is similar with simpler cabling.
- High end workstations or other systems in need of larger number of disks typically use SCSI disks:

    - The SCSI standard supports up to 16 ***targets*** on each SCSI bus, one of which is generally the host adapter and the other 15 of which can be disk or tape drives.
    - A SCSI target is usually a single drive, but the standard also supports up to 8 ***units*** within each target. These would generally be used for accessing individual disks within a RAID array. (See below.)
    - The SCSI standard also supports multiple host adapters in a single computer, i.e. multiple SCSI busses.
    - Modern advancements in SCSI include "fast" and "wide" versions, as well as SCSI-2.
    - SCSI cables may be either 50 or 68 conductors. SCSI devices may be external as well as internal.
    - See wikipedia for more information on the SCSI interface.
- FC is a high-speed serial architecture that can operate over optical fiber or four-conductor copper wires, and has two variants:
    - A large switched fabric having a 24-bit address space. This variant allows for multiple devices and multiple hosts to interconnect, forming the basis for the ***storage-area networks, SANs,*** to be discussed in a future section.
    - The ***arbitrated loop, FC-AL,*** that can address up to 126 devices (drives and controllers.)

Network-Attached Storage

- Network attached storage connects storage devices to computers using a remote procedure call, RPC, interface, typically with something like NFS filesystem mounts. This is convenient for allowing several computers in a group common access and naming conventions for shared storage.
- NAS can be implemented using SCSI cabling, or ***ISCSI*** uses Internet protocols and standard network connections, allowing long-distance remote access to shared files.
- NAS allows computers to easily share data storage, but tends to be less efficient than standard host-attached storage

Storage-Area Network

- A ***Storage-Area Network, SAN,*** connects computers and storage devices in a network, using storage protocols instead of network protocols.

- One advantage of this is that storage access does not tie up regular networking bandwidth.
- SAN is very flexible and dynamic, allowing hosts and devices to attach and detach on the fly.
- SAN is also controllable, allowing restricted access to certain hosts and devices.

Disk Scheduling

- As mentioned earlier, 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.

Disk Management

Disk Formatting

- Before a disk can be used, it has to be ***low-level formatted***, which means laying down all of the headers and trailers demarking 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. (See below.)
- 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 or inode structure), 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 (e.g. network daemons, sched, init, etc.), 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 a large number of 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 of 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. (Disk analysis tools could be either destructive or non-destructive.)
- 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. (Recall that blocks are tested with every write as well as with every read, so often errors can be detected before the write operation is complete, and the data simply written to a different sector instead.)
- 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 at all!
- 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.)

Dynamic memory allocation:

Dynamic memory allocation is when an executing program requests that the operating system give it a block of main memory. The program then uses this memory for some purpose. Usually the purpose is to add a node to a data structure. In object oriented languages, dynamic memory allocation is used to get the memory for a new object.

The memory comes from above the static part of the data segment. Programs may request memory and may also return previously dynamically allocated memory. Memory may be returned whenever it is no longer needed. Memory can be returned in any order without any relation to the order in which it was allocated. The heap may develop

"holes" where previously allocated memory has been returned between blocks of memory still in use.

A new dynamic request for memory might return a range of addresses out of one of the holes. But it might not use up all the hole, so further dynamic requests might be satisfied out of the original hole.

If too many small holes develop, memory is wasted because the total memory used by the holes may be large, but the holes cannot be used to satisfy dynamic requests. This situation is called **memory fragmentation**. Keeping track of allocated and deallocated memory is complicated. A modern operating system does all this.

Library functions:

System Calls and Library Functions

All operating systems provide service points through which programs request services from the kernel. All implementations of the UNIX System provide a well-defined, limited number of entry points directly into the kernel called *system calls* (recall Figure 1.1). Version 7 of the Research UNIX System provided about 50 system calls, 4.4BSD provided about 110, and SVR4 had around 120. Linux has anywhere between 240 and 260 system calls, depending on the version. FreeBSD has around 320.

The system call interface has always been documented in Section 2 of the *UNIX Programmer's Manual*. Its definition is in the C language, regardless of the actual implementation technique used on any given system to invoke a system call. This differs from many older operating systems, which traditionally defined the kernel entry points in the assembler language of the machine.

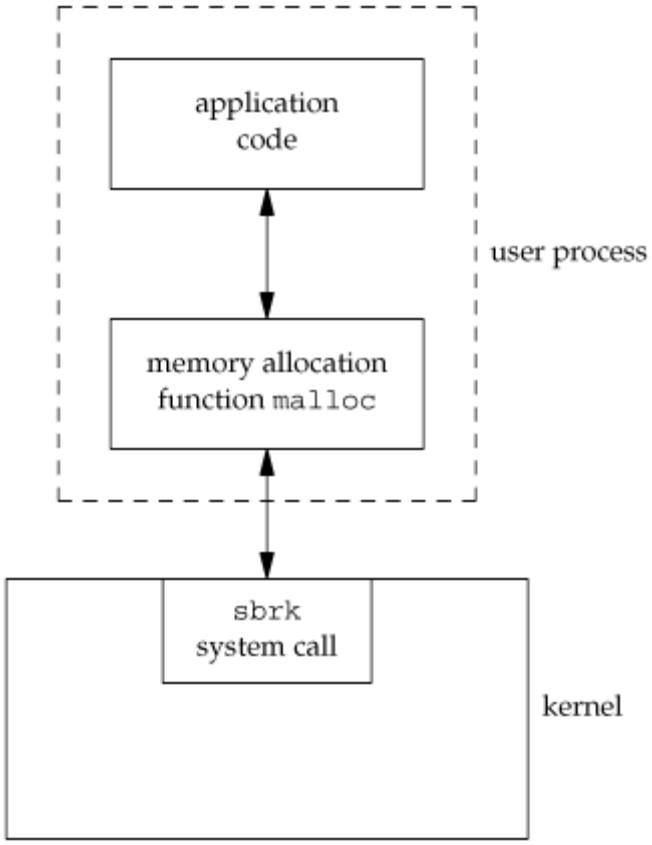
The technique used on UNIX systems is for each system call to have a function of the same name in the standard C library. The user process calls this function, using the standard C calling sequence. This function then invokes the appropriate kernel service, using whatever technique is required on the system. For example, the function may put one or more of the C arguments into general registers and then execute some machine instruction that generates a software interrupt in the kernel. For our purposes, we can consider the system calls as being C functions.

Section 3 of the *UNIX Programmer's Manual* defines the general-purpose functions available to programmers. These functions aren't entry points into the kernel, although they may invoke one or more of the kernel's system calls. For example, the `printf` function may use the `write` system call to output a string, but the `strcpy` (copy a string) and `atoi` (convert ASCII to integer) functions don't involve the kernel at all.

From an implementor's point of view, the distinction between a system call and a library function is fundamental. But from a user's perspective, the difference is not as critical. From our perspective in this text, both system calls and library functions appear as normal C functions. Both exist to provide services for application programs. We should realize, however, that we can replace the library functions, if desired, whereas the system calls usually cannot be replaced.

Consider the memory allocation function `malloc` as an example. There are many ways to do memory allocation and its associated garbage collection (best fit, first fit, and so on). No single technique is optimal for all programs. The UNIX system call that handles memory allocation, `sbrk`(2), is not a general-purpose memory manager. It increases or decreases the address space of the process by a specified number of bytes. How that space is managed is up to the process. The memory allocation function, `malloc`(3), implements one particular type of allocation. If we don't like its operation, we can define our own `malloc` function, which will probably use the `sbrk` system call. In fact, numerous software packages implement their own memory allocation algorithms with the `sbrk`system call. Figure 1.11 shows the relationship between the application, the `malloc` function, and the `sbrk` system call.

Figure 1.11. Separation of `malloc` function and `sbrk` system call

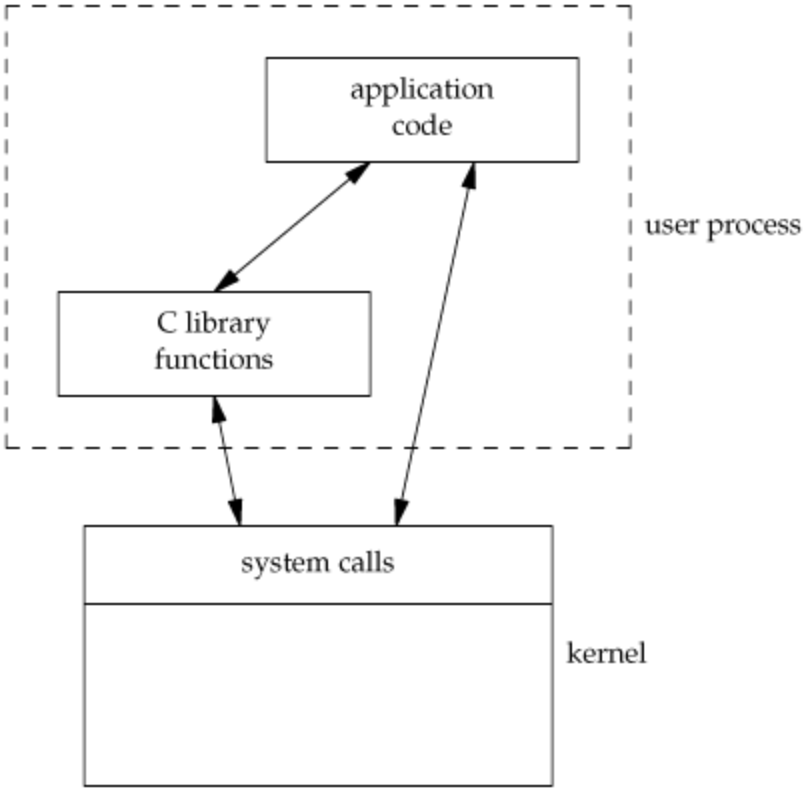


Here we have a clean separation of duties: the system call in the kernel allocates an additional chunk of space on behalf of the process. The `malloc` library function manages this space from user level.

Another example to illustrate the difference between a system call and a library function is the interface the UNIX System provides to determine the current time and date. Some operating systems provide one system call to return the time and another to return the date. Any special handling, such as the switch to or from daylight saving time, is handled by the kernel or requires human intervention. The UNIX System, on the other hand, provides a single system call that returns the number of seconds since the Epoch: midnight, January 1, 1970, Coordinated Universal Time. Any interpretation of this value, such as converting it to a human-readable time and date using the local time zone, is left to the user process. The standard C library provides routines to handle most cases. These library routines handle such details as the various algorithms for daylight saving time.

An application can call either a system call or a library routine. Also realize that many library routines invoke a system call. This is shown in Figure 1.12.

Figure 1.12. Difference between C library functions and system calls



SYSTEM PROTECTION:

14.1 Goals of Protection

- Obviously to prevent malicious misuse of the system by users or programs. See chapter 15 for a more thorough coverage of this goal.
- To ensure that each shared resource is used only in accordance with system *policies,* which may be set either by system designers or by system administrators.
- To ensure that errant programs cause the minimal amount of damage possible.
- Note that protection systems only provide the *mechanisms* for enforcing policies and ensuring reliable systems. It is up to administrators and users to implement those mechanisms effectively.

14.2 Principles of Protection

- The ***principle of least privilege*** dictates that programs, users, and systems be given just enough privileges to perform their tasks.
- This ensures that failures do the least amount of harm and allow the least of harm to be done.
- For example, if a program needs special privileges to perform a task, it is better to make it a SGID program with group ownership of "network" or "backup" or some other pseudo group, rather than SUID with root ownership. This limits the amount of damage that can occur if something goes wrong.
- Typically each user is given their own account, and has only enough privilege to modify their own files.
- The root account should not be used for normal day to day activities - The System Administrator should also have an ordinary account, and reserve use of the root account for only those tasks which need the root privileges

14.3 Domain of Protection

- A computer can be viewed as a collection of *processes* and *objects* (both HW & SW).
- The ***need to know principle*** states that a process should only have access to those objects it needs to accomplish its task, and furthermore only in the modes for which it needs access and only during the time frame when it needs access.
- The modes available for a particular object may depend upon its type.

14.3.1 Domain Structure

- A ***protection domain*** specifies the resources that a process may access.
- Each domain defines a set of objects and the types of operations that may be invoked on each object.
- An ***access right*** is the ability to execute an operation on an object.
- A domain is defined as a set of < object, { access right set } > pairs, as shown below. Note that some domains may be disjoint while others overlap.

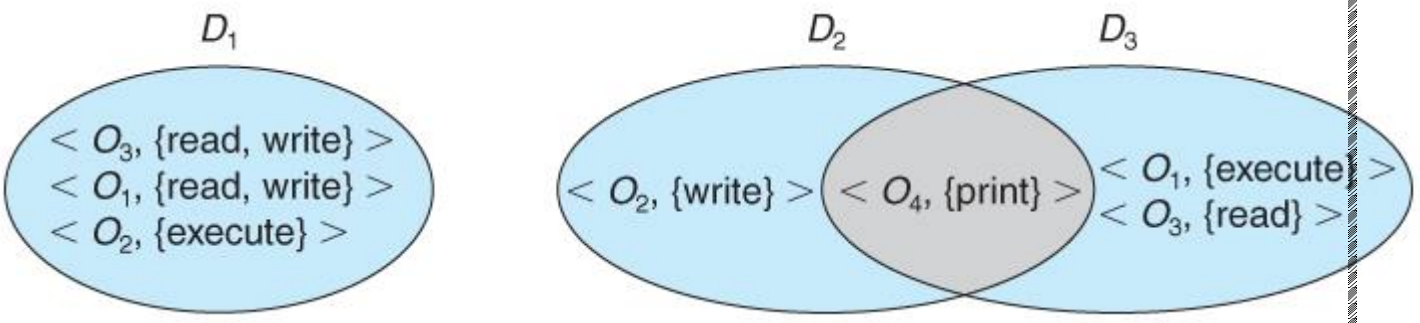


Figure 14.1 - System with three protection domains.

- The association between a process and a domain may be *static* or *dynamic.*
  - If the association is static, then the need-to-know principle requires a way of changing the contents of the domain dynamically.
  - If the association is dynamic, then there needs to be a mechanism for ***domain switching.***
- Domains may be realized in different fashions - as users, or as processes, or as procedures. E.g. if each user corresponds to a domain, then that domain defines the access of that user, and changing domains involves changing user ID.

14.3.2 An Example: UNIX

- UNIX associates domains with users.
- Certain programs operate with the SUID bit set, which effectively changes the user ID, and therefore the access domain, while the program is running. (and similarly for the SGID bit.) Unfortunately this has some potential for abuse.
- An alternative used on some systems is to place privileged programs in special directories, so that they attain the identity of the directory owner when they run. This prevents crackers from placing SUID programs in random directories around the system.

- Yet another alternative is to not allow the changing of ID at all. Instead, special privileged daemons are launched at boot time, and user processes send messages to these daemons when they need special tasks performed.

14.3.3 An Example: MULTICS

- The MULTICS system uses a complex system of rings, each corresponding to a different protection domain, as shown below:

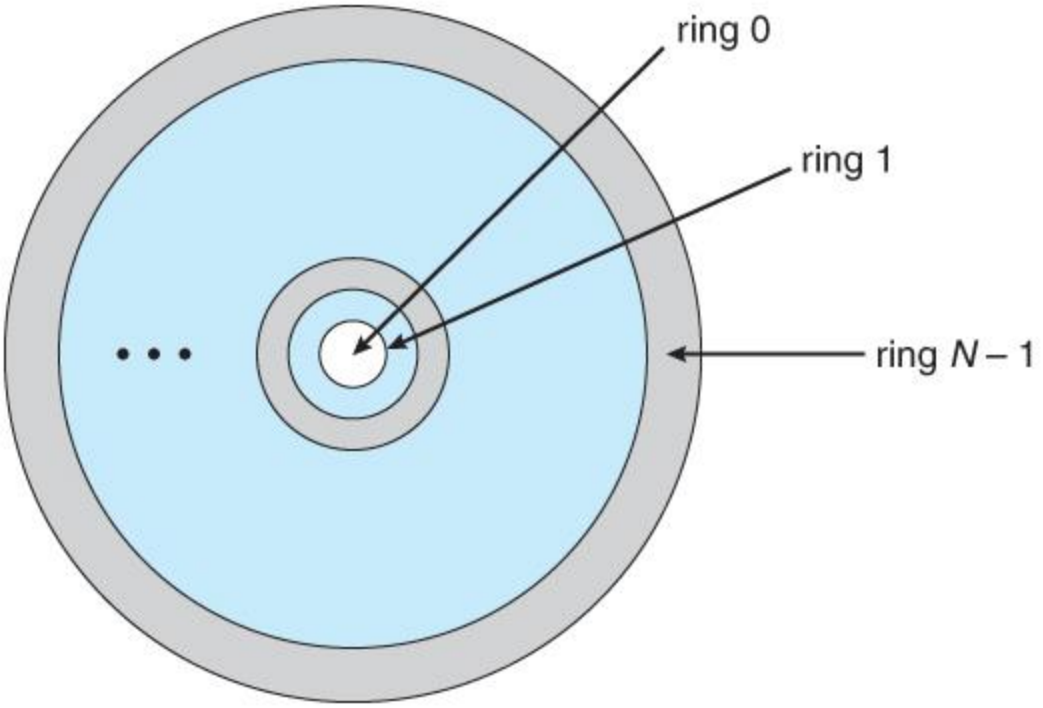


Figure 14.2 - MULTICS ring structure.

- Rings are numbered from 0 to 7, with outer rings having a subset of the privileges of the inner rings.
- Each file is a memory segment, and each segment description includes an entry that indicates the ring number associated with that segment, as well as read, write, and execute privileges.
- Each process runs in a ring, according to the *current-ring-number,* a counter associated with each process.
- A process operating in one ring can only access segments associated with higher (farther out) rings, and then only according to the access bits. Processes cannot access segments associated with lower rings.

- Domain switching is achieved by a process in one ring calling upon a process operating in a lower ring, which is controlled by several factors stored with each segment descriptor:
  - An ***access bracket***, defined by integers b1 <= b2.
  - A ***limit*** b3 > b2
  - A ***list of gates,*** identifying the entry points at which the segments may be called.
- If a process operating in ring i calls a segment whose bracket is such that b1 <= i <= b2, then the call succeeds and the process remains in ring i.
- Otherwise a trap to the OS occurs, and is handled as follows:
  - If i < b1, then the call is allowed, because we are transferring to a procedure with fewer privileges. However if any of the parameters being passed are of segments below b1, then they must be copied to an area accessible by the called procedure.
  - If i > b2, then the call is allowed only if i <= b3 and the call is directed to one of the entries on the list of gates.
- Overall this approach is more complex and less efficient than other protection schemes.

14.4 Access Matrix

- The model of protection that we have been discussing can be viewed as an ***access matrix,*** in which columns represent different system resources and rows represent different protection domains. Entries within the matrix indicate what access that domain has to that resource.

domain \ object	F_1	F_2	F_3	printer
D_1	read		read	
D_2				print
D_3		read	execute	
D_4	read write		read write	

Figure 14.3 - Access matrix.

- Domain switching can be easily supported under this model, simply by providing "switch" access to other domains:

domain \ object	F_1	F_2	F_3	laser printer	D_1	D_2	D_3	D_4
D_1	read		read			switch		
D_2				print			switch	switch
D_3		read	execute					
D_4	read write		read write		switch			

Figure 14.4 - Access matrix of Figure 14.3 with domains as objects.

- The ability to ***copy*** rights is denoted by an asterisk, indicating that processes in that domain have the right to copy that access within the same column, i.e. for the same object. There are two important variations:
    - If the asterisk is removed from the original access right, then the right is ***transferred,*** rather than being copied. This may be termed a ***transfer*** right as opposed to a ***copy*** right.
    - If only the right and not the asterisk is copied, then the access right is added to the new domain, but it may not be propagated further. That is the new domain does not also receive the right to copy the access. This may be termed a ***limited copy*** right, as shown in Figure 14.5 below:

object / domain	F_1	F_2	F_3
D_1	execute		write*
D_2	execute	read*	execute
D_3	execute		

(a)

object / domain	F_1	F_2	F_3
D_1	execute		write*
D_2	execute	read*	execute
D_3	execute	read	

(b)

Figure 14.5 - Access matrix with *copy* rights.

- The ***owner*** right adds the privilege of adding new rights or removing existing ones:

object / domain	F_1	F_2	F_3
D_1	owner execute		write
D_2		read* owner	read* owner write
D_3	execute		

(a)

object / domain	F_1	F_2	F_3
D_1	owner execute		write
D_2		owner read* write*	read* owner write
D_3		write	write

(b)

Figure 14.6 - Access matrix with *owner* rights.

- Copy and owner rights only allow the modification of rights within a column. The addition of ***control rights***, which only apply to domain objects, allow a process operating in one domain to affect the rights available in other domains. For example in the table below, a process operating in domain D2 has the right to control any of the rights in domain D4.

domain \ object	F_1	F_2	F_3	laser printer	D_1	D_2	D_3	D_4
D_1	read		read			switch		
D_2				print			switch	switch control
D_3		read	execute					
D_4	write		write		switch			

Figure 14.7 - Modified access matrix of Figure 14.4

14.5 Implementation of Access Matrix

14.5.1 Global Table

- The simplest approach is one big global table with < domain, object, rights > entries.
- Unfortunately this table is very large (even if sparse) and so cannot be kept in memory (without invoking virtual memory techniques.)
- There is also no good way to specify groupings - If everyone has access to some resource, then it still needs a separate entry for every domain.

14.5.2 Access Lists for Objects

- Each column of the table can be kept as a list of the access rights for that particular object, discarding blank entries.
- For efficiency a separate list of default access rights can also be kept, and checked first.

14.5.3 Capability Lists for Domains

- In a similar fashion, each row of the table can be kept as a list of the capabilities of that domain.
- Capability lists are associated with each domain, but not directly accessible by the domain or any user process.

- Capability lists are themselves protected resources, distinguished from other data in one of two ways:
    - A ***tag,*** possibly hardware implemented, distinguishing this special type of data. (other types may be floats, pointers, booleans, etc.)
    - The address space for a program may be split into multiple segments, at least one of which is inaccessible by the program itself, and used by the operating system for maintaining the process's access right capability list.

14.5.4 A Lock-Key Mechanism

- Each resource has a list of unique bit patterns, termed locks.
- Each domain has its own list of unique bit patterns, termed keys.
- Access is granted if one of the domain's keys fits one of the resource's locks.
- Again, a process is not allowed to modify its own keys.

14.5.5 Comparison

- Each of the methods here has certain advantages or disadvantages, depending on the particular situation and task at hand.
- Many systems employ some combination of the listed methods.

14.6 Access Control

- ***Role-Based Access Control, RBAC,*** assigns privileges to users, programs, or roles as appropriate, where "privileges" refer to the right to call certain system calls, or to use certain parameters with those calls.
- RBAC supports the principle of least privilege, and reduces the susceptibility to abuse as opposed to SUID or SGID programs.

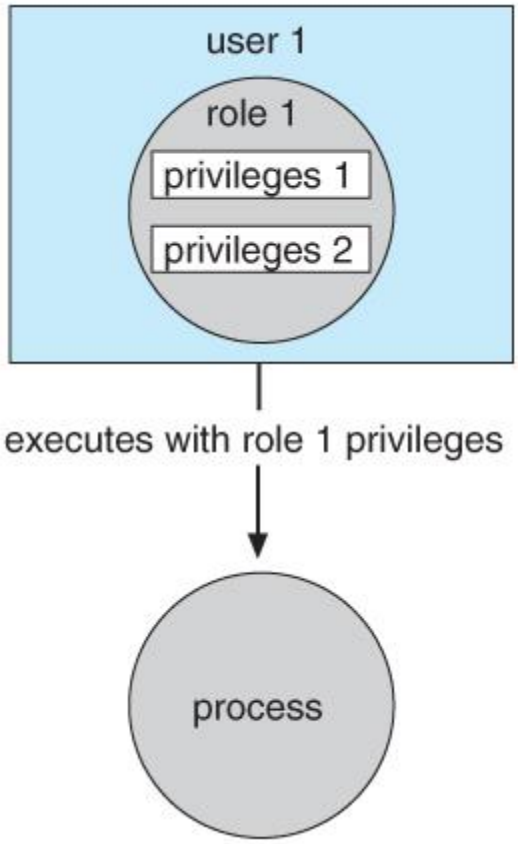


Figure 14.8 - Role-based access control in Solaris 10.

14.7 Revocation of Access Rights

- The need to revoke access rights dynamically raises several questions:
  - Immediate versus delayed - If delayed, can we determine when the revocation will take place?
  - Selective versus general - Does revocation of an access right to an object affect *all* users who have that right, or only some users?
  - Partial versus total - Can a subset of rights for an object be revoked, or are all rights revoked at once?
  - Temporary versus permanent - If rights are revoked, is there a mechanism for processes to re-acquire some or all of the revoked rights?
- With an access list scheme revocation is easy, immediate, and can be selective, general, partial, total, temporary, or permanent, as desired.
- With capabilities lists the problem is more complicated, because access rights are distributed throughout the system. A few schemes that have been developed include:

- Reacquisition - Capabilities are periodically revoked from each domain, which must then re-acquire them.
- Back-pointers - A list of pointers is maintained from each object to each capability which is held for that object.
- Indirection - Capabilities point to an entry in a global table rather than to the object. Access rights can be revoked by changing or invalidating the table entry, which may affect multiple processes, which must then re-acquire access rights to continue.
- Keys - A unique bit pattern is associated with each capability when created, which can be neither inspected nor modified by the process.
    - A master key is associated with each object.
    - When a capability is created, its key is set to the object's master key.
    - As long as the capability's key matches the object's key, then the capabilities remain valid.
    - The object master key can be changed with the set-key command, thereby invalidating all current capabilities.
    - More flexibility can be added to this scheme by implementing a ***list*** of keys for each object, possibly in a global table.

14.8 Capability-Based Systems (Optional)

14.8.1 An Example: Hydra

- Hydra is a capability-based system that includes both system-defined ***rights*** and user-defined rights. The interpretation of user-defined rights is up to the specific user programs, but the OS provides support for protecting access to those rights, whatever they may be
- Operations on objects are defined procedurally, and those procedures are themselves protected objects, accessed indirectly through capabilities.
- The names of user-defined procedures must be identified to the protection system if it is to deal with user-defined rights.
- When an object is created, the names of operations defined on that object become ***auxiliary rights,*** described in a capability for an ***instance*** of the type. For a process to act on an object, the capabilities it holds for that object must contain the name of the operation being invoked. This allows access to be controlled on an instance-by-instance and process-by-process basis.
- Hydra also allows ***rights amplification,*** in which a process is deemed to be ***trustworthy,*** and thereby allowed to act on any object corresponding to its parameters.

- Programmers can make direct use of the Hydra protection system, using suitable libraries which are documented in appropriate reference manuals.

14.8.2 An Example: Cambridge CAP System

- The CAP system has two kinds of capabilities:
    - ***Data capability,*** used to provide read, write, and execute access to objects. These capabilities are interpreted by microcode in the CAP machine.
    - ***Software capability,*** is protected but not interpreted by the CAP microcode.
        - Software capabilities are interpreted by protected (privileged) procedures, possibly written by application programmers.
        - When a process executes a protected procedure, it temporarily gains the ability to read or write the contents of a software capability.
        - This leaves the interpretation of the software capabilities up to the individual subsystems, and limits the potential damage that could be caused by a faulty privileged procedure.
        - Note, however, that protected procedures only get access to software capabilities for the subsystem of which they are a part. Checks are made when passing software capabilities to protected procedures that they are of the correct type.
        - Unfortunately the CAP system does not provide libraries, making it harder for an individual programmer to use than the Hydra system.

14.9 Language-Based Protection (Optional)

- As systems have developed, protection systems have become more powerful, and also more specific and specialized.
- To refine protection even further requires putting protection capabilities into the hands of individual programmers, so that protection policies can be implemented on the application level, i.e. to protect resources in ways that are known to the specific applications but not to the more general operating system.

14.9.1 Compiler-Based Enforcement

- In a compiler-based approach to protection enforcement, programmers directly specify the protection needed for different resources at the time the resources are declared.
- This approach has several advantages:
    1. Protection needs are simply declared, as opposed to a complex series of procedure calls.
    2. Protection requirements can be stated independently of the support provided by a particular OS.
    3. The means of enforcement need not be provided directly by the developer.
    4. Declarative notation is natural, because access privileges are closely related to the concept of data types.
- Regardless of the means of implementation, compiler-based protection relies upon the underlying protection mechanisms provided by the underlying OS, such as the Cambridge CAP or Hydra systems.
- Even if the underlying OS does not provide advanced protection mechanisms, the compiler can still offer some protection, such as treating memory accesses differently in code versus data segments. (E.g. code segments cant be modified, data segments can't be executed.)
- There are several areas in which compiler-based protection can be compared to kernel-enforced protection:
    - **Security.** Security provided by the kernel offers better protection than that provided by a compiler. The security of the compiler-based enforcement is dependent upon the integrity of the compiler itself, as well as requiring that files not be modified after they are compiled. The kernel is in a better position to protect itself from modification, as well as protecting access to specific files. Where hardware support of individual memory accesses is available, the protection is stronger still.
    - **Flexibility.** A kernel-based protection system is not as flexible to provide the specific protection needed by an individual programmer, though it may provide support which the programmer may make use of. Compilers are more easily changed and updated when necessary to change the protection services offered or their implementation.
    - **Efficiency.** The most efficient protection mechanism is one supported by hardware and microcode. Insofar as software based protection is concerned, compiler-based systems have the advantage that many

checks can be made off-line, at compile time, rather that during execution.

The concept of incorporating protection mechanisms into programming languages is in its infancy, and still remains to be fully developed. However the general goal is to provide mechanisms for three functions:

0. Distributing capabilities safely and efficiently among customer processes. In particular a user process should only be able to access resources for which it was issued capabilities.
1. Specifying the ***type*** of operations a process may execute on a resource, such as reading or writing.
2. Specifying the ***order*** in which operations are performed on the resource, such as opening before reading.

14.9.2 Protection in Java

- Java was designed from the very beginning to operate in a distributed environment, where code would be executed from a variety of trusted and untrusted sources. As a result the Java Virtual Machine, JVM incorporates many protection mechanisms
- When a Java program runs, it load up classes dynamically, in response to requests to instantiates objects of particular types. These classes may come from a variety of different sources, some trusted and some not, which requires that the protection mechanism be implemented at the resolution of individual classes, something not supported by the basic operating system.
- As each class is loaded, it is placed into a separate protection domain. The capabilities of each domain depend upon whether the source URL is trusted or not, the presence or absence of any digital signatures on the class (Chapter 15), and a configurable policy file indicating which servers a particular user trusts, etc.
- When a request is made to access a restricted resource in Java, (e.g. open a local file), some process on the current ***call stack*** must specifically assert a privilege to perform the operation. In essence this method ***assumes responsibility*** for the restricted access. Naturally the method must be part of a class which resides in a protection domain that includes the capability for the requested operation. This approach is termed ***stack inspection,*** and works like this:
    - When a caller may not be trusted, a method executes an access request within a `doPrivileged( )` block, which is noted on the calling stack.

- When access to a protected resource is requested, `checkPermissions( )` inspects the call stack to see if a method has asserted the privilege to access the protected resource.
  - If a suitable doPriveleged block is encountered on the stack before a domain in which the privilege is disallowed, then the request is granted.
  - If a domain in which the request is disallowed is encountered first, then the access is denied and a AccessControlException is thrown.
  - If neither is encountered, then the response is implementation dependent.

- In the example below the untrusted applet's call to `get( )` succeeds, because the trusted URL loader asserts the privilege of opening the specific URL lucent.com. However when the applet tries to make a direct call to `open( )` it fails, because it does not have privilege to access any sockets.

protection domain:	untrusted applet	URL loader	networking
socket permission:	none	*.lucent.com:80, connect	any

class:	gui:
	...
	get(url);
	open(addr);
	...
		get(URL u):
		...
		doPrivileged {
		open('proxy.lucent.com:80');
		}
		<request u from proxy>
		...
			open(Addr a):
			...
			checkPermission
			(a, connect);
			connect (a);
			...

Figure 14.9 - Stack inspection.