OPERATING SYSTEM

An **Operating System** acts as a communication bridge (interface) between the user and computer hardware. The purpose of an operating system is to provide a platform on which a user can execute programs in a convenient and efficient manner.
An operating system is a piece of software that manages the allocation of computer hardware. The coordination of the hardware must be appropriate to ensure the correct working of the computer system and to prevent user programs from interfering with the proper working of the system.
Example: Just like a boss gives order to his employee, in the similar way we request or pass our orders to the Operating System. The main goal of the Operating System is to thus make the computer environment more convenient to use and the secondary goal is to use the resources in the most efficient manner.

What is Operating System

An operating system is a program on which application programs are executed and acts as an communication bridge (interface) between the user and the computer hardware.
The main task an operating system carries out is the allocation of resources and services, such as allocation of: memory, devices, processors and information. The operating system also includes programs to manage these resources, such as a traffic controller, a scheduler, memory management module, I/O programs, and a file system.

Important functions of an operating System:

1. **Security: –**

The operating system uses password protection to protect user data and similar other techniques. it also prevents unauthorized access to programs and user data.

2. **Control over system performance –**

Monitors overall system health to help improve performance. records the response time between service requests and system response to have a complete view of the system health. This can help improve performance by providing important information needed to troubleshoot problems.

3. **Job accounting–**

Operating system Keeps track of time and resources used by various tasks and users, this information can be used to track resource usage for a particular user or group of user.

4. **Error detecting aids –**

Operating system constantly monitors the system to detect errors and avoid the malfunctioning of computer system.

5. Coordination between other software and users –

Operating systems also coordinate and assign interpreters, compilers, assemblers and other software to the various users of the computer systems.

6. Memory Management –

The operating system manages the Primary Memory or Main Memory. Main memory is made up of a large array of bytes or words where each byte or word is assigned a certain address. Main memory is a fast storage and it can be accessed directly by the CPU. For a program to be executed, it should be first loaded in the main memory An Operating System performs the following activities for memory management:

It keeps tracks of primary memory, i.e., which bytes of memory are used by which user program. The memory addresses that have already been allocated and the memory addresses of the memory that has not yet been used. In multi programming, the OS decides the order in which process are granted access to memory, and for how long. It Allocates the memory to a process when the process requests it and deallocates the memory when the process has terminated or is performing an I/O operation.

7. **Processor Management –**
   In a multi programming environment, the OS decides the order in which processes have access to the processor, and how much processing time each process has. This function of OS is called process scheduling. An Operating System performs the following activities for processor management.
   Keeps tracks of the status of processes. The program which perform this task is known as traffic controller. Allocates the CPU that is processor to a process. De-allocates processor when a process is no more required.

8. **Device Management –**
   An OS manages device communication via their respective drivers. It performs the following activities for device management. Keeps tracks of all devices connected to system. designates a program responsible for every device known as the Input/Output controller. Decides which process gets access to a certain device and for how long. Allocates devices in an effective and efficient way. Deallocates devices when they are no longer required.

9. **File Management –**
   A file system is organized into directories for efficient or easy navigation and usage. These directories may contain other directories and other files. An Operating System carries out the following file management activities. It keeps track of where information is stored, user access settings and status of every file and more… These facilities are collectively known as the file system.

   Moreover, Operating System also provides certain services to the computer system in one form or the other.
   The Operating System provides certain services to the users which can be listed in the following manner:

1. **Program Execution**: The Operating System is responsible for execution of all types of programs whether it be user programs or system programs. The Operating System utilises various resources available for the efficient running of all types of functionalities.
2. **Handling Input/Output Operations**: The Operating System is responsible for handling all sort of inputs, i.e, from keyboard, mouse, desktop, etc. The Operating System does all interfacing in the most appropriate manner regrading all kind of Inputs and Outputs.
   For example, there is difference in nature of all types of peripheral devices such as mouse or keyboard, then Operating System is responsible for handling data between them.
3. **Manipulation of File System**: The Operating System is responsible for making of decisions regarding the storage of all types of data or files, i.e, floppy disk/hard disk/pen drive, etc. The Operating System decides as how the data should be manipulated and stored.
4. **Error Detection and Handling**: The Operating System is responsible for detection of any types of error or bugs that can occur while any task. The well secured OS

sometimes also acts as countermeasure for preventing any sort of breach to the Computer System from any external source and probably handling them.

5. **Resource Allocation:** The Operating System ensures the proper use of all the resources available by deciding which resource to be used by whom for how much time. All the decisions are taken by the Operating System.
6. **Accounting:** The Operating System tracks an account of all the functionalities taking place in the computer system at a time. All the details such as the types of errors occurred are recorded by the Operating System.
7. **Information and Resource Protection:** The Operating System is responsible for using all the information and resources available on the machine in the most protected way. The Operating System must foil an attempt from any external resource to hamper any sort of data or information.

All these services are ensured by the Operating System for the convenience of the users to make the programming task easier. All different kinds of Operating System more or less provide the same services.

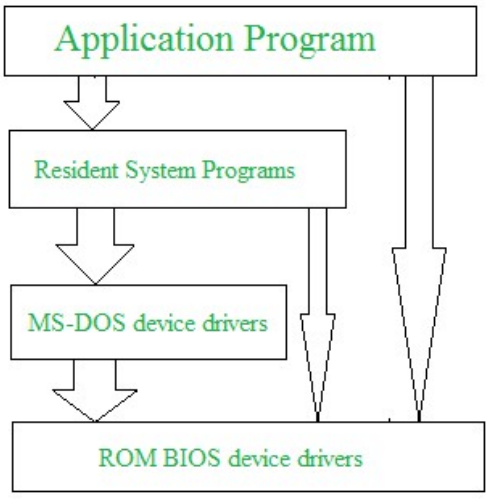
Different approaches or Structures of Operating Systems

Operating system can be implemented with the help of various structures. The structure of the OS depends mainly on how the various common components of the operating system are interconnected and melded into the kernel. Depending on this we have following structures of the operating system:

Simple structure:

Such operating systems do not have well defined structure and are small, simple and limited systems. The interfaces and levels of functionality are not well separated. MS-DOS is an example of such operating system. In MS-DOS application programs are able to access the basic I/O routines. These types of operating system cause the entire system to crash if one of the user programs fails.

Diagram of the structure of MS-DOS is shown below.

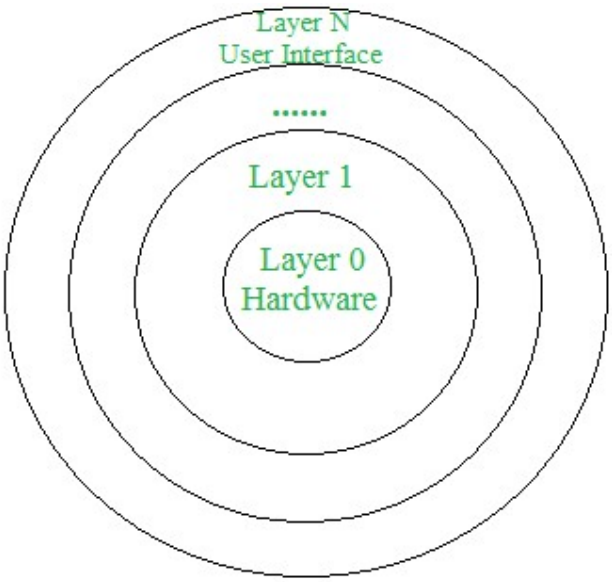


Layered structure:

An OS can be broken into pieces and retain much more control on system. In this

structure the OS is broken into number of layers (levels). The bottom layer (layer 0) is the hardware and the topmost layer (layer N) is the user interface. These layers are so designed that each layer uses the functions of the lower level layers only. This simplifies the debugging process as if lower level layers are debugged and an error occurs during debugging then the error must be on that layer only as the lower level layers have already been debugged.

The main disadvantage of this structure is that at each layer, the data needs to be modified and passed on which adds overhead to the system. Moreover careful planning of the layers is necessary as a layer can use only lower level layers. UNIX is an example of this structure.



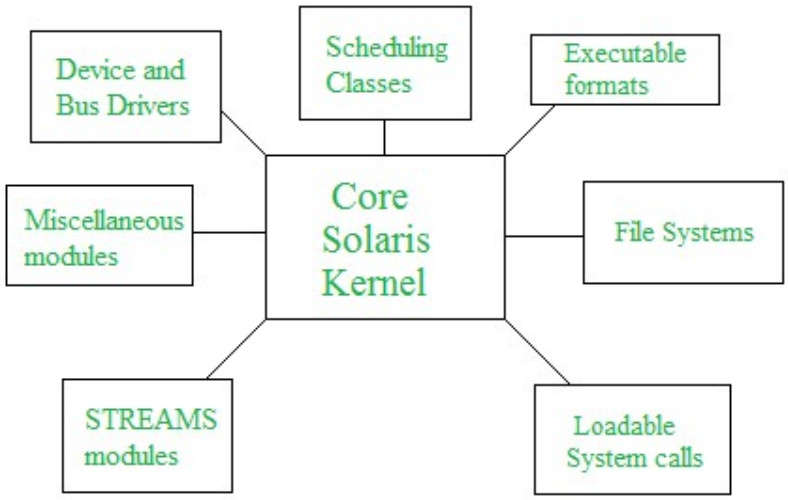
Micro-kernel:

This structure designs the operating system by removing all non-essential components from the kernel and implementing them as system and user programs. This result in a smaller kernel called the micro-kernel.
Advantages of this structure are that all new services need to be added to user space and does not require the kernel to be modified. Thus it is more secure and reliable as if a service fails then rest of the operating system remains untouched. Mac OS is an example of this type of OS.

Modular structure or approach:

It is considered as the best approach for an OS. It involves designing of a modular kernel. The kernel has only set of core components and other services are added as dynamically loadable modules to the kernel either during run time or boot time. It resembles layered structure due to the fact that each kernel has defined and protected interfaces but it is more flexible than the layered structure as a module can call any other module.

For example, Solaris OS is organized as shown in the figure.



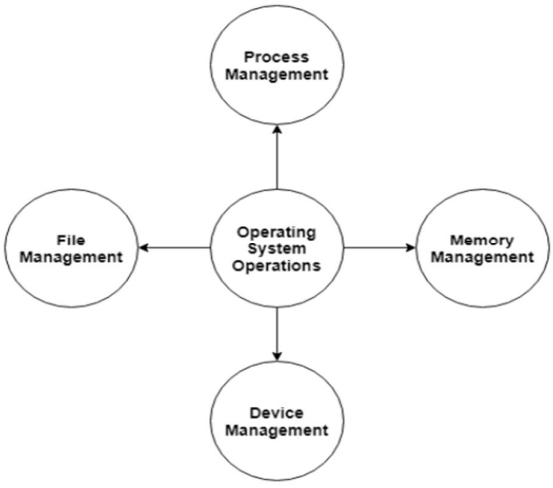
Important operations of an operating System

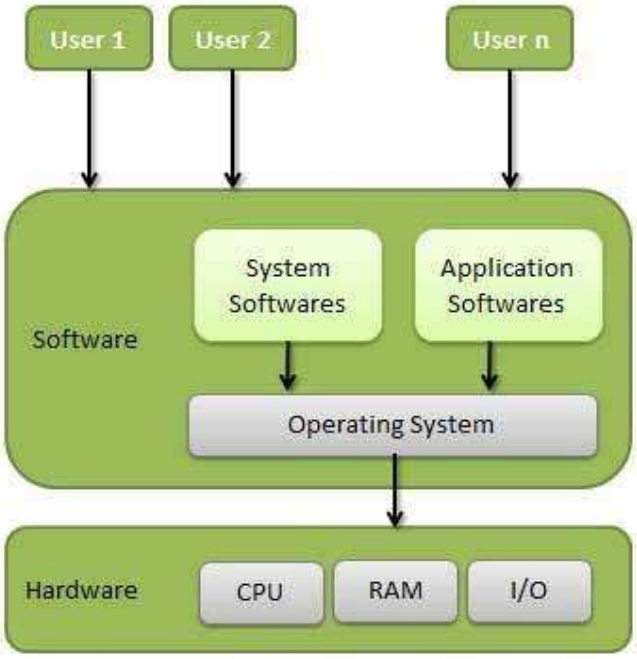
An operating system is a construct that allows the user application programs to interact with the system hardware. Operating system by itself does not provide any function but it provides an atmosphere in which different applications and programs can do useful work.

The major operations of the operating system are process management, memory management, device management and file management. These are given in detail as follows:

Definition

An operating system is a program that acts as an interface between the user and the computer hardware and controls the execution of all kinds of programs.





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- Memory Management
- Processor Management
- Device Management
- File Management
- Security
- Control over system performance
- Job accounting
- Error detecting aids
- Coordination between other software and users

Memory Management

Memory management refers to management of Primary Memory or Main Memory. Main memory is a large array of words or bytes where each word or byte has its own address.

Main memory provides a fast storage that can be accessed directly by the CPU. For a program to be executed, it must in the main memory. An Operating System does the following activities for memory management −

- Keeps tracks of primary memory, i.e., what part of it are in use by whom, what part are not in use.
- In multiprogramming, the OS decides which process will get memory when and how much.
- Allocates the memory when a process requests it to do so.
- De-allocates the memory when a process no longer needs it or has been terminated.

Processor Management

In multiprogramming environment, the OS decides which process gets the processor when and for how much time. This function is called **process scheduling**. An Operating System does the following activities for processor management −

- Keeps tracks of processor and status of process. The program responsible for this task is known as **traffic controller**.
- Allocates the processor (CPU) to a process.
- De-allocates processor when a process is no longer required.

Device Management

An Operating System manages device communication via their respective drivers. It does the following activities for device management −

- Keeps tracks of all devices. Program responsible for this task is known as the **I/O controller**.
- Decides which process gets the device when and for how much time.
- Allocates the device in the efficient way.
- De-allocates devices.

File Management

A file system is normally organized into directories for easy navigation and usage. These directories may contain files and other directions.

An Operating System does the following activities for file management −

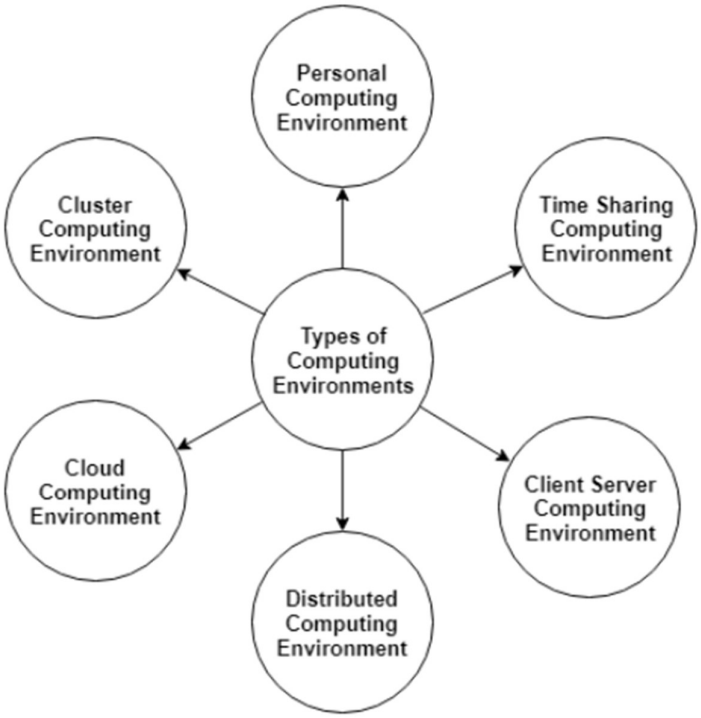
- Keeps track of information, location, uses, status etc. The collective facilities are often known as **file system**.
- Decides who gets the resources.
- Allocates the resources.
- De-allocates the resources.

Other Important Activities

Following are some of the important activities that an Operating System performs −

- **Security** − By means of password and similar other techniques, it prevents unauthorized access to programs and data.
- **Control over system performance** − Recording delays between request for a service and response from the system.
- **Job accounting** − Keeping track of time and resources used by various jobs and users.
- **Error detecting aids** − Production of dumps, traces, error messages, and other debugging and error detecting aids.

- **Coordination between other softwares and users** − Coordination and assignment of compilers, interpreters, assemblers and other software to the various users of the computer systems.
- A computer system uses many devices, arranged in different ways to solve many problems. This constitutes a computing environment where many computers are used to process and exchange information to handle multiple issues.
- The different types of Computing Environments are −



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- Let us begin with Personal Computing Environment −
- Personal Computing Environment
- In the personal computing environment, there is a single computer system. All the system processes are available on the computer and executed there. The different devices that constitute a personal computing environment are laptops, mobiles, printers, computer systems, scanners etc.
- Time Sharing Computing Environment
- The time sharing computing environment allows multiple users to share the system simultaneously. Each user is provided a time slice and the processor switches rapidly among the users according to it. Because of this, each user believes that they are the only ones using the system.
- Client Server Computing Environment
- Distributed Computing Environment

- Cloud Computing Environment
- The computing is moved away from individual computer systems to a cloud of computers in cloud computing environment. The cloud users only see the service being provided and not the internal details of how the service is provided. This is done by pooling all the computer resources and then managing them using a software.
- Cluster Computing Environment
- The clustered computing environment is similar to parallel computing environment as they both have multiple CPUs. However a major difference is that clustered systems are created by two or more individual computer systems merged together which then work parallel to each other.

Open-source operating systems

Open source is a term that originally referred to **open source** software (OSS). **Open source** software is code that is designed to be publicly accessible—anyone can see, modify, and distribute the code as they see fit.

What's the difference between free software and open source?

These are two terms that get confused with one another in practice,and even get used as equivalents. All free software is open-source, but not all open-source software is free.

Open source is considered to have more flexible rules than free software, since it allows companies and developers to impose certain usage restrictions and licenses in order to protect the code's integrity. On the other hand, free software, strictly speaking, must literally adhere to the four points of freedom, according to Richard Stallman:

- There is freedom to execute the code however one wishes and for whatever purpose one wishes.
- The source code can be known and modified in its entirety.
- The code can be distributed freely (either without cost, or with a charge).
- Modifications to the code can also be freely distributed (with or without cost).

Examples of open source programs

Some widely used programs, platforms, and languages which are considered open source are:

- Linux operating system
- Android by Google
- Open office
- Firefox browser
- VCL media player

- Moodle
- ClamWinantivirus
- WordPress content management syste

Operating System Services

An 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

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.

OPERATING SYSTEM AND USER INTERFACE

As already mentioned, in addition to the hardware, a computer also needs a set of programs—an operating system—to control the devices. This page will discuss the following:

- **There are different kinds of operating systems**: such as Windows, Linux and Mac OS
- **There are also different versions of these operating systems,** e.g. Windows 7, 8 and 10
- **Operating systems can be used with different user interfaces (UI)**: text user interfaces (TUI) and graphical user interfaces (GUI) as examples
- **Graphical user interfaces have many similarities in different operating systems**: such as the start menu, desktop etc.

When you can recognize the typical parts of each operating system's user interface, you will mostly be able to use both Windows and Linux as well as e.g. Mac OS.

THE ROLE OF OPERATING SYSTEM IN THE COMPUTER

An operating system (OS) is a set of programs which ensures the interoperability of the hardware and software in your computer. The operating system enables, among other things,

- the identification and activation of devices connected to the computer,
- the installation and use of programs, and
- the handling of files.

What happens when you turn on your computer or smartphone?
– The computer checks the functionality of its components and any devices connected to it, and starts to look for the OS on a hard drive or other memory media.
– If the OS is found, the computer starts to load it into the RAM (Random Access Memory).
– When the OS has loaded, the computer waits for commands from you.

DIFFERENT OPERATING SYSTEMS

Over the years, several different operating systems have been developed for different purposes. The most typical operating systems in ordinary computers are Windows, Linux and Mac OS.

WINDOWS

The name of the Windows OS comes from the fact that programs are run in "windows": each program has its own window, and you can have several programs open at the same time. Windows is the most popular OS for home computers, and there are several versions of it. The newest version is Windows 10.

LINUX AND UNIX

Linux is an open-source OS, which means that its program code is freely available to software developers. This is why thousands of programmers around the world have developed Linux, and it is considered the most tested OS in the world. Linux has been very much influenced by the commercial Unix OS.

In addition to servers, Linux is widely used in home computers, since there are a great number of free programs for it (for text and image processing, spreadsheets, publishing, etc.). Over the years, many different versions of Linux have become available for distribution, most of which are free for the user (such as Ubuntu, Fedora and Mint, to name a few). See the additional reading material for more information on Linux.

MAC OS X

Apple's Mac computers have their own operating system, OS X. Most of the programs that are available for PCs are also available for Macs running under OS X, but these two types of computers cannot use the exact same programs: for example, you cannot install the Mac version of the Microsoft Office suite on a Windows computer. You can install other operating systems on Mac computers, but the OS X is only available for computers made by Apple. Apple's lighter portable devices (iPads, iPhones) use a light version of the same operating system, called iOS.

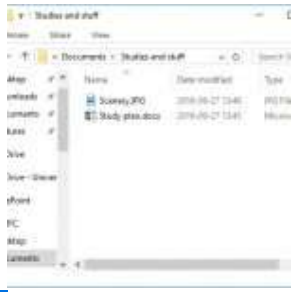
Mac computers are popular because OS X is considered fast, easy to learn and very stable and Apple's devices are considered well-designed—though rather expensive. See the additional reading material for more information on OS X.

ANDROID

Android is an operating system designed for phones and other mobile devices. Android is not available for desktop computers, but in mobile devices it is extremely popular: more than a half of all mobile devices in the world run on Android.

USER INTERFACES

A user interface (UI) refers to the part of an operating system, program, or device that allows a user to enter and receive information. A **text-based user interface** (see the image to the left) displays text, and its commands are usually typed on a command line using a keyboard. With a **graphical user interface** (see the right-hand image), the functions are carried out by clicking or moving buttons, icons and menus by means of a pointing device.



Larger image: text UI | graphical UI

The images contain the same information: a directory listing of a computer. You can often carry out the same tasks regardless of which kind of UI you are using.

TEXT USER INTERFACE (TUI)

Modern graphical user interfaces have evolved from text-based UIs. Some operating systems can still be used with a text-based user interface. In this case, the commands are entered as text (e.g., "cat story.txt").

To display the text-based Command Prompt in Windows, open the **Start** menu and type **cmd**. Press **Enter** on the keyboard to launch the command prompt in a separate window. With the command prompt, you can type your commands from the keyboard instead of using the mouse.

GRAPHICAL USER INTERFACE

In most operating systems, the primary user interface is graphical, i.e. instead of typing the commands you manipulate various graphical objects (such as icons) with a pointing device. The underlying principle of different graphical user interfaces (GUIs) is largely the same, so by knowing how to use a Windows UI, you will most likely know how to use Linux or some other GUI.

Most GUIs have the following basic components:

- a start menu with program groups
- a taskbar showing running programs
- a desktop
- various icons and shortcuts.

What is System Call in Operating System?

A **system call** is a mechanism that provides the interface between a process and the operating system. It is a programmatic method in which a computer program requests a service from the kernel of the OS.

System call offers the services of the operating system to the user programs via API (Application Programming Interface). System calls are the only entry points for the kernel system.

In this operating system tutorial, you will learn:

- What is System Call in Operating System?
- Example of System call
- How did the System call work?
- Types of System calls
- Rules for passing Parameters for System Call
- Important System Calls used in OS

System Calls in Operating System

Example of System Call

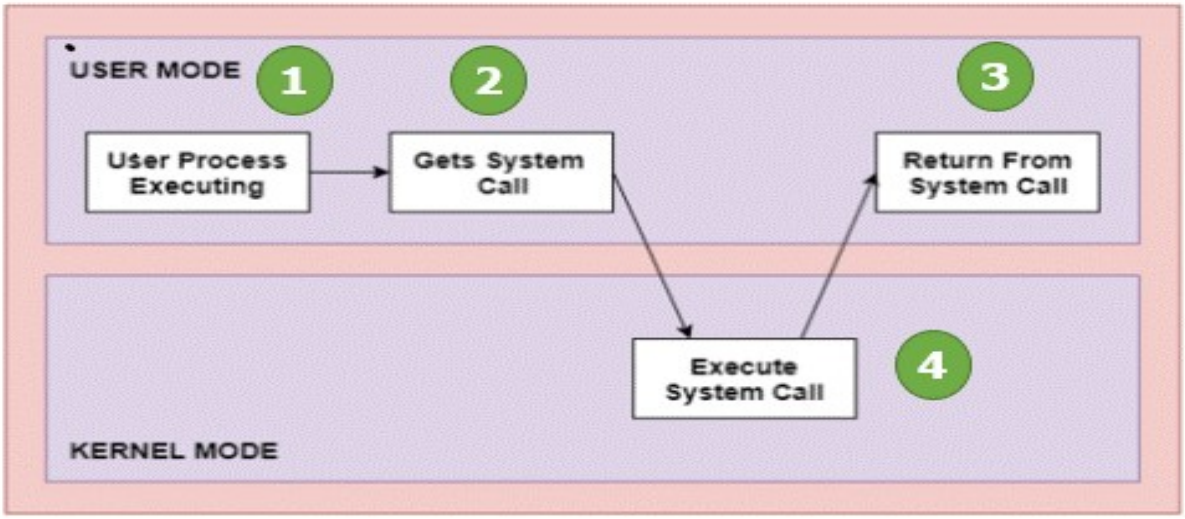
For example, if we need to write a program code to read data from one file, copy that data into another file. The first information that the program requires is the name of the two files, the input and output files.

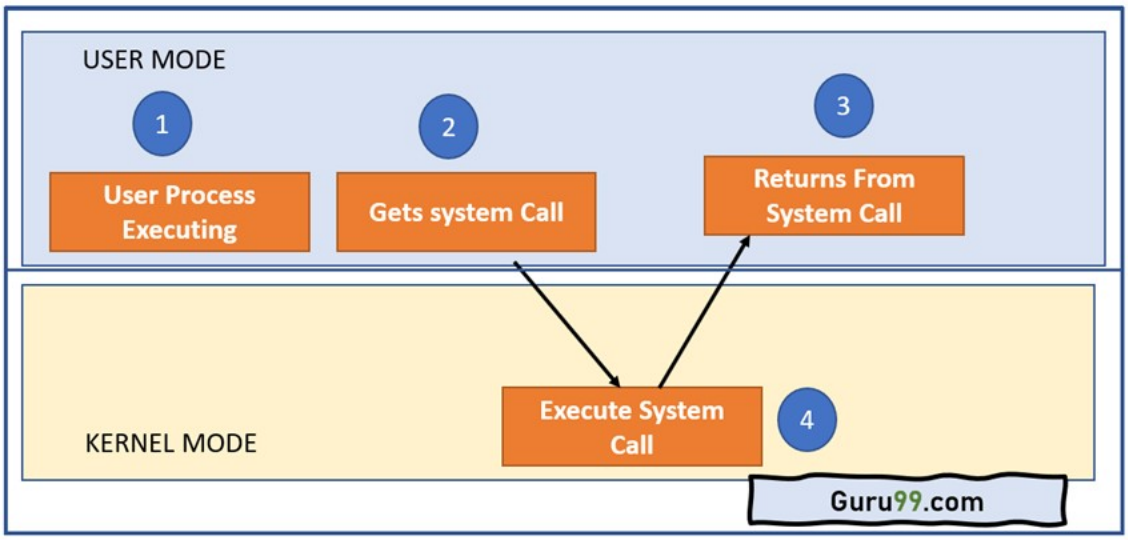
In an interactive system, this type of program execution requires some system calls by OS.

- First call is to write a prompting message on the screen
- Second, to read from the keyboard, the characters which define the two files.

How System Call Works?

Here are steps for System Call:





Architecture of the System Call

As you can see in the above-given diagram.

Step 1) The processes executed in the user mode till the time a system call interrupts it.

Step 2) After that, the system call is executed in the kernel-mode on a priority basis.

Step 3) Once system call execution is over, control returns to the user mode.,

Step 4) The execution of user processes resumed in Kernel mode.

Why do you need System Calls in OS?

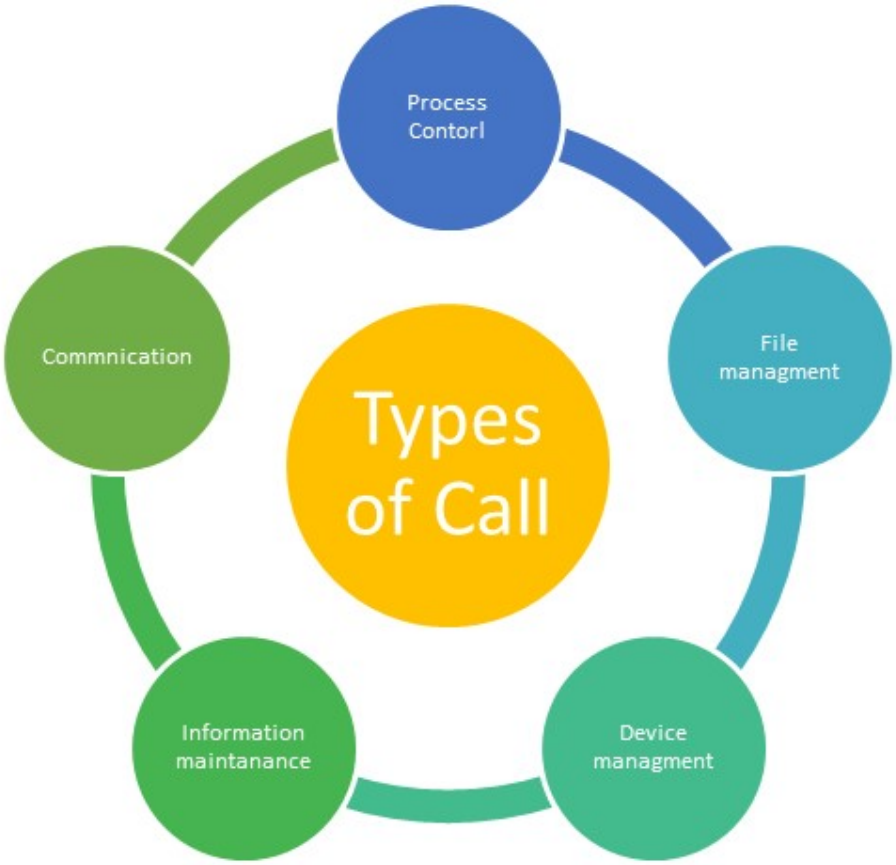
Following are situations which need system calls in OS:

- Reading and writing from files demand system calls.
- If a file system wants to create or delete files, system calls are required.
- System calls are used for the creation and management of new processes.
- Network connections need system calls for sending and receiving packets.
- Access to hardware devices like scanner, printer, need a system call.

Types of System calls

Here are the five types of system calls used in OS:

- Process Control
- File Management
- Device Management
- Information Maintenance
- Communications



Process Control

This system calls perform the task of process creation, process termination, etc.

Functions:

- End and Abort
- Load and Execute
- Create Process and Terminate Process
- Wait and Signed Event
- Allocate and free memory

File Management

File management system calls handle file manipulation jobs like creating a file, reading, and writing, etc.

Functions:

- Create a file
- Delete file
- Open and close file
- Read, write, and reposition
- Get and set file attributes

Device Management

Device management does the job of device manipulation like reading from device buffers, writing into device buffers, etc.

Functions

- Request and release device
- Logically attach/ detach devices
- Get and Set device attributes

Information Maintenance

It handles information and its transfer between the OS and the user program.

Functions:

- Get or set time and date
- Get process and device attributes

Communication:

These types of system calls are specially used for interprocess communications.

Functions:

- Create, delete communications connections
- Send, receive message
- Help OS to transfer status information
- Attach or detach remote devices

Rules for passing Parameters for System Call

Here are general common rules for passing parameters to the System Call:

- Parameters should be pushed on or popped off the stack by the operating system.
- Parameters can be passed in registers.
- When there are more parameters than registers, it should be stored in a block, and the block address should be passed as a parameter to a register.

Important System Calls Used in OS

wait()

In some systems, a process needs to wait for another process to complete its execution. This type of situation occurs when a parent process creates a child process, and the execution of the parent process remains suspended until its child process executes.

The suspension of the parent process automatically occurs with a wait() system call. When the child process ends execution, the control moves back to the parent process.

fork()

Processes use this system call to create processes that are a copy of themselves. With the help of this system Call parent process creates a child process, and the execution of the parent process will be suspended till the child process executes.

exec()

This system call runs when an executable file in the context of an already running process that replaces the older executable file. However, the original process identifier remains as a new process is not built, but stack, data, head, data, etc. are replaced by the new process.

kill():

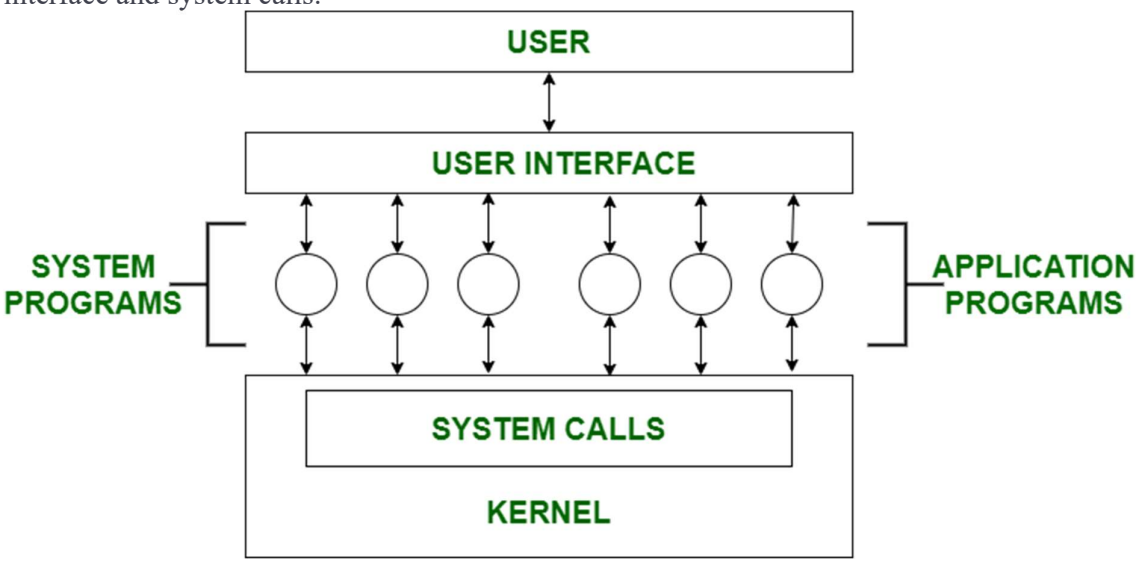
The kill() system call is used by OS to send a termination signal to a process that urges the process to exit. However, a kill system call does not necessarily mean killing the process and can have various meanings.

exit():

The exit() system call is used to terminate program execution. Specially in the multi-threaded environment, this call defines that the thread execution is complete. The OS reclaims resources that were used by the process after the use of exit() system call.

System Programs in Operating System

System Programming can be defined as act of building Systems Software using System Programming Languages. According to Computer Hierarchy, one which comes at last is Hardware. Then it is Operating System, System Programs, and finally Application Programs. Program Development and Execution can be done conveniently in System Programs. Some of System Programs are simply user interfaces, others are complex. It traditionally lies between user interface and system calls.



So here, user can only view up-to-the System Programs he can't see System Calls.

System Programs can be divided into these categories :

1. **File Management –**

   A file is a collection of specific information stored in memory of computer system. File management is defined as process of manipulating files in computer system, it management includes process of creating, modifying and deleting files.

   - It helps to create new files in computer system and placing them at specific locations.
   - It helps in easily and quickly locating these files in computer system.
   - It makes process of sharing of files among different users very easy and user friendly.
   - It helps to stores files in separate folders known as directories.
   - These directories help users to search file quickly or to manage files according to their types or uses.
   - It helps user to modify data of files or to modify he name of file in directories.

2. **Status Information –**

   Information like date, time amount of available memory, or disk space is asked by some of users. Others providing detailed performance, logging and debugging information which is more complex. All this information is formatted and displayed on output devices or printed. Terminal or other output devices or files or a window of GUI is used for showing output of programs.

3. **File Modification –**

   For modifying contents of files we use this. For Files stored on disks or other storage devices we used different types of editors. For searching contents of files or perform transformations of files we use special commands.

4. **Programming-Language support –**
   For common programming languages we use Compilers, Assemblers, Debuggers and interpreters which are already provided to user. It provides all support to users. We can run any programming languages. All languages of importance are already provided.

5. **Program Loading and Execution –**
   When program is ready after Assembling and compilation, it must be loaded into memory for execution. A loader is part of an operating system that is responsible for loading programs and libraries. It is one of essential stages for starting a program. Loaders, relocatable loaders, linkage editors and Overlay loaders are provided by system.

6. **Communications –**
   Virtual connections among processes, users and computer systems are provided by programs. User can send messages to other user on their screen, User can send e-

mail, browsing on web pages, remote login, transformation of files from one user to another.

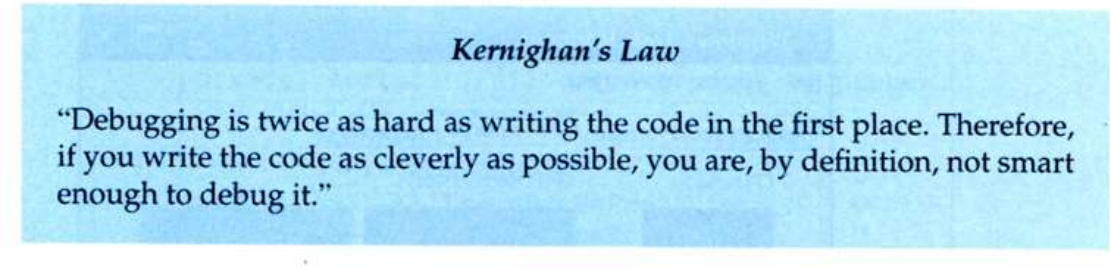
Some examples of system programs in O.S. are –

- Windows 10
- Mac OS X
- Ubuntu
- Linux
- Unix
- Android
- Anti-virus
- Disk formatting
- Computer language translator

Operating-System Debugging

Kernighan's Law

"Debugging is twice as hard as writing the code in the first place. Therefore,
if you write the code as cleverly as possible, you are, by definition, not smart
enough to debug it."



- Debugging here includes both error discovery and elimination and performance tuning.

2.8.1 Failure Analysis

- Debuggers allow processes to be executed stepwise, and provide for the examination of variables and expressions as the execution progresses.
- Profilers can document program execution, to produce statistics on how much time was spent on different sections or even lines of code.
- If an ordinary process crashes, a memory dump of the state of that process's memory at the time of the crash can be saved to a disk file for later analysis.
    - The program must be specially compiled to include debugging information, which may slow down its performance.

- These approaches don't really work well for OS code, for several reasons:
    - The performance hit caused by adding the debugging (tracing) code would be unacceptable. (Particularly if one tried to "single-step" the OS while people were trying to use it to get work done!)
    - Many parts of the OS run in kernel mode, and make direct access to the hardware.
    - If an error occurred during one of the kernel's file-access or direct disk-access routines, for example, then it would not be practical to try to write a crash dump into an ordinary file on the filesystem.
        - Instead the kernel crash dump might be saved to a special unallocated portion of the disk reserved for that purpose.

2.8.2 Performance Tuning

- Performance tuning (debottlenecking) requires monitoring system performance.
- One approach is for the system to record important events into log files, which can then be analyzed by other tools. These traces can also be used to evaluate how a proposed new system would perform under the same workload.
- Another approach is to provide utilities that will report system status upon demand, such as the unix "top" command. (w, uptime, ps, etc.)
- System utilities may provide monitoring support.

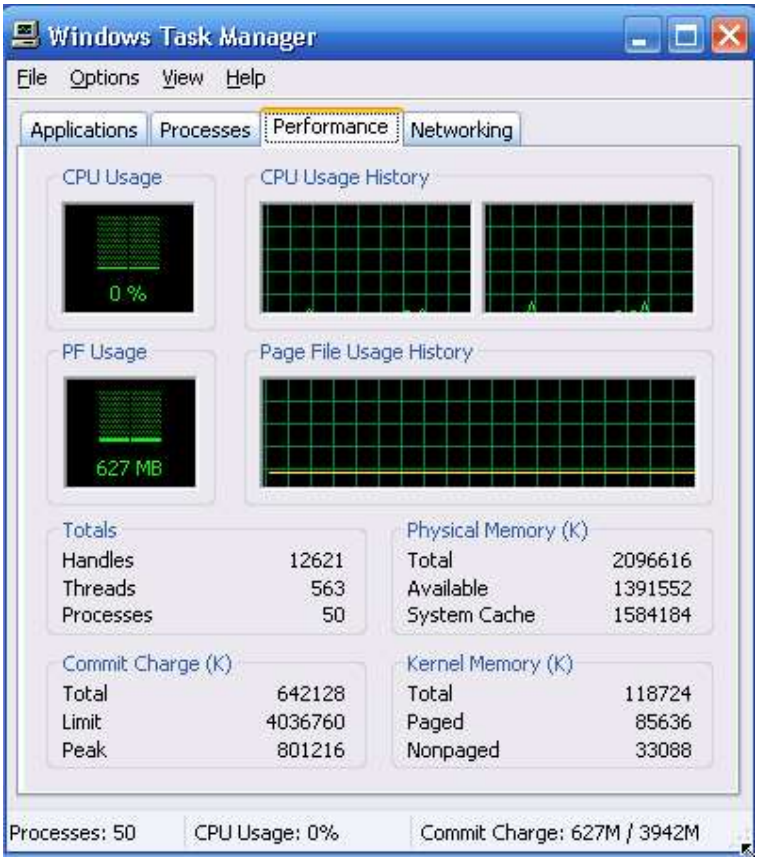


Figure 2.19 - The Windows task manager.

2.8.3 DTrace

- DTrace is a special facility for tracing a running OS, developed for Solaris 10.

- DTrace adds "probes" directly into the OS code, which can be queried by "probe consumers".
- Probes are removed when not in use, so the DTrace facility has zero impact on the system when not being used, and a proportional impact in use.
- Consider, for example, the trace of an ioctl system call as shown in Figure 2.22 below.

System Boot

The general approach when most computers boot up goes something like this:

- When the system powers up, an interrupt is generated which loads a memory address into the program counter, and the system begins executing instructions found at that address. This address points to the "bootstrap" program located in ROM chips (or EPROM chips) on the motherboard.
- The ROM bootstrap program first runs hardware checks, determining what physical resources are present and doing power-on self tests (POST) of all HW for which this is applicable. Some devices, such as controller cards may have their own on-board diagnostics, which are called by the ROM bootstrap program.
- The user generally has the option of pressing a special key during the POST process, which will launch the ROM BIOS configuration utility if pressed. This utility allows the user to specify and configure certain hardware parameters as where to look for an OS and whether or not to restrict access to the utility with a password.
    - Some hardware may also provide access to additional configuration setup programs, such as for a RAID disk controller or some special graphics or networking cards.
- Assuming the utility has not been invoked, the bootstrap program then looks for a non-volatile storage device containing an OS. Depending on configuration, it may look for a floppy drive, CD ROM drive, or primary or secondary hard drives, in the order specified by the HW configuration utility.
- Assuming it goes to a hard drive, it will find the first sector on the hard drive and load up the fdisk table, which contains information about how the physical hard drive is divided up into logical partitions, where each partition starts and ends, and which partition is the "active" partition used for booting the system.
- There is also a very small amount of system code in the portion of the first disk block not occupied by the fdisk table. This bootstrap code is the first step that is not built into the hardware, i.e. the first part which might be in any way OS-specific. Generally this code knows just enough to access the hard drive, and to load and execute a (slightly) larger boot program.
- For a single-boot system, the boot program loaded off of the hard disk will then proceed to locate the kernel on the hard drive, load the kernel into memory, and then transfer control over to the kernel. There may be some opportunity to specify a particular kernel to be loaded at this stage, which may be useful if a new kernel has just been generated and doesn't work, or if the system has multiple kernels available with different configurations

for different purposes. (Some systems may boot different configurations automatically, depending on what hardware has been found in earlier steps.)

- For dual-boot or multiple-boot systems, the boot program will give the user an opportunity to specify a particular OS to load, with a default choice if the user does not pick a particular OS within a given time frame. The boot program then finds the boot loader for the chosen single-boot OS, and runs that program as described in the previous bullet point.
- Once the kernel is running, it may give the user the opportunity to enter into single-user mode, also known as maintenance mode. This mode launches very few if any system services, and does not enable any logins other than the primary log in on the console. This mode is used primarily for system maintenance and diagnostics.
- When the system enters full multi-user multi-tasking mode, it examines configuration files to determine which system services are to be started, and launches each of them in turn. It then spawns login programs (gettys) on each of the login devices which have been configured to enable user logins.
    - (The getty program initializes terminal I/O, issues the login prompt, accepts login names and passwords, and authenticates the user. If the user's password is authenticated, then the getty looks in system files to determine what shell is assigned to the user, and then "execs" (becomes) the user's shell. The shell program will look in system and user configuration files to initialize itself, and then issue prompts for user commands. Whenever the shell dies, either through logout or other means, then the system will issue a new getty for that terminal device.)

OPERATING SYSTEMS

UNIT I

Operating Systems Overview: Operating system functions, Operating system structure, operating systems Operations, protection and security, Computing Environments, OpenSource Operating Systems System Structures: Operating System Services, User and Operating-System Interface, systems calls, Types of System Calls, system programs, operating system structure, operating system debugging, System Boot.

UNIT I

1.1 OPERATING SYSTEMS OVERVIEW

1.1.1 Operating systems functions What is an Operating System?

A program that acts as an intermediary between a user of a computer and the computer hardware Operating system goals:

- Execute user programs and make solving user problems easier
- Make the computer system convenient to use
- Use the computer hardware in an efficient manner

Computer System Structure

Computer system can be divided into four components

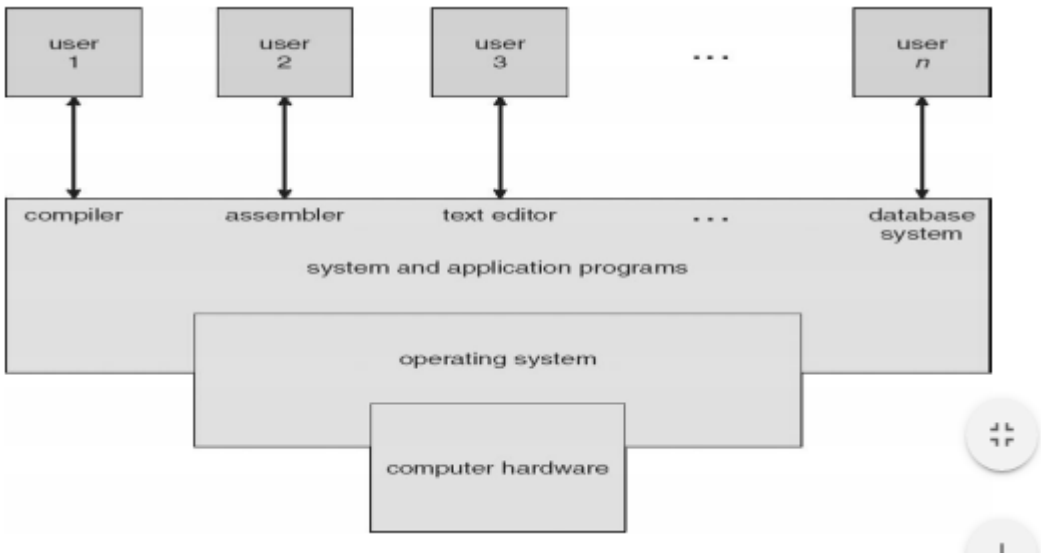
- Hardware – provides basic computing resources CPU, memory, I/O devices
- Operating system-Controls and coordinates use of hardware among various applications and users
- Application programs – define the ways in which the system resources are used to solve the computing problems of the users

-Word processors, compilers, web browsers, database systems, video games

Users

- People, machines, other computers

Four Components of a Computer System



A process is a program in execution. It is a unit of work within the system. Program is a passive entity, process is an active entity.

Process needs resources to accomplish its task

- CPU, memory, I/O, files
- Initialization data
- Process termination requires reclaim of any reusable resources
- Single-threaded process has one program counter specifying location of next instruction to
- execute Process executes instructions sequentially, one at a time, until completion
- Multi-threaded process has one program counter per thread
- Typically system has many processes, some user, some operating system running concurrently on
- one or more CPUs Concurrency by multiplexing the CPUs among the processes / threads

Process Management Activities

The operating system is responsible for the following activities in connection with process

- management: Creating and deleting both user and system processes
- Suspending and resuming processes
- Providing mechanisms for process synchronization
- Providing mechanisms for process communication
- Providing mechanisms for deadlock handling

Memory Management

All data in memory before and after processing

- All instructions in memory in order to execute
- Memory management determines what is in memory when
- Optimizing CPU utilization and computer response to users
- **Memory management activities**

- Keeping track of which parts of memory are currently being used and by whom
- Deciding which processes (or parts thereof) and data to move into and out of memory
- Allocating and deal locating memory space as needed

Storage Management

OS provides uniform, logical view of information storage

- Abstracts physical properties to logical storage unit – file
- Each medium is controlled by device (i.e., disk drive, tape drive)
- Varying properties include access speed, capacity, data-transfer rate, access method (sequential or random)
- File-System management
- Files usually organized into directories
- Access control on most systems to determine who can access what

OS activities include

- Creating and deleting files and directories
- Primitives to manipulate files and dirs
- 6 Mapping files onto secondary storage
- Backup files onto stable (non-volatile) storage media

Mass-Storage Management

- Usually disks used to store data that does not fit in main memory or data that must be kept for a "long" period of time
- Proper management is of central importance
- Entire speed of computer operation hinges on disk subsystem and its algorithms

MASS STORAGE activities

- Free-space management

- Storage allocation
- Disk scheduling
- Some storage need not be fast
- Tertiary storage includes optical storage, magnetic tape
- Still must be managed
- Varies between WORM (write-once, read-many-times) and RW (read-write)

1.1.2 Operating-System Structure

Simple Structure

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

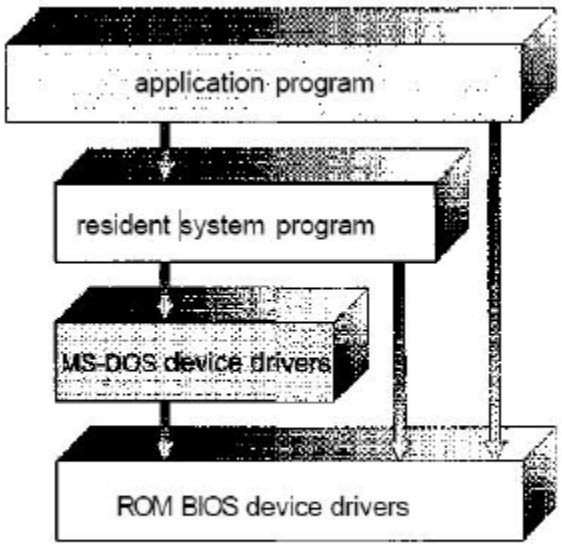


Figure 2.10 MS-DOS layer structure.

It was written to provide the most functionality in the least space, so it was not divided into modules carefully. In MS-DOS, the interfaces and levels of functionality are not well separated. For instance, application programs are able to access the basic I/O routines to write directly to the display and disk drives. Such freedom leaves MS-DOS vulnerable to errant (or malicious) programs, causing entire system crashes when user programs fail. Of course, MS-DOS was also

limited by the hardware of its era. Another example of limited structuring is the original UNIX operating system. UNIX is another system that initially was limited by hardware functionality.

It consists of two separable parts: the kernel and the system programs. The kernel is further separated into
a series of interfaces and device drivers, which have been added and expanded over the years as UNIX
has evolved.

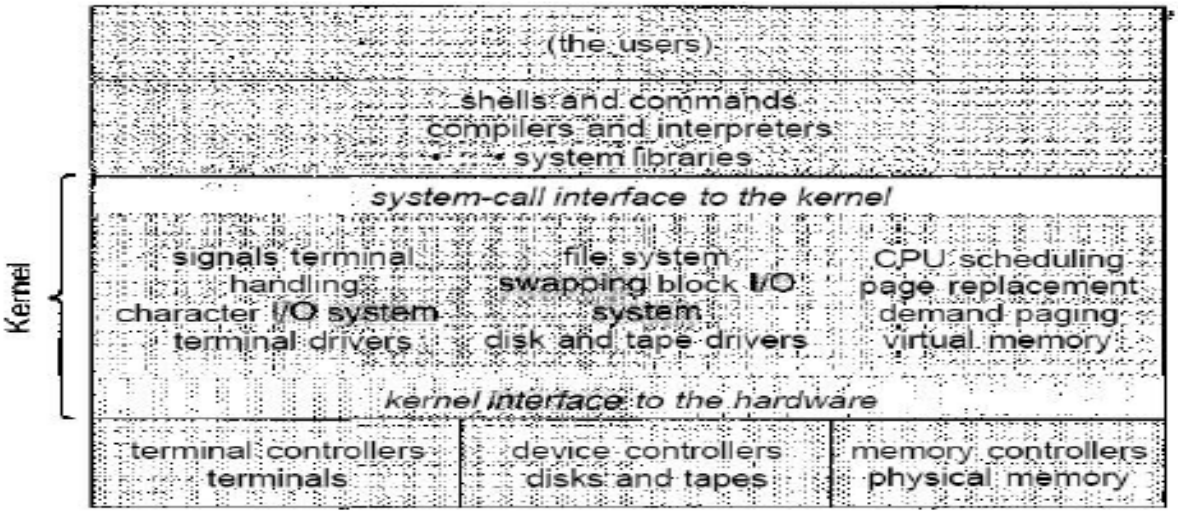
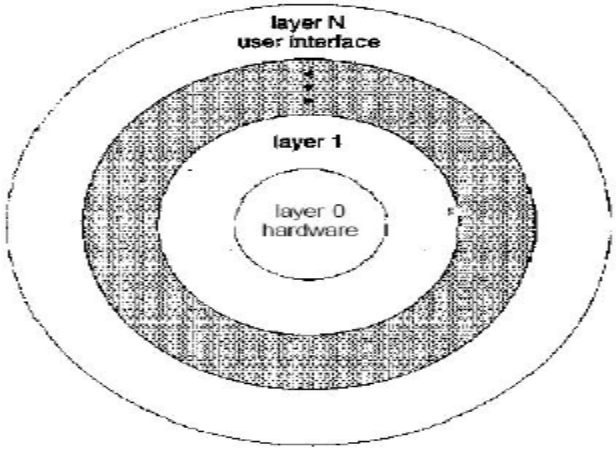


Figure 2.11 UNIX system structure.

Layered Approach

The operating system can then retain much greater control over the computer and over the applications that make use of that computer. Implementers have more freedom in changing the inner workings of the system and in creating modular operating systems. Under the top down approach, the overall functionality and features are determined and are separated into components. Information hiding is also important, because it leaves programmers free to implement the low-level routines as they see fit, provided that the external interface of the routine stays unchanged and that the routine itself performs the advertised task.

A system can be made modular in many ways. One method is the **layered approach,** in which the operating system is broken up into a number of layers (levels). The bottom layer (layer 0) is the hardware; the highest (layer N) is the user interface.



An operating-system layer is an implementation of an abstract object made up of data and the operations that can manipulate those data. A typical operating-system layer—say, layer M—consists of data structures and a set of routines that can be invoked by higher-level layers. Layer *M,* in turn, can invoke operations on lower-level layers.

The main advantage of the layered approach is simplicity of construction and debugging. The layers are selected so that each uses functions (operations) and services of only lower-level layers. This approach simplifies debugging and system verification. The first layer can be debugged without any
concern for the rest of the system, because, by definition, it uses only the basic hardware (which is assumed correct) to implement its functions. Once the first layer is debugged, its correct unctioning can be assumed while the second layer is debugged, and so on. If an error is found during the debugging of a particular layer, the error must be on that layer, because the layers below it are already debugged. Thus, the design and implementation of the system is simplified. Each layer is implemented with only those operations provided by lower level layers. A layer does not need to know how these operations are implemented; it needs to know only what these operations do. Hence, each layer hides the existence of certain data structures, operations, and hardware from higher-level layers.

The major difficulty with the layered approach involves appropriately defining the various layers. The backing-store driver would normally be above the CPU scheduler, because the driver may need to wait for I/O and the CPU can be rescheduled during this time. A final problem with layered implementations is that they tend to be less efficient than other types. For instance, when a user program executes an I/O operation, it executes a system call that is trapped to the I/O layer, which calls the memory-management layer, which in turn calls the CPU-scheduling layer, which is then passed to the hardware.

Micro kernels

The kernel became large and difficult to manage. In the mid-1980s, researchers at Carnegie Mellon University developed an operating system called **Mach** that modularized the kernel using the **microkernel** approach. This method structures the operating system by removing all nonessential components from the kernel and implementing them as system and user-level

programs. The result is a smaller kernel. microkernels provide minimal process and memory management, in addition to a communication facility.

The main function of the microkernel is to provide a communication facility between the client program and the various services that are also running in user space. One benefit of the microkernel approach is ease of extending the operating system. All new services are added to user space and consequently do not require modification of the kernel. When the kernel does have to be modified, the changes tend to be fewer, because the microkernel is a smaller kernel.

The resulting operating system is easier to port from one hardware design to another. The microkernel also provides more security and reliability, since most services are running as user rather than kernel processes. If a service fails, the rest of the operating system remains untouched.

Modules

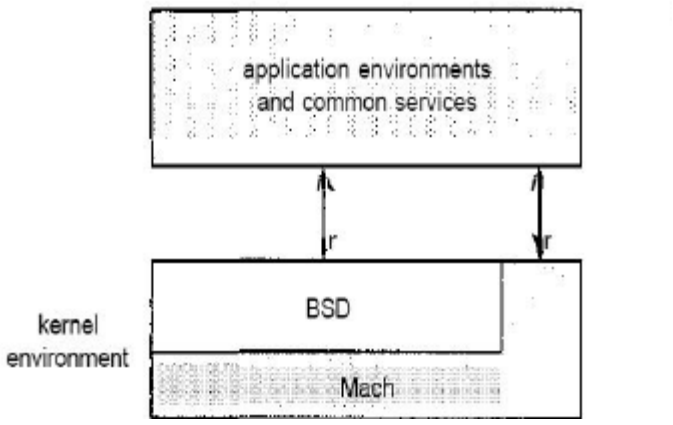
The best current methodology for operating-system design involves using object-oriented programming techniques to create a modular kernel. Here, the kernel has a set of core components and dynamically links in additional services either during boot time or during run time. Such a strategy uses dynamically loadable modules and is common in modern implementations of UNIX, such as Solaris, Linux, and Mac OS X.

A core kernel with seven types of loadable kernel modules:
1. Scheduling classes
2. File systems
3. Loadable system calls
4. Executable formats
5. STREAMS modules
6. Miscellaneous
7. Device and bus drivers

Such a design allows the kernel to provide core services yet also allows certain features to be implemented dynamically. The overall result resembles a layered system in that each kernel section has defined, protected interfaces; but it is more flexible than a layered system in that any module can call any other module. The approach is like the microkernel approach in that the primary module has only core functions and knowledge of how to load and communicate with other modules; but it is more efficient, because modules do not need to invoke message passing in order to communicate.

The Apple Macintosh Mac OS X operating system uses a hybrid structure. Mac OS X (also known as *Danvin)* structures the operating system using a layered technique where one layer consists of the Mach microkernel. The top layers include application environments and a set of services providing a graphical interface to applications. Below these layers is the kernel environment, which consists primarily of the Mach microkernel and the BSD kernel. Mach provides memory management; support for remote procedure calls (RPCs) and inter process communication (IPC) facilities, including message passing; and thread scheduling. The BSD

component provides a BSD command line interface, support for networking and file systems, and an implementation of POSIX APIs, including Pthreads.



1.1.2 Operating-System Operations

1. 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

2. A **trap (or** an **exception)** is a software-generated interrupt caused either by an error or by a specific request from a user program that an operating-system service is performed.

3. 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.

4. 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.

5. Without protection against these sorts of errors, either the computer must execute only one process at a time or all output must be suspect.

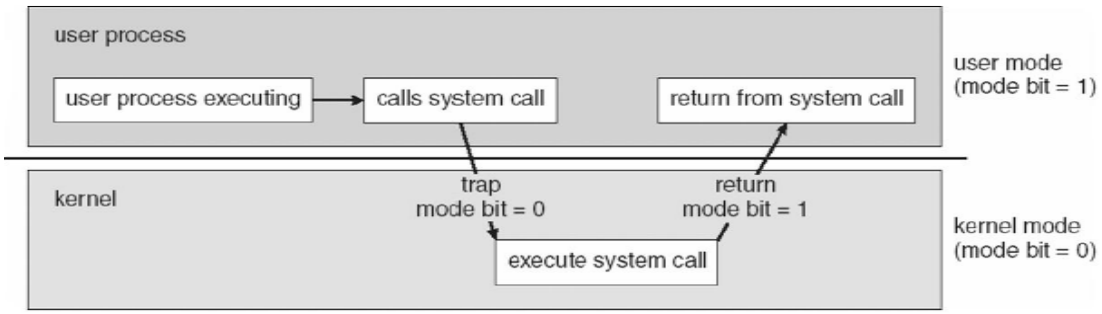
Dual-Mode Operation

Dual-mode operation allows OS to protect itself and other system components

User mode and **kernel mode**
Mode bit provided by hardware Provides ability to distinguish when system is running user code or kernel code Some instructions designated as **privileged**, only executable in kernel mode System call changes mode to kernel, return from call resets it to user

Transition from User to Kernel Mode

- Timer to prevent infinite loop / process hogging resources Set interrupt after specific period
- Operating system decrements counter
- When counter zero generate an interrupt
- Set up before scheduling process to regain control or terminate program that exceeds allotted time



If a computer system has multiple users and allows the concurrent execution of multiple processes, then access to data must be regulated. For that purpose, mechanisms ensure that files, memory segments, CPU, and other resources can be operated on by only those processes that have gained proper authorization from the operating system.

1.1.4 Protection and security

Protection is any mechanism for controlling the access of processes or users to the resources defined by a computer system. This mechanism must provide means for specification of the controls to be imposed and means for enforcement.

Protection can improve reliability by detecting latent errors at the interfaces between component subsystems. Early detection of interface errors can often prevent contamination of a healthy subsystem by another subsystem that is malfunctioning. An unprotected resource cannot defend against use (or misuse) by an unauthorized or incompetent user. A protection-oriented system provides a means to distinguish between authorized and unauthorized usage, A system can have adequate protection but still be prone to failure and allow inappropriate access.

It is the job of **security** to defend a system from external and internal attacks. Such attacks spread across a huge range and include viruses and worms, denial-of service attacks Protection and security require the system to be able to distinguish among all its users. Most operating systems maintain a list of user names and associated **user identifiers (user IDs).**

- User ID then associated with all files, processes of that user to determine access control

• Group identifier (**group ID**) allows set of users to be defined and controls managed, then also associated with each process, file **Privilege escalation** allows user to change to effective ID with more rights

1.1.5 Kernel Data Structures

The operating system must keep a lot of information about the current state of the system. As things happen within the system these data structures must be changed to reflect the current eality. For example, a new process might be created when a user logs onto the system. The kernel must create a data structure representing the new process and link it with the data structures representing all of the other processes in the system.

Mostly these data structures exist in physical memory and are accessible only by the kernel and its subsystems. Data structures contain data and pointers, addresses of other data structures, or the addresses of routines. Taken all together, the data structures used by the Linux kernel can look very confusing. Every data structure has a purpose and although some are used by several kernel subsystems, they are more simple than they appear at first sight.

Understanding the Linux kernel hinges on understanding its data structures and the use that the various functions within the Linux kernel makes of them. This section bases its description of the Linux kernel on its data structures. It talks about each kernel subsystem in terms of its algorithms, which are its
methods of getting things done, and their usage of the kernel's data structures.

1.1.6 Computing Environments

Traditional Computing

As computing matures, the lines separating many of the traditional computing environments are blurring. this environment consisted of PCs connected to a network, with servers providing file and print services.
Terminals attached to mainframes were prevalent at many companies as well, with even fewer remote access and portability options.

The current trend is toward providing more ways to access these computing environments. Web technologies are stretching the boundaries of traditional computing. Companies establish **portals,** which provide web accessibility to their internal servers. **Network computers** are essentially terminals that understand web-based computing. Handheld computers can synchronize with PCs to allow very portable use of company information. Handheld PDAs can also connect to **wireless networks** to use the company's web portal.

Batch system processed jobs in bulk, with predetermined input. Interactive systems waited for input from users. To optimize the use of the computing resources, multiple users shared time on these systems. Time-sharing systems used a timer and scheduling algorithms to rapidly cycle processes through the CPU, giving each user a share of the resources.

Client-Server Computing

Designers have shifted away from centralized system architecture. Terminals connected to centralized systems are now being supplanted by PCs. Correspondingly, user interface functionality once handled directly by the centralized systems is increasingly being handled by

the PCs. As a result, many of today's systems acts as **server systems to** satisfy requests generated by **client systems** Server systems can be broadly categorized as compute servers and file servers:

• The **compute-server system** provides an interface to which a client can send a request to perform an action (for example, read data); in response, the server executes the action and sends back results to the client. A server running a database that responds to client requests for data is an example of such a system.

The **file-server system** provides a file-system interface where clients can create, update, read, and delete files. An example of such a system is a web server that delivers files to clients running web browsers.

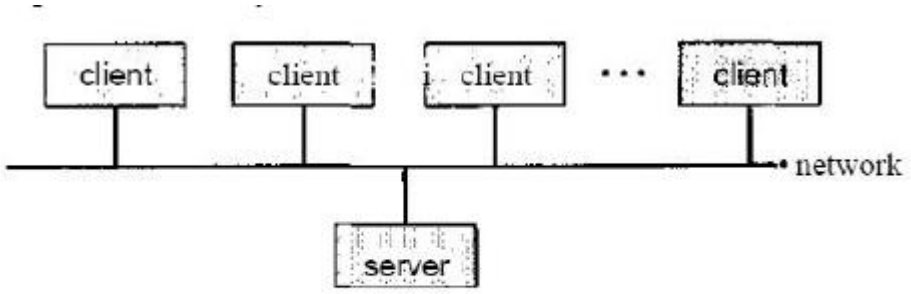


Figure 1.11 General structure of a client-server system.

Peer-to-Peer Computing

In this model, clients and servers are not distinguished from one another; instead, all nodes within the system are considered peers, and each may act as either a client or a server, depending on whether it is requesting or providing a service. Peer-to-peer systems offer an advantage over traditional client-server systems. In a client-server system, the server is a bottleneck; but in a peer-to-peer system, services can be provided by several nodes distributed throughout the network.

To participate in a peer-to-peer system, a node must first join the network of peers. Once a node has joined the network, it can begin providing services to—and requesting services from—other nodes in the network.

Determining what services are available is accomplished in one of two general ways:

• When a node joins a network, it registers its service with a centralized lookup service on the network. Any node desiring a specific service first contacts this centralized lookup service to determine which node provides the service. The remainder of the communication takes place between the client and the service provider.

• A peer acting as a client must first discover what node provides a desired service by broadcasting a request for the service to all other nodes in the network. The node (or nodes) providing that service responds to the peer making the request. To support this approach, a

discovery protocol must be provided that allows peers to discover services provided by other peers in the network.

Web-Based Computing

The Web has become ubiquitous, leading to more access by a wider variety of devices than was dreamt of a few years ago. Web computing has increased the emphasis on networking. Devices that were not previously networked now include wired or wireless access. Devices that were networked now have faster network connectivity, provided by either improved networking technology, optimized network implementation code, or both.

The implementation of web-based computing has given rise to new categories of devices, such as **load balancers,** which distribute network connections among a pool of similar servers. Operating systems like Windows 95, which acted as web clients, have evolved into Linux and Windows XP, which can act as web servers as well as clients. Generally, the Web has increased the complexity of devices, because their users require them to be web-enabled.

1.1.7 Open-Source Operating Systems

- Operating systems made available in source-code format rather than just binary closed-source
- Counter to the copy protection and Digital Rights Management (DRM) movement
- Examples include GNU/Linux, BSD UNIX (including core of Mac OS X), and Sun Solaris

CHAPTER - 2
OPERATING SYSTEM STRUCTURE

1.2.1 Operating System Services

- One set of operating-system services provides functions that are helpful to the user
- Communications – Processes may exchange information, on the same computer or between computers over a network.

- Communications may be via shared memory or through message passing (packets moved by the
OS)

- Error detection – OS needs to be constantly aware of possible errors may occur in the CPU and memory hardware, in I/O devices, in user program

- For each type of error, OS should take the appropriate action to ensure correct and consistent computing.

- Debugging facilities can greatly enhance the user's and programmer's abilities to efficiently use
the system.

- Another set of OS functions exists for ensuring the efficient operation of the system itself via resource sharing

• **Resource allocation -** When multiple users or multiple jobs running concurrently, resources must be allocated to each of them

• Many types of resources - Some (such as CPU cycles, main memory, and file storage) may have
special allocation code, others (such as I/O devices) may have general request and release code

• **Accounting -** To keep track of which users use how much and what kinds of computer resources

• **Protection and security -** The owners of information stored in a multiuser or networked computer system may want to control use of that information, concurrent processes should not interfere with each other.

• **Protection** involves ensuring that all access to system resources is controlled.

• **Security** of the system from outsiders requires user authentication, extends to defending external
I/O devices from invalid access attempts.

• If a system is to be protected and secure, precautions must be instituted throughout it. A chain is
only as strong as its weakest link.

1.2.2 User and 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 If the latter, adding new features doesn't require shell modification

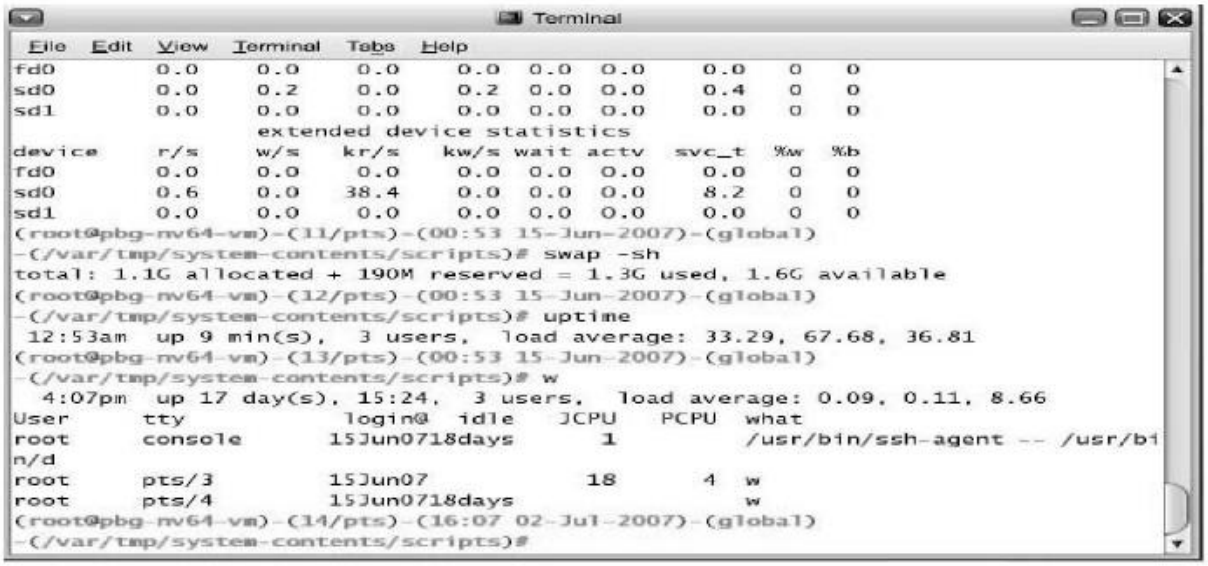
User Operating System Interface - GUI

• User-friendly desktop metaphor interface
• Usually mouse, keyboard, and monitor
• Icons represent 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)

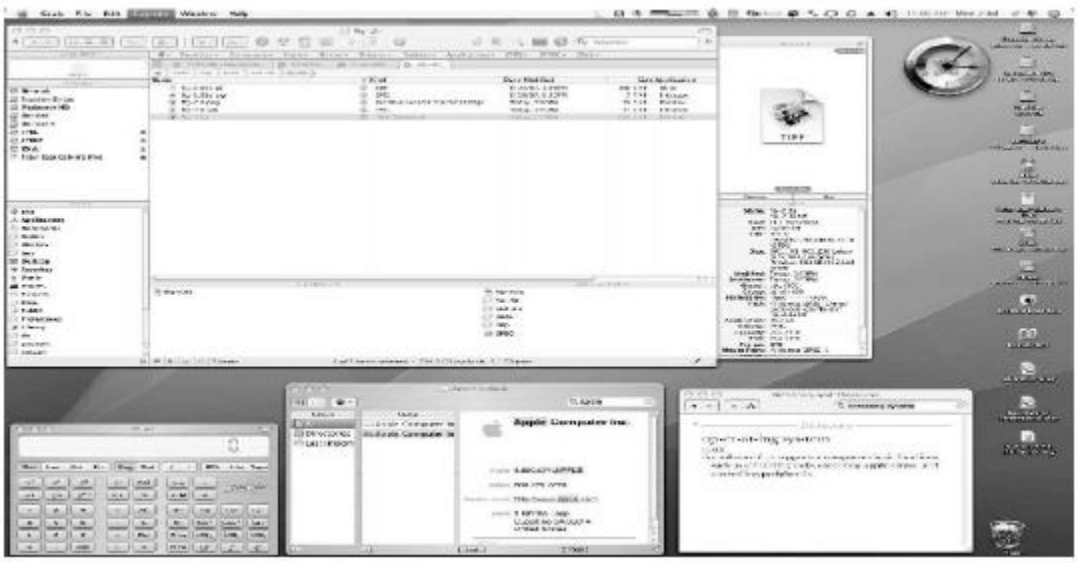
Invented at Xerox PARC

• Many systems now include both CLI and GUI interfaces
• Microsoft Windows is GUI with CLI "command" shell
• Apple Mac OS X as "Aqua" GUI interface with UNIX kernel underneath and shells available
• Solaris is CLI with optional GUI interfaces (Java Desktop, KDE)

Bourne Shell Command Interpreter



The Mac OS X GUI

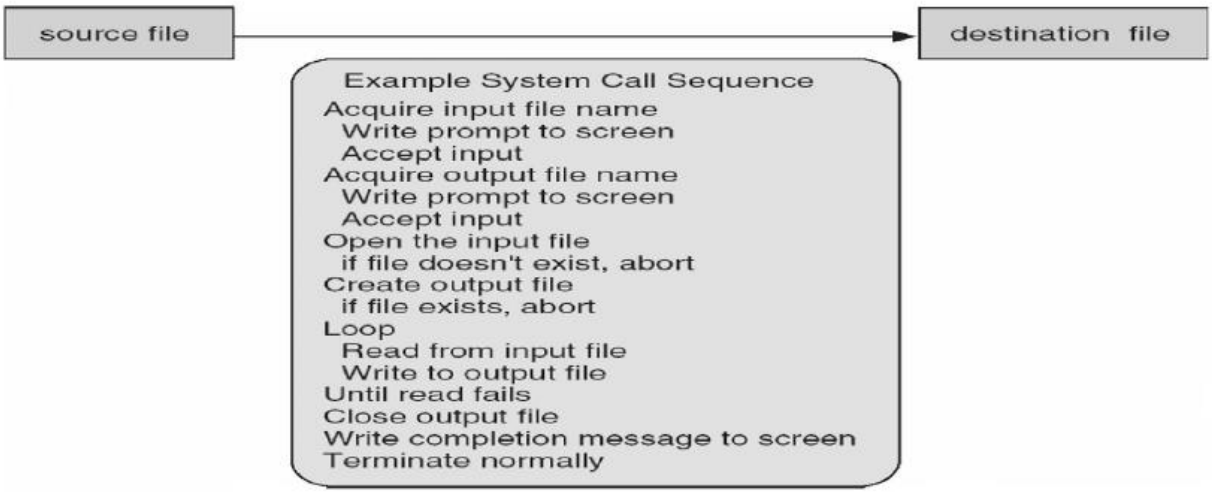


1.2.3 System Calls

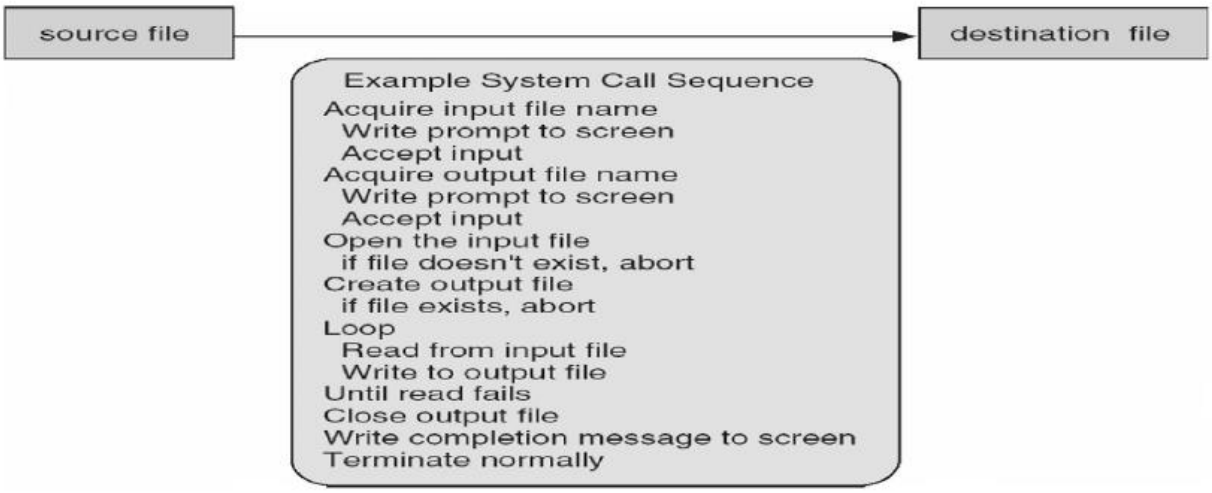
- Programming interface to the services provided by the OS
- Typically written in a high-level language (C or C++)

• Mostly accessed by programs via a high-level Application Program Interface (API) rather than direct system call usenThree most common APIs are Win32 API for Windows, POSIX API for POSIX-based systems (including virtually all versions of UNIX, Linux, and Mac OS X), and Java API for the Java virtual machine (JVM)
• Why use APIs rather than system calls?(Note that the system-call names used throughout this text are generic)

Example of System Calls



System Call Implementation



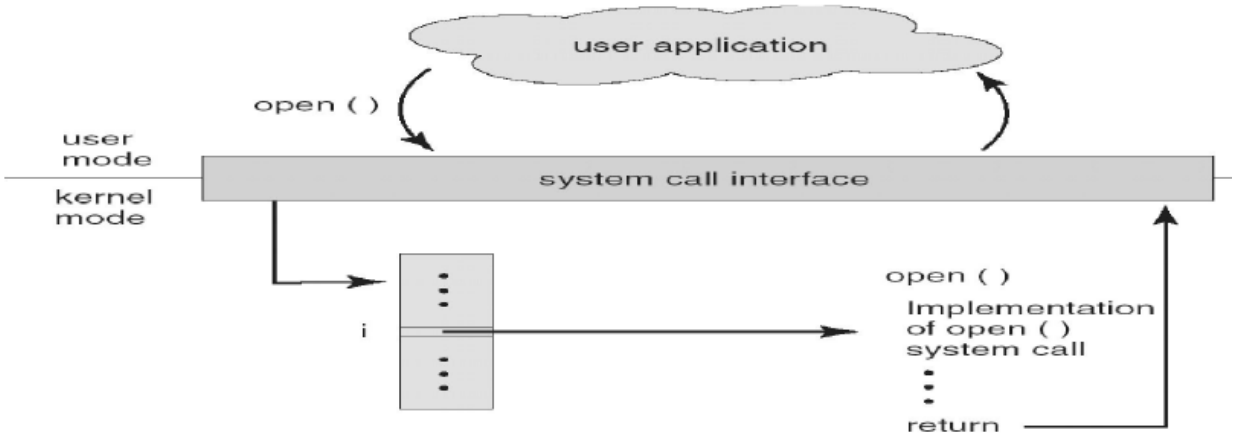
System Call Implementation

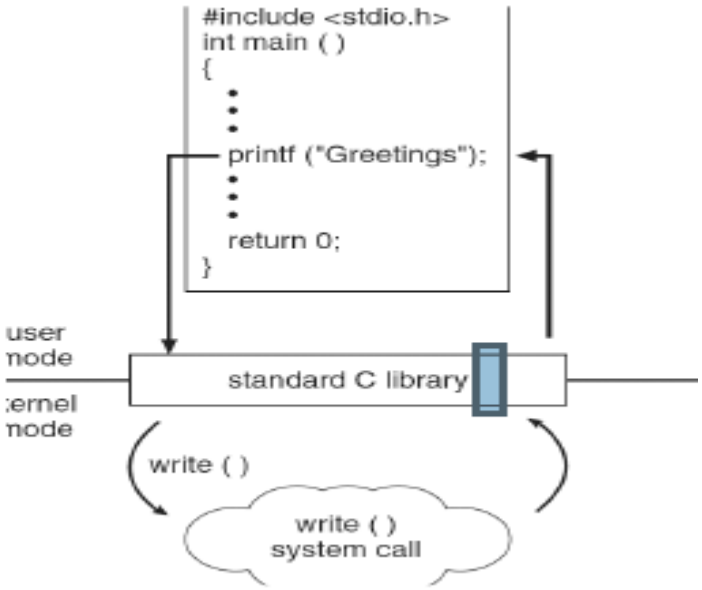
System Call Implementation

• Typically, a number associated with each system call
• System-call interface maintains a table indexed according to these numbers
• The system call interface invokes intended system call in OS kernel and returns status of the system call and any return values
• The caller need know nothing about how the system call is implemented

- Just needs to obey API and understand what OS will do as a result call
- Most details of OS interface hidden from programmer by API Managed by run-time support library (set of functions built into libraries included with compiler)

API — System Call – OS Relationship



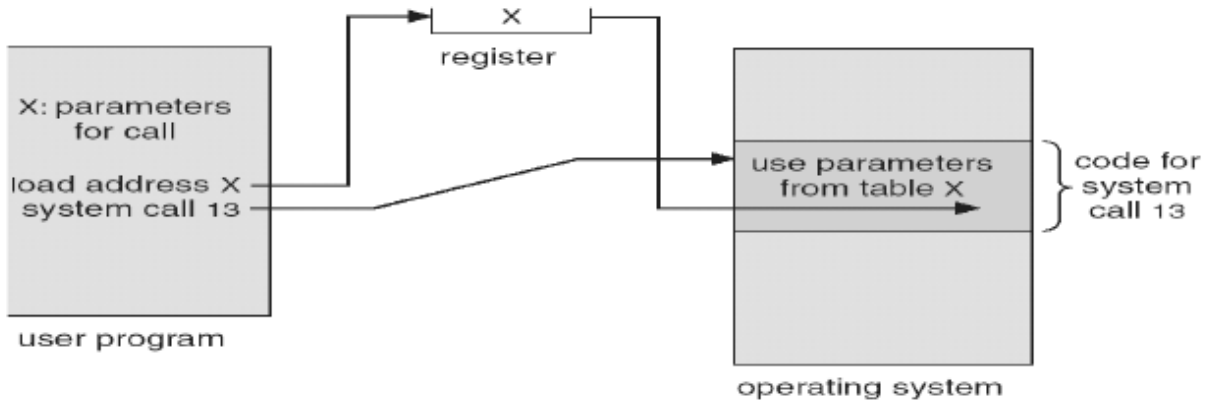


System Call Parameter Passing

- Often, more information is required than simply identity of desired system call
- Exact type and amount of information vary according to OS and call
- Three general methods used to pass parameters to the OS
- Simplest: pass the parameters in *registers*
  - In some cases, may be more parameters than registers

- Parameters stored in a *block,* or table, in memory, and address of block passed as a parameter in a register This approach taken by Linux and Solaris
- Parameters placed, or *pushed,* onto the *stack* by the program and *popped* off the stack by the operating system
- Block and stack methods do not limit the number or length of parameters being passed

Parameter Passing via Table



1.2.4 Types of System Calls

- Process control
- File management
- Device management
- Information maintenance
- Communications
- Protection

Process Control

A running program needs to be able to halt its execution either normally (end) or abnormally (abort). If a system call is made to terminate the currently running program abnormally, or if the program runs into a problem and causes an error trap, a dump of memory is sometimes taken and an error message generated.

The dump is written to disk and may be examined by a **debugger**—a system program designed to aid the programmer in finding and correcting bugs-—to determine the cause of the problem. Under either normal or abnormal circumstances, the operating system must transfer control to the invoking command interpreter. The command interpreter then reads the next command. In an interactive system, the command interpreter simply continues with the next command; it is assumed that the user will issue an appropriate command to respond to any error.

File Management

We first need to be able to create and delete files. Either system call requires the name of the file and perhaps some of the file's attributes. Once the file is created, we need to open it and to use it. We may also read, write, or reposition (rewinding or skipping to the end of the file, for example). Finally, we need to close the file, indicating that we are no longer using it. We may need these same sets of operations for directories if we have a directory structure for organizing files in the file system. In addition, for either files or directories, we need to be able to determine the values

of various attributes and perhaps to reset them if necessary. File attributes include the file name, a file type, protection codes, accounting information, and so on.

At least two system calls, get file attribute and set file attribute, are required for this function. Some operating systems provide many more calls, such as calls for file move and copy.

Device Management

A process may need several resources to execute—main memory, disk drives, access to files, and so on. If the resources are available, they can be granted, and control can be returned to the user process.

Otherwise, the process will have to wait until sufficient resources are available. The various resources controlled by the operating system can be thought of as devices. Some of these devices are physical devices (for example, tapes), while others can be thought of as abstract or virtual devices (for example, files). If there are multiple users of the system, the system may require us to first request the device, to ensure exclusive use of it. After we are finished with the device, we release it. These functions are similar to the open and close system calls for files.

Information Maintenance

Many system calls exist simply for the purpose of transferring information between the user program and the operating system. For example, most systems have a system call to return the current tim e and date . Other system calls may return information about the system, such as the number of current users, the version number of the operating system, the amount of free memory or disk space, and so on.

In addition, the operating system keeps information about all its processes, and system calls are used to access this information. Generally, calls are also used to reset the process information (get process attributes and set process attributes) .

Communication

There are two common models of inter process communication: the message passing model and the shared-memory model. In the message-passing model, the communicating processes exchange messages with one another to transfer information.

Messages can be exchanged between the processes either directly or indirectly through a common mailbox. Before communication can take place, a connection must be opened.

The name of the other communicator must be known, be it another process on the same system or a process on another computer connected by a communications network. Each computer in a network has a *host name* by which it is commonly known.

A host also has a network identifier, such as an IP address. Similarly, each process has a *process name,* and this name is translated into an identifier by which the operating system can refer to the process.

The get host id and get process id system calls do this translation. The identifiers are then passed to the general purpose open and close calls provided by the file system or to specific open connection and close connection system calls, depending on the system's model of communication.

In the shared-memory model, processes use shared memory creates and shared memory attaches system calls to create and gain access to regions of memory owned by other processes. Recall that, normally, the operating system tries to prevent one process from accessing another process's memory.

Shared memory requires that two or more processes agree to remove this restriction.

They can then exchange information by reading and writing data in the shared areas. The form of the data and the location are determined by the processes and are not under the operating system's control.

The processes are also responsible for ensuring that they are not writing to the same location simultaneously.

1.2.5 System Programs

At the lowest level is hardware. Next are the operating system, then the system programs, and finally the application programs. System programs provide a convenient environment for program development and execution. Some of them are simply user interfaces to system calls; others are considerably more complex. They can be divided into these categories:

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

• **Status information.** Some programs simply ask the system for the date, time, amount of available memory or disk space, number of users, or similar status information. Others are more complex, providing detailed performance, logging, and debugging information. Typically, these programs format and print the output to the terminal or other output devices or files or display it in a window of the GUI. Some systems also support a registry, which is used to store and retrieve configuration information.

• **File modification.** Several text editors may be available to create and modify the content of files stored on disk or other storage devices. There may also be special commands to search contents of files or perform transformations of the text.

• **Programming-language support.** Compilers, assemblers, debuggers and interpreters for common programming languages (such as C, C++, Java, Visual Basic, and PERL) are often provided to the user with the operating system.

• **Program loading and execution.** Once a program is assembled or compiled, it must be loaded into memory to be executed. The system may provide absolute loaders, relocatable loaders,

linkage editors, and overlay loaders. Debugging systems for either higher-level languages or machine language are needed as well.

• **Communications.** These programs provide the mechanism for creating virtual connections among processes, users, and computer systems. They allow users to send messages to one another's screens, to browse web pages, to send electronic-mail messages, to log in remotely, or to transfer files from one machine to another.

In addition to systems programs, most In addition to systems programs, most operating systems are supplied with programs that are useful in solving common problems or performing common operations. Such programs include web browsers, word processors and text formatters, spreadsheets, database systems, compilers, plotting and statistical-analysis packages, and games. These programs are known as system utilities or application programs.

1.2.6 Operating-System Structure

Refer above pages

1.2.7 Operating-System Debugging

- Debugging is finding and fixing errors, or bugs
- OS generate log files containing error information
- Failure of an application can generate core dump file capturing memory of the process
- Operating system failure can generate crash dump file containing kernel memory
- Beyond crashes, performance tuning can optimize system performance
- Kernighan's Law: "Debugging is twice as hard as writing the code in the rst place. Therefore, if you write the code as cleverly as possible, you are, by definition, not smart enough to debug it."
- DTrace tool in Solaris, FreeBSD, Mac OS X allows live instrumentation on production systems
- Probes fire when code is executed, capturing state data and sending it to consumers of those Probes

1.2.8 System Boot

The procedure of starting a computer by loading the kernel is known as *booting* the system. On most computer systems, a small piece of code known as the **bootstrap program** or **bootstrap loader** locates the kernel, loads it into main memory, and starts its execution. Some computer systems, such as PCs, use a two-step process in which a simple bootstrap loader fetches a more complex boot program from disk, which in turn loads the kernel.

When a CPU receives a reset event—for instance, when it is powered up or rebooted—the instruction register is loaded with a predefined memory location, and execution starts there. At that location is the initial bootstrap program. This program is in the form of **read-only memory (ROM),** because the RAM is in an unknown state at system startup. ROM is convenient because it needs no initialization and cannot be infected by a computer virus.

The bootstrap program can perform a variety of tasks. Usually, one task is to run diagnostics to determine the state of the machine. If the diagnostics pass, the program can continue with the booting steps. It can also initialize all aspects of the system, from CPU registers to device controllers and the contents of main memory.

Sooner or later, it starts the operating system.
Some systems—such as cellular phones, PDAs, and game consoles—store the entire operating system in ROM. Storing the operating system in ROM is suitable for small operating systems, simple supporting hardware, and rugged operation.

A problem with this approach is that changing the bootstrap code requires changing the ROM hardware chips. Some systems resolve this problem by using **erasable programmable read-only memory** (EPROM), which is read only except when explicitly given a command to become writable.

All forms of ROM are also known as **firmware,** since their characteristics fall somewhere between those of hardware and those of software. A problem with firmware in general is that executing code there is slower than executing code in RAM.
Some systems store the operating system in firmware and copy it to RAM for fast execution. A final issue with firmware is that it is relatively expensive, so usually only small amounts are available.
For large operating systems (including most general-purpose operating systems like Windows, Mac OS X, and UNIX) or for systems that change frequently, the bootstrap loader are stored in firmware, and the operating system is on disk. In this case, the bootstrap runs diagnostics and has a bit of code that can read a single block at a fixed location (say block zero) from disk into memory and execute the code from that **boot block.** The program stored in the boot block may be sophisticated enough to load the entire operating system into memory and begin its execution. More typically, it is simple code (as it fits in a single disk block) and only knows the address on disk and length of the remainder of the bootstrap program. All of the disk-bound bootstrap, and the operating system itself, can be easily changed by writing new versions to disk.

UNIT-II
CHAPTER -3
PROCESSES

1.3.1 Process concepts

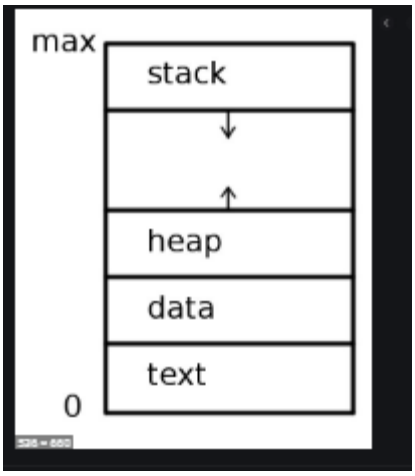
Process : A process is a program in execution. A process is more than the program code, which is sometimes known as the **text section.** It also includes the current activity, as represented by the value of the **program counter** and the contents of the processor's registers. A process generally also includes the process **stack,** which contains temporary data (such as function parameters, return addresses, and local variables), and a **data section,** which contains global variables. A process may also include a **heap,** which is memory that is dynamically allocated during process run time.

Structure of a process

We emphasize that a program by itself is not a process; a program is a *passive* entity, such as a file containing a list of instructions stored on disk (often called an **executable file),** whereas a process is an *active* entity, with a program counter specifying the next instruction to execute and a set of associated resources. A program becomes a process when an executable file is loaded into memory.

Two common techniques for loading executable files are double-clicking an icon representing the executable file and entering the name of the executable file on the command line (as in prog. exe or a.out.)

Process



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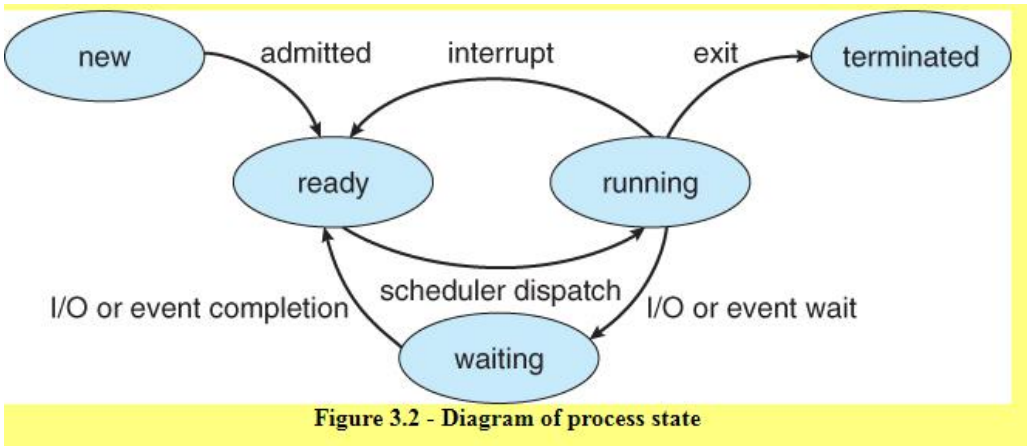


Figure 3.2 - Diagram of process state

Process State

As a process executes, it changes **state.** The state of a process is defined in part by the current activity of
that process. Each process may be in one of the following states:

• **New.** The process is being created.
• **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).
• **Ready.** The process is waiting to be assigned to a processor.
• **Terminated.** The process has finished execution. These names are arbitrary, and they vary across operating systems. The states that they represent are fotind on all systems, however. Certain operating systems also more finely delineate process states. It is important to realize that only one process can be *running* on any processor at any instant.

Process Control Block

Each process is represented in the operating system by a **process control block (PCB)**—also called a *task control block.*

Process state. The state may be new, ready, running, and waiting, halted, and so on.

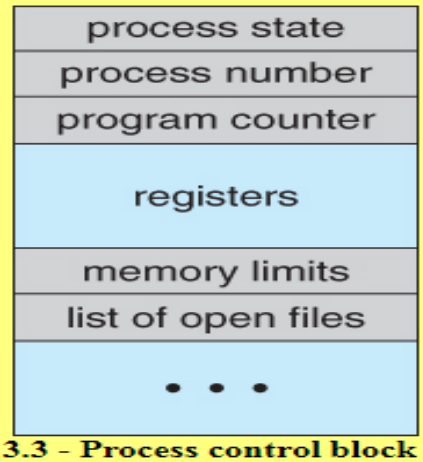


Figure 3.3 - Process control block (PCB)

Program counter-The counter indicates the address of the next instruction to be executed for this process.

• CPU **registers-** The registers vary in number and type, depending on the computer architecture. They include accumulators, index registers, stack pointers, and general-purpose registers, plus any condition code information.

CPU-scheduling information- This information includes a process priority, pointers to scheduling queues, and any other scheduling parameters.

Memory-management information- This information may include such information as the value of the base and limit registers, the page tables, or the segment tables, depending on the memory system used by the operating system

Accounting information-This information includes the amount of CPU and real time used, time limits, account members, job or process numbers, and so on.

I/O status information-This information includes the list of I/O devices allocated to the process, a list of open files, and so on.

1.3.2 Process Scheduling

The **process scheduler** selects an available process (possibly from a set of several available processes) for program execution on the CPU. As processes enter the system, they are put into a **job queue,** which consists of all processes in the system. The processes that are residing in main memory and are ready and waiting to execute are kept on a list called the **ready queue.**

This queue is generally stored as a linked list. A ready-queue header contains pointers to the first and final PCBs in the list. Each PCB includes a pointer field that points to the next PCB in the ready queue.

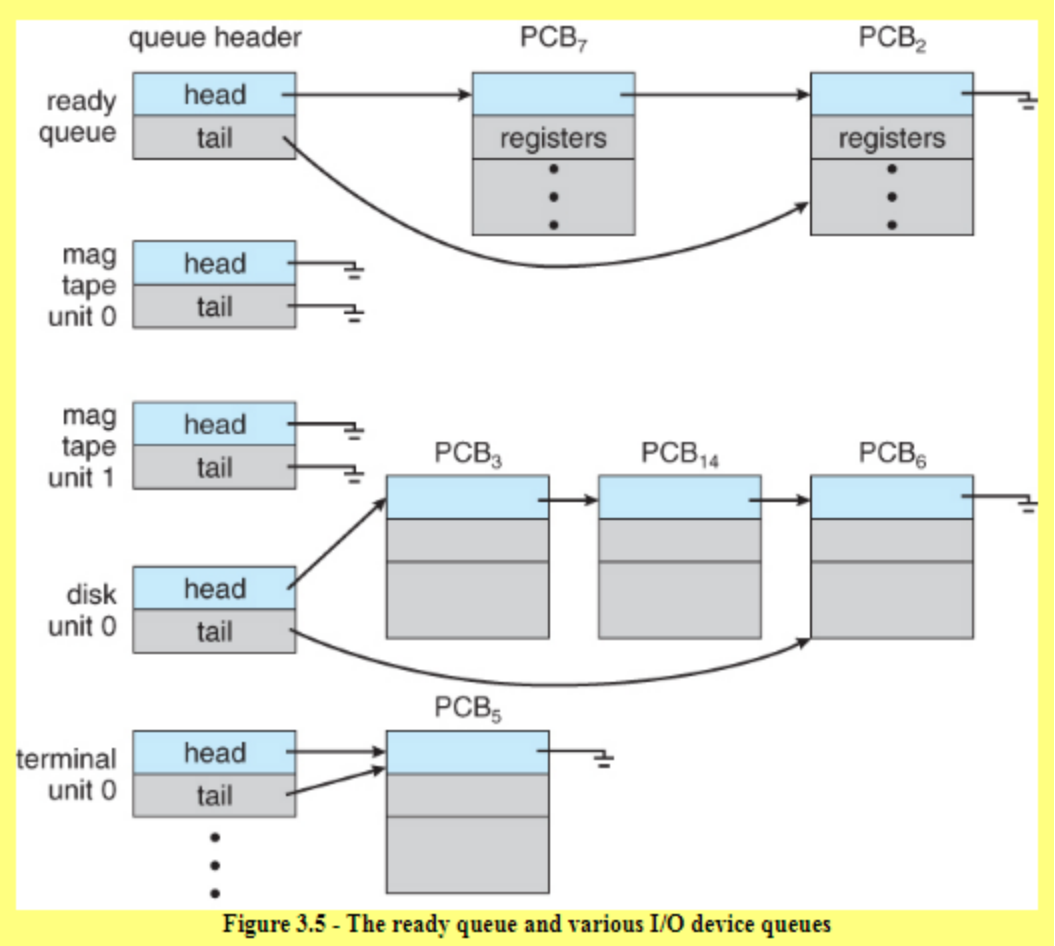


Figure 3.5 - The ready queue and various I/O device queues

The **process scheduler** selects an available process (possibly from a set of several available processes) for program execution on the CPU. As processes enter the system, they are put into a **job queue,** which consists of all processes in the system. The processes that are residing in main memory and are ready and waiting to execute are kept on a list called the **ready queue.**

This queue is generally stored as a linked list. A ready-queue header contains pointers to the first and final PCBs in the list. Each PCB includes a pointer field that points to the next PCB in the ready queue.
Each rectangular box represents a queue. Two types of queues are present: the ready queue and a set of device queues. The circles represent the resources that serve the queues, and the arrows indicate the flow of processes in the system.

A new process is initially put in the ready queue. It waits there till it is selected for execution, or is **dispatched.** Once the process is allocated the CPU and is executing, one of several events could occur:
• The process could issue an I/O request and then be placed in an I/O queue.
• The process could create a new sub process and wait for the sub process's termination.
• The process could be removed forcibly from the CPU, as a result of an interrupt, and be put back in the
ready queue.

Schedulers
A process migrates among the various scheduling queues throughout its lifetime. The operating system must select, for scheduling purposes, processes from these queues in some fashion.

The selection process is carried out by the appropriate **scheduler.** The **long-term scheduler,** or **job scheduler,** selects processes from this pool and loads them into memory for execution. The **short-term scheduler, or** CPU **scheduler,** selects from among the processes that are ready to execute and allocates the CPU to one of them.

1.3.3 Operations on Processes
Process Creation
A process may create several new processes, via a create-process system call, during the course of execution. The creating process is called a **parent** process, and the new processes are called the **children** of that process. Each of these new processes may in turn create other processes, forming a **tree** of processes.

Most operating systems identify processes according to a unique **process identifier** (or **pid),** which is typically an integer number. These processes are responsible for managing memory and file systems. The sched process also creates the init process, which serves as the root parent process for all user processes.

When a process creates a new process, two possibilities exist in terms of execution:
1. The parent continues to execute concurrently with its children.
2. The parent waits until some or all of its children have terminated.
There are also two possibilities in terms of the address space of the new process:

1. The child process is a duplicate of the parent process (it has the same program and data as the parent).
2. The child process has a new program loaded into it.

```
#include <sys/types.h>
#include <stdio.h>
#include <unistd.h>
int main()
{
pid-t pid;
/* fork a child process */
pid = fork();
if (pid < 0) {/* error occurred */
fprintf(stderr, "Fork Failed");
exit (-1) ;
}
else if (pid == 0} {/* child process */
execlpf"/bin/Is","Is",NULL);
}
else {/* parent process */
/* parent will wait for the child to complete */
wait(NULL);
printf("Child Complete");
exit (0) ;
}
}
```

In UNIX, as we've seen, each process is identified by its process identifier, which is a unique integer. A new process is created by the fork() system call. The new process consists of a copy of the address space of the original process.

This mechanism allows the parent process to communicate easily with its child process. Both processes (the parent and the child) continue execution at the instruction after the fork(), with one difference: The return code for the fork() is zero for the new (child) process, whereas the (nonzero) process identifier of the child is returned to the parent. the exec() system call is used after a fork() system call by one of the two processes to replace the process's memory space with a new program.

The exec () system call loads a binary file into memory (destroying the memory image of the program containing the execO system call) and starts its execution.

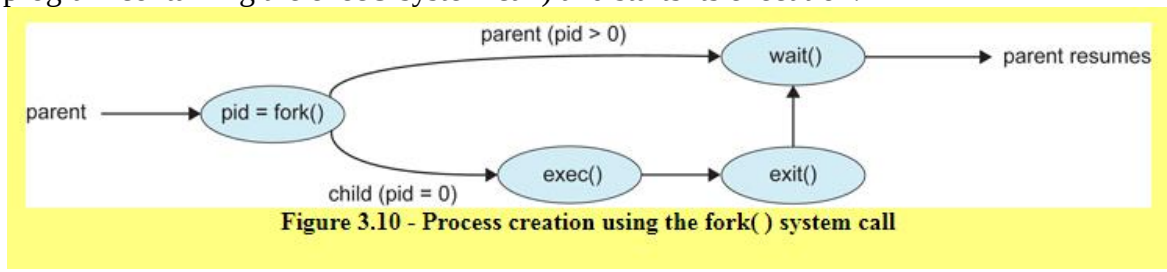


Figure 3.10 - Process creation using the fork( ) system call

Process Termination

A process terminates when it finishes executing its final statement and asks the operating system to delete it by using the exit () system call. At that point, the process may return a status value (typically an integer) to its parent process (via the wait() system call). All the resources of the process—including physical and virtual memory, open files, and I/O buffers—are deal located by the operating system.
Termination can occur in other circumstances as well. A process can cause the termination of another process via an appropriate system call (for example, TerminateProcessO in Win32). Usually, such a system call can be invoked only by the parent of the process that is to be terminated.
A parent may terminate the execution of one of its children for a variety of reasons, such as these:
• The child has exceeded its usage of some of the resources that it has been allocated.
• The task assigned to the child is no longer required.
• The parent is exiting, and the operating system does not allow a child to
continue if its parent terminates.
Consider that, in UNIX, we can terminate a process by using the exit() system call; its parent process may wait for the termination of a child process by using the wait() system call. The wait () system call returns the process identifier of a terminated child so that the parent can tell which of its possibly many children has terminated.
If the parent terminates, however, all its children have assigned as their new parent the init process.

1.3.4 Interprocess Communication

Processes executing concurrently in the operating system may be either independent processes or cooperating processes. A process is **independent** if it cannot affect or be affected by the other processes executing in the system.

Any process that does not share data with any other process is independent. A process is **cooperating** if **it** can affect or be affected by the other processes executing in the system.
There are several reasons for providing an environment that allows process cooperation:

• **Information sharing.** Since several users may be interested in the same piece of information (for instance, a shared file), we must provide an environment to allow concurrent access to such information.
• **Computation speedup.** If we want a particular task to run faster, we must break it into subtasks, each of
which will be executing in parallel with the others. Notice that such a speedup can be achieved only if the
computer has multiple processing elements (such as CPUs or I/O channels).
• **Modularity.** We may want to construct the system in a modular fashion, dividing the system functions into separate processes or threads. • **Convenience.** Even an individual user may work on many tasks at the same time. For instance, a user may be editing, printing, and compiling in parallel.
Cooperating processes require an **interprocess communication (IPC)** mechanism that will allow them to exchange data and information. There are two fundamental models of interprocess

communication:

(1) shared memory and (2) **message passing.** In the shared-memory model, a region of memory that is shared by cooperating processes is established. Processes can then exchange information by reading and writing data to the shared region. In the message passing model, communication takes place by means of messages exchanged between the cooperating processes.

Message passing is useful for exchanging smaller amounts of data, because no conflicts need be avoided. Message passing is also easier to implement than is shared memory for intercomputer communication. Shared memory allows maximum speed and convenience of communication, as it can be done at memory speeds when within a computer.

Shared memory is faster than message passing, as message-passing systems are typically implemented using system calls and thus require the more time consuming task of kernel intervention.

Shared-Memory Systems Interprocess communication using shared memory requires communicating processes to establish a region of shared memory.
Typically, a shared-memory region resides in the address space of the process creating the shared-memory segment. Other processes that wish to communicate using this shared-memory segment must attach it to their address space.
The operating system tries to prevent one process from accessing another process's memory. Shared memory requires that two or more processes agree to remove this restriction. They can then exchange information by reading and writing data in the shared areas.

The form of the data and the location are determined by these processes and are not under the operating system's control. The processes are also responsible for ensuring that they are not writing to the same location simultaneously.
Message-Passing Systems The scheme requires that these processes share a region of memory and that the code for accessing and manipulating the shared memory be written explicitly by the application programmer. Another way to achieve the same effect is for the operating system to provide the means for cooperating processes to communicate with each other via a message-passing facility.

Message passing provides a mechanism to allow processes to communicate and to synchronize their actions without sharing the same address space and is particularly useful in a distributed environment, where the communicating processes may reside on different computers connected by a network.
A message-passing facility provides at least two operations: send(message) and receive(message). Messages sent by a process can be of either fixed or variable size. If only fixed-sized messages can be sent, the system-level implementation is straightforward. This restriction, however, makes the task of programming more difficult. Conversely, variable-sized messages require a more complex system-level implementation, but the programming task becomes simpler. This is a common kind of tradeoff seen throughout operating system design.

Naming

Processes that want to communicate must have a way to refer to each other. They can use either direct or indirect communication.
Under direct communication, each process that wants to communicate must explicitly name the recipient or sender of the communication. In this scheme, the send.0 and receive() primitives are defined as:
• send(P, message)—Send a message to process P.
• receive (Q, message)—Receive a message from process Q.
A communication link in this scheme has the following properties:
• A link is established automatically between every pair of processes that want to communicate. The processes need to know only each other's identity to communicate.
• A link is associated with exactly two processes.
• Between each pair of processes, there exists exactly one link.
The disadvantage in both of these schemes (symmetric and asymmetric) is the limited modularity of the resulting process definitions. Changing the identifier of a process may necessitate examining all other process definitions.

Synchronization
Communication between processes takes place through calls to send() and receive () primitives. There are different design options for implementing each primitive. Message passing may be either **blocking** or **nonblocking**— also known as **synchronous** and **asynchronous.**

• **Blocking send-** The sending process is blocked until the message is received by the receiving process or by the mailbox.

• **Nonblocking send-** The sending process sends the message and resumes operation.
• **Blocking receive-** The receiver blocks until a message is available.

• **Nonblocking receive-** The receiver retrieves either a valid message or a null.
Buffering

Whether communication is direct or indirect, messages exchanged by communicating processes reside in a temporary queue. Basically, such queues can be implemented in three ways:

• **Zero capacity-** The queue has a maximum length of zero; thus, the link cannot have any messages waiting in it. In this case, the sender must block until the recipient receives the message.

• **Bounded capacity-** The queue has finite length *n;* thus, at most *n* messages can reside in it. If the queue is not full when a new message is sent, the message is placed in the queue (either the message is copied or a pointer to the message is kept), and the sender can continue execution without waiting. The links capacity is finite, however. If the link is full, the sender must block until space is available in the queue.

• **Unbounded capacity-** The queues length is potentially infinite; thus, any number of messages can wait in it. The sender never blocks.

1.3.5 Examples of IPC Systems

An Example: POSIX Shared Memory

Several IPC mechanisms are available for POSIX systems, including shared memory and message passing. A process must first create a shared memory segment using the shmget () system call (shmget () is derived from SHared Memory GET).

The following example illustrates the use of shmget ():
segment_id = shmget(IPCJPRIVATE, size, SJRUSR | SJVVUSR) ;
This first parameter specifies the key (or identifier) of the shared-memory segment. If this is set to IPCPRIVATE, a new shared-memory segment is created. The second parameter specifies the size (in bytes) of the shared memory segment. Finally, the third parameter identifies the mode, which indicates how the shared-memory segment is to be used—that is, for reading, writing, or both. By setting the mode to SJRUSR | SJVVUSR, we are indicating that the owner may read or write to the shared memory segment.

Processes that wish to access a shared-memory segment must attach it to their address space using the shmat () (SHared Memory ATtach) system call.
The call to shmat () expects three parameters as well. The first is the integer identifier of the shared-memory segment being attached, and the second is a pointer location in memory indicating where the shared memory will be attached.
If we pass a value of NULL, the operating system selects the location on the user's behalf. The third parameter identifies a flag that allows the shared memory region to be attached in read-only or read-write mode; by passing a parameter of 0, we allow both reads and writes to the shared region.

The third parameter identifies a mode flag. If set, the mode flag allows the shared-memory region to be attached in read-only mode; if set to 0, the flag allows both reads and writes to the shared region.

We attach a region of shared memory using shmat () as follows:
shared_memory = (char *) shmat(id, NULL, 0);
If successful, shmat () returns a pointer to the beginning location in memory where the shared-memory region has been attached.

An Example: Windows XP

The Windows XP operating system is an example of modern design that employs modularity to increase functionality and decrease the time needed to implement new features. Windows XP provides support for multiple operating environments, or *subsystems,* with which application programs communicate via a message-passing mechanism. The application programs can be considered clients of the Windows XP subsystem server.

The message-passing facility in Windows XP is called the **local procedure call (LPC)** facility. The LPC in Windows XP communicates between two processes on the same machine. It is similar to the standard RPC mechanism that is widely used, but it is optimized for and specific to

Windows XP. Windows XP uses a port object to establish and maintain a connection between two processes. Every client that calls a subsystem needs a communication channel, which is provided by a port object and is never inherited.
Windows XP uses two types of ports: connection ports and communication ports. They are really the same but are given different names according to how they are used. Connection ports are named *objects* and are visible to all processes

The communication works as follows:
• The client opens a handle to the subsystem's connection port object.
• The client sends a connection request.
• The server creates two private communication ports and returns the handle to one of them to the client.
• The client and server use the corresponding port handle to send messages or callbacks and to listen for replies.
Windows XP uses two types of message-passing techniques over a port that the client specifies when it establishes the channel.

The simplest, which is used for small messages, uses the port's message queue as intermediate storage and copies the message from one process to the other. Under this method, messages of up to 256 bytes can be sent. If a client needs to send a larger message, it passes the message through a section object, which sets up a region of shared memory. The client has to decide when it sets up the channel whether or not it will need to send a large message. If the client determines that it does want to send large messages, it asks for a section object to be created. Similarly, if the server decides that replies will be large, it creates a section object. So that the section object can be used, a small message is sent that contains a pointer and size information about the section object. This method is more complicated than the first method, but it avoids data copying. In both cases, a callback mechanism can be used when either the client or the server cannot respond immediately to a request.

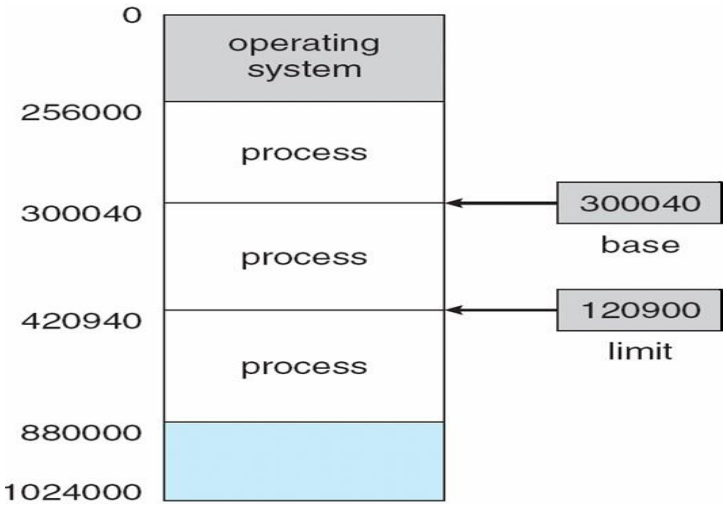
UNIT III

Memory Management

- To provide a detailed description of various ways of organizing memory hardware
- To discuss various memory-management techniques, including paging and segmentation
- To provide a detailed description of the Intel Pentium, which supports both pure segmentation and segmentation with paging
- Program must be brought (from disk) into memory and placed within a process for it to be run
- Main memory and registers are only storage CPU can access directly
- Register access in one CPU clock (or less)
- Main memory can take many cycles
- **Cache** sits between main memory and CPU registers
- Protection of memory required to ensure correct operation

Base and Limit Registers

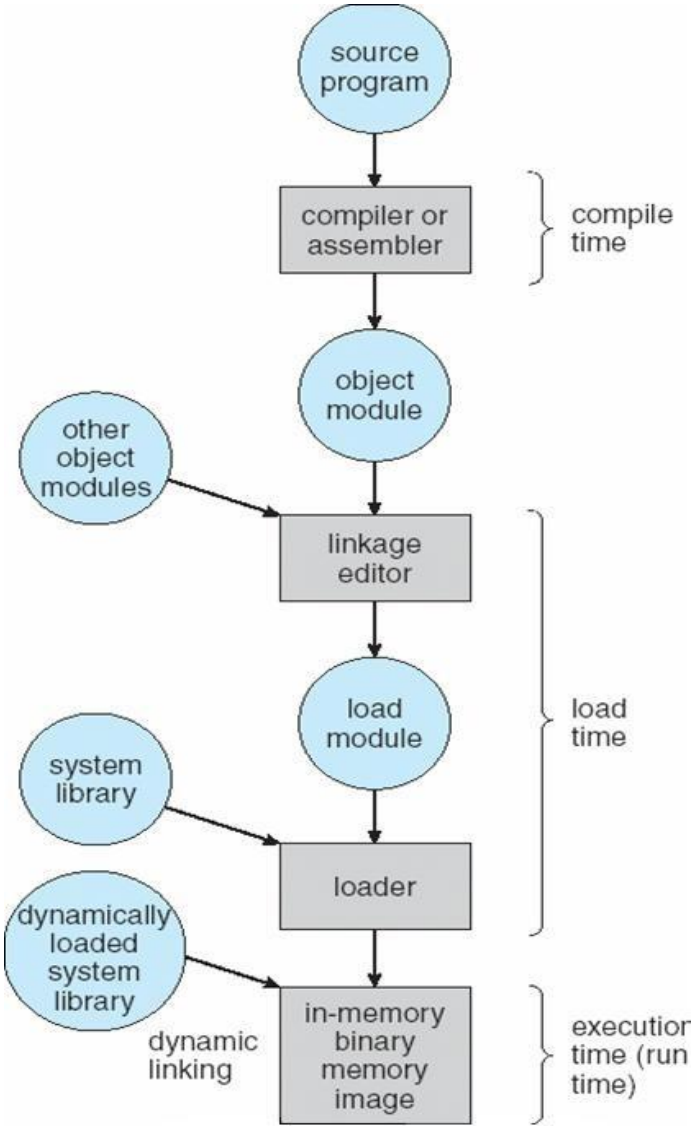
A pair of **base** and **limit** registers define the logical address space



Binding of Instructions and Data to Memory

- Address binding of instructions and data to memory addresses can happen at three different stages
- **Compile time**: If memory location known a priori, **absolute code** can be generated; must recompile code if starting location changes
- **Load time**: Must generate **relocatable code** if memory location is not known at compile time
- **Execution time**: Binding delayed until run time if the process can be moved during its execution from one memory segment to another. Need hardware support for address maps (e.g., base and limit registers)

Multistep Processing of a User Program



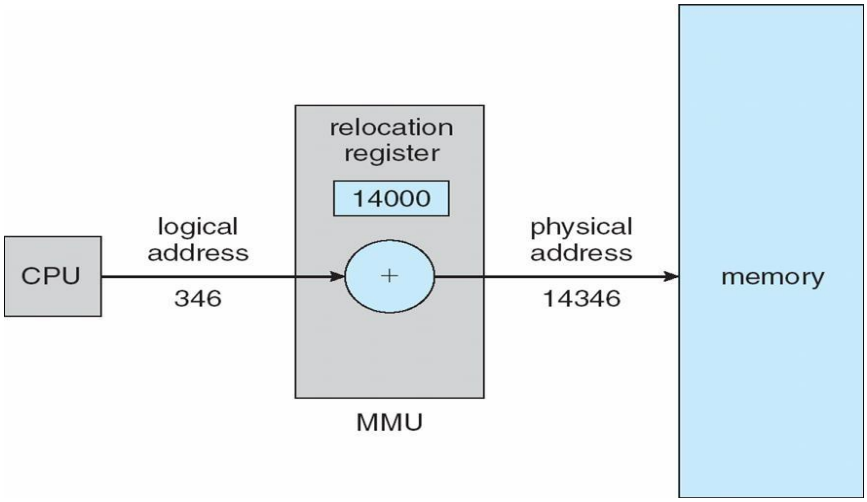
Logical vs. Physical Address Space

- The concept of a logical address space that is bound to a separate **physical address space** is central to proper memory management
- **Logical address** – generated by the CPU; also referred to as **virtual address**
- **Physical address** – address seen by the memory unit
- Logical and physical addresses are the same in compile-time and load-time address-binding schemes; logical (virtual) and physical addresses differ in execution-time address-binding scheme

Memory-Management Unit (MMU)

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

Dynamic relocation using a relocation register



Dynamic Loading

- Routine is not loaded until it is called
- Better memory-space utilization; unused routine is never loaded
- Useful when large amounts of code are needed to handle infrequently occurring cases
- No special support from the operating system is required implemented through program design

Dynamic Linking

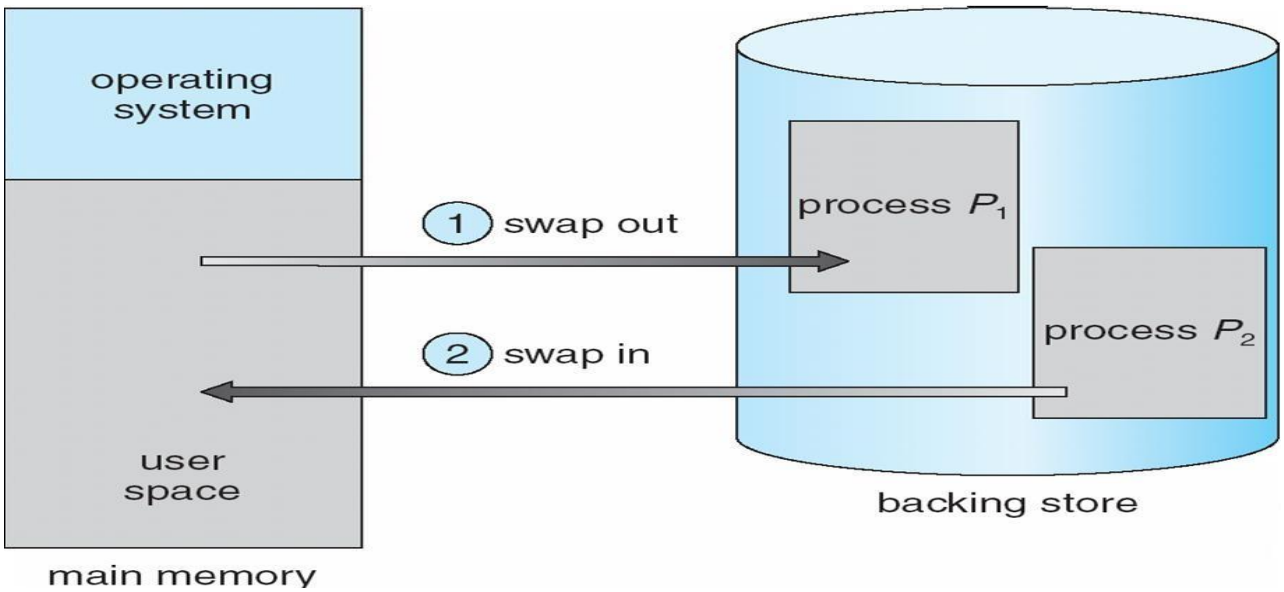
- Linking postponed until execution time
- Small piece of code, *stub*, used to locate the appropriate memory-resident library routine
- Stub replaces itself with the address of the routine, and executes the routine
- Operating system needed to check if routine is in processes' memory address
- Dynamic linking is particularly useful for libraries
- System also known as **shared libraries**

Swapping

A process can be swapped temporarily out of memory to a backing store, and then brought back into memory for continued executionn**Backing store** – fast disk large enough to accommodate copies of all memory images for all users; must provide direct access to these memory imagesn**Roll out, roll in** – swapping variant used for priority-based scheduling algorithms; lower-priority process is swapped out so higher-priority process can be loaded and executednMajor part of swap time is transfer time; total transfer time is directly proportional to the amount of memory swappednModified versions of swapping are found on many systems (i.e., UNIX, Linux, and Windows)

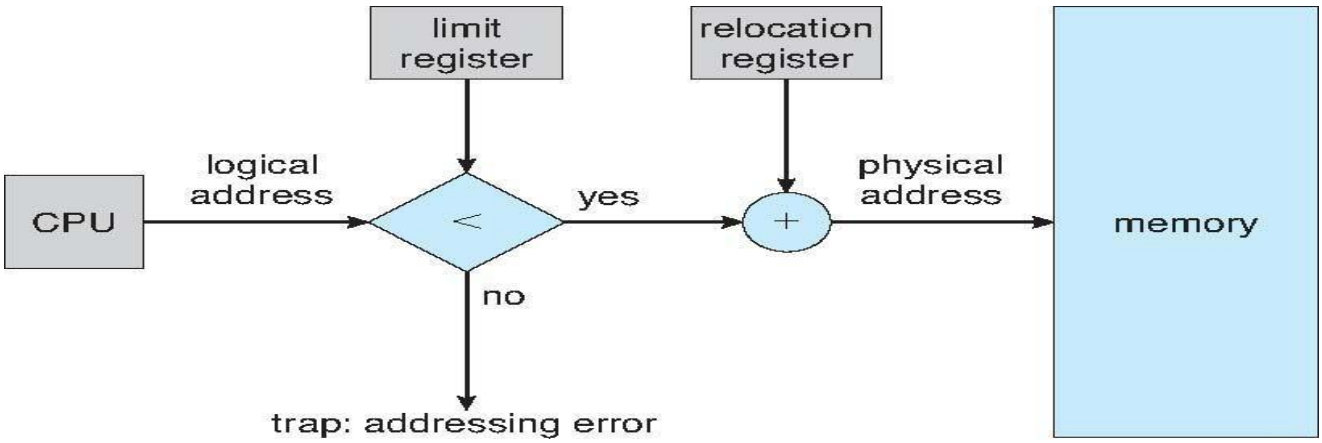
System maintains a **ready queue** of ready-to-run processes which have memory images on disk

Schematic View of Swapping



- Main memory usually into two partitions:
- Resident operating system, usually held in low memory with interrupt vector
- User processes then held in high memorynRelocation registers used to protect user processes from each other, and from changing operating-system code and data
- Base register contains value of smallest physical address
- Limit register contains range of logical addresses – each logical address must be less than the limit register
- MMU maps logical address *dynamically*

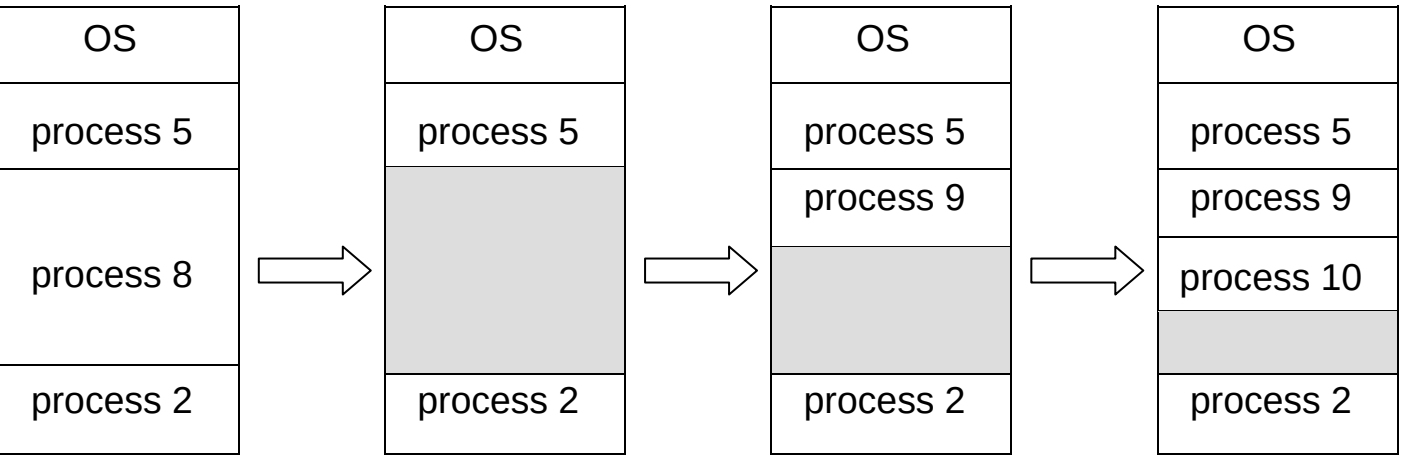
Hardware Support for Relocation and Limit Registers



- Multiple-partition allocation
- Hole – block of available memory; holes of various size are scattered throughout memory
- When a process arrives, it is allocated memory from a hole large enough to accommodate it

- Operating system maintains information about:

- a) allocated partitions b) free partitions (hole)



Dynamic Storage-Allocation Problem

- **First-fit**: Allocate the *first* hole that is big enough
- **Best-fit**: Allocate the *smallest* hole that is big enough; must search entire list, unless ordered by size Produces the smallest leftover hole
- **Worst-fit**: Allocate the *largest* hole; must also search entire list
- Produces the largest leftover hole
- First-fit and best-fit better than worst-fit in terms of speed and storage utilization

Fragmentation

- **External Fragmentation** – total memory space exists to satisfy a request, but it is not contiguous
- **Internal Fragmentation** – allocated memory may be slightly larger than requested memory; this size difference is memory internal to a partition, but not being used
- Reduce external fragmentation by **compaction**
- Shuffle memory contents to place all free memory together in one large block
- Compaction is possible *only* if relocation is dynamic, and is done at execution time.
- I/O problem
    - Latch job in memory while it is involved in I/O
    - Do I/O only into OS buffers

Paging

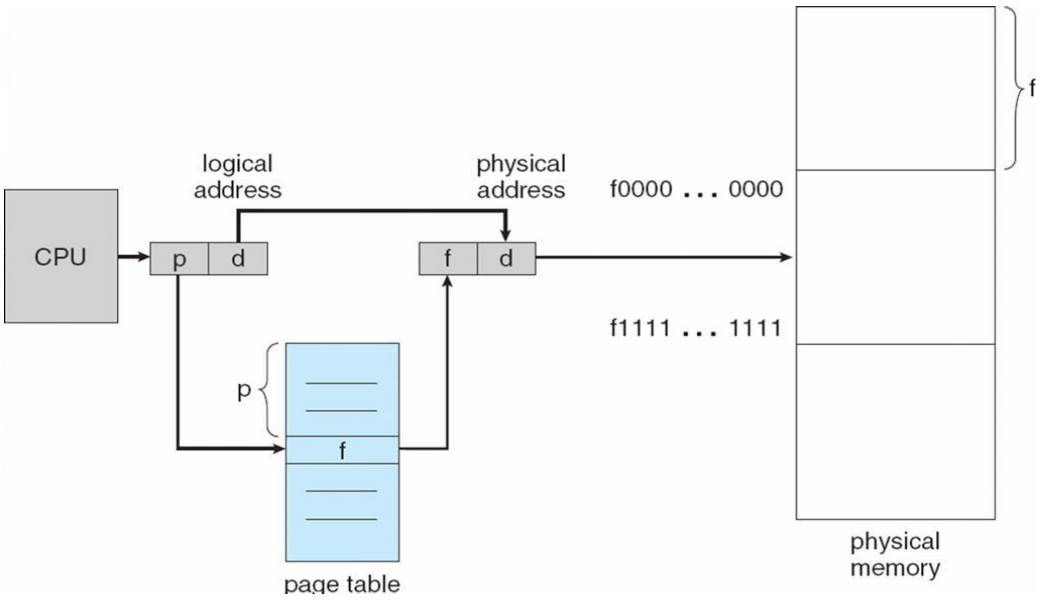
- Logical address space of a process can be noncontiguous; process is allocated physical memory whenever the latter is available
- Divide physical memory into fixed-sized blocks called **frames** (size is power of 2, between 512 bytes and 8,192 bytes)
- Divide logical memory into blocks of same size called **pages**nKeep track of all free frames

- To run a program of size ***n*** pages, need to find *n* free frames and load program
- Set up a page table to translate logical to physical addresses
- Internal fragmentation

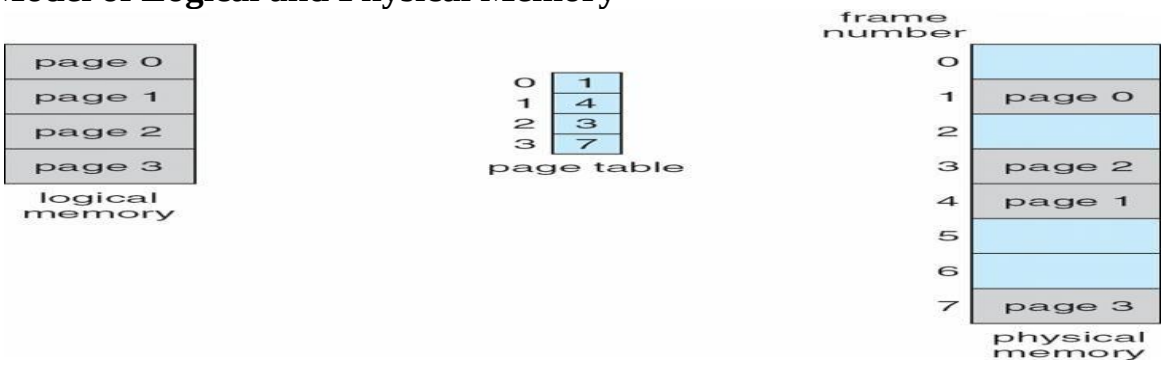
Address Translation Scheme

- Address generated by CPU is divided into
- **Page number (*p*)** – used as an index into a *page table* which contains base address of each page in physical memory
- **Page offset (d)** – combined with base address to define the physical memory address that is sent to the memory unit
- For given logical address space 2^m *and page size* 2^n

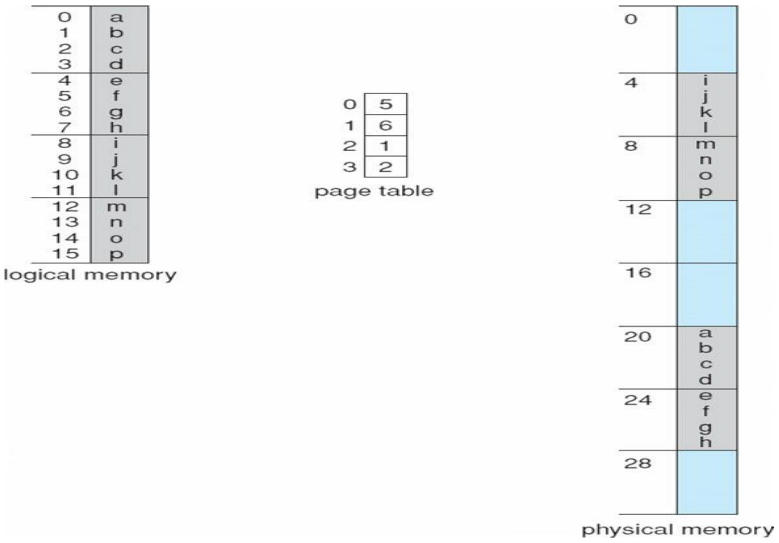
Paging Hardware



Paging Model of Logical and Physical Memory

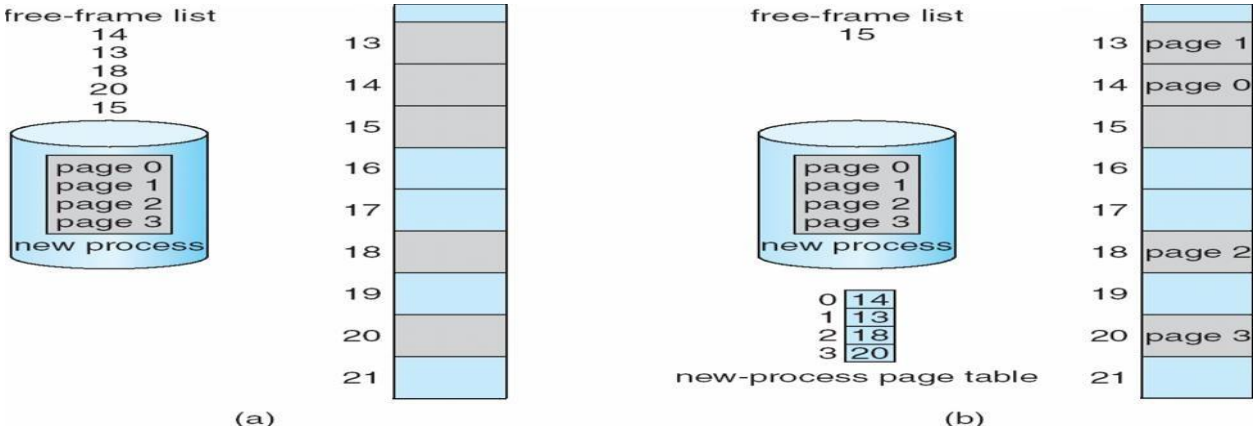


Paging Example



32-byte memory and 4-byte pages

Free Frames



Implementation of Page Table

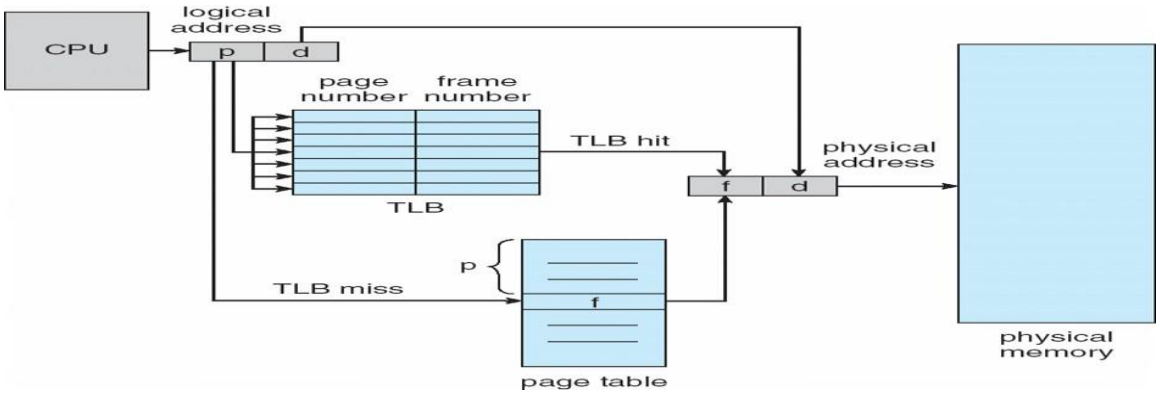
- Page table is kept in main memory
- **Page-table base register (PTBR)** points to the page table
- **Page-table length register (PRLR)** indicates size of the page table
- In this scheme every data/instruction access requires two memory accesses. One for the page table and one for the data/instruction.
- The two memory access problem can be solved by the use of a special fast-lookup hardware cache called **associative memory** or **translation look-aside buffers (TLBs)**
- Some TLBs store **address-space identifiers (ASIDs)** in each TLB entry – uniquely identifies each process to provide address-space protection for that process

Associative Memory

- Associative memory – parallel search
- Address translation (p, d)
- If p is in associative register, get frame # out
- Otherwise get frame # from page table in memory

Page #	Frame #

Paging Hardware With TLB



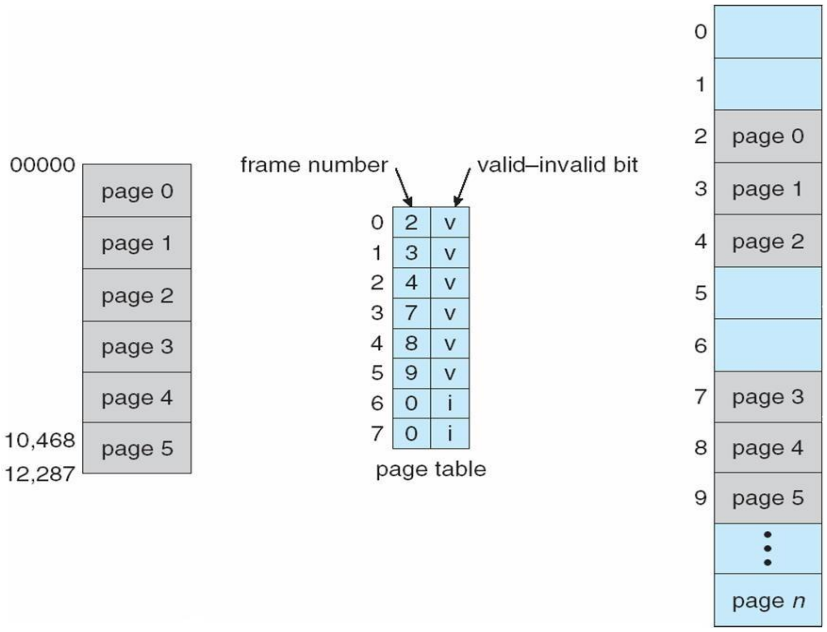
Effective Access Time

- Associative Lookup = e time unit
- Assume memory cycle time is 1 microsecond
- Hit ratio – percentage of times that a page number is found in the associative registers; ratio related to number of associative registers
- Hit ratio = an **Effective Access Time** (EAT)

$$EAT = (1 + e)\, a + (2 + e)(1 - a)$$
$$= 2 + e - a$$

Memory Protection

- Memory protection implemented by associating protection bit with each frame
- **Valid-invalid** bit attached to each entry in the page table:
- "valid" indicates that the associated page is in the process' logical address space, and is thus a legal page
- "invalid" indicates that the page is not in the process' logical address space
- **Valid (v) or Invalid (i) Bit In A Page Table**



Shared Pages

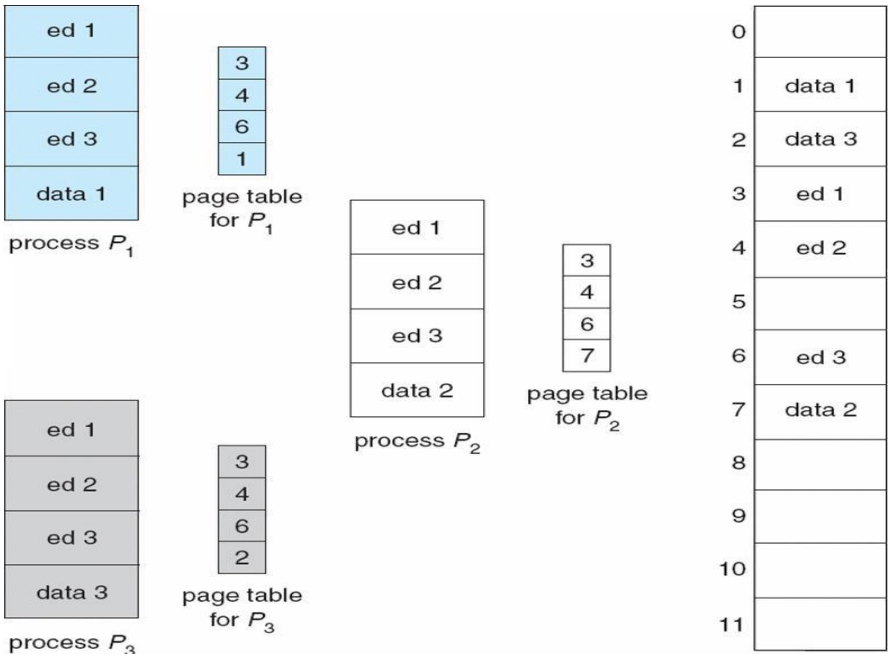
Shared code

- One copy of read-only (reentrant) code shared among processes (i.e., text editors, compilers, window systems).
- Shared code must appear in same location in the logical address space of all processes

Private code and data

- Each process keeps a separate copy of the code and data
- The pages for the private code and data can appear anywhere in the logical address space

Shared Pages Example



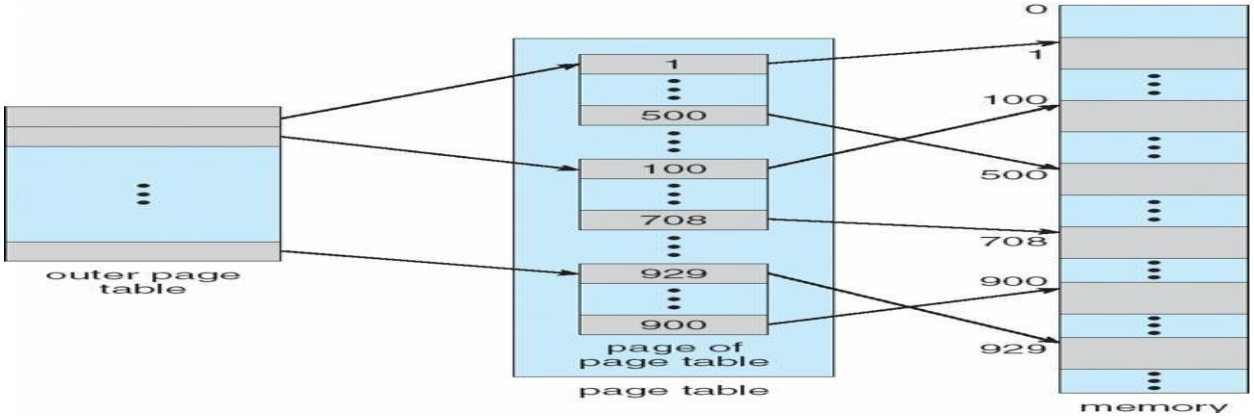
Structure of the Page Table

- Hierarchical Paging
- Hashed Page Tables
- Inverted Page Tables

Hierarchical Page Tables

- Break up the logical address space into multiple page tables
- A simple technique is a two-level page table

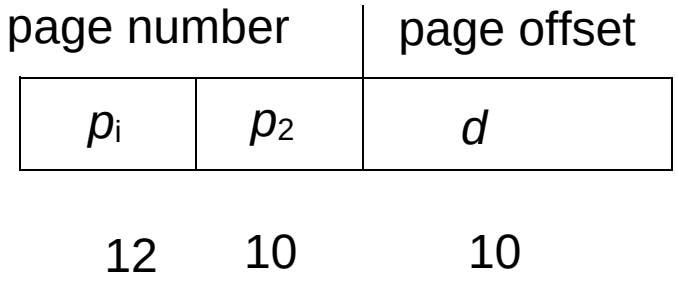
Two-Level Page-Table Scheme



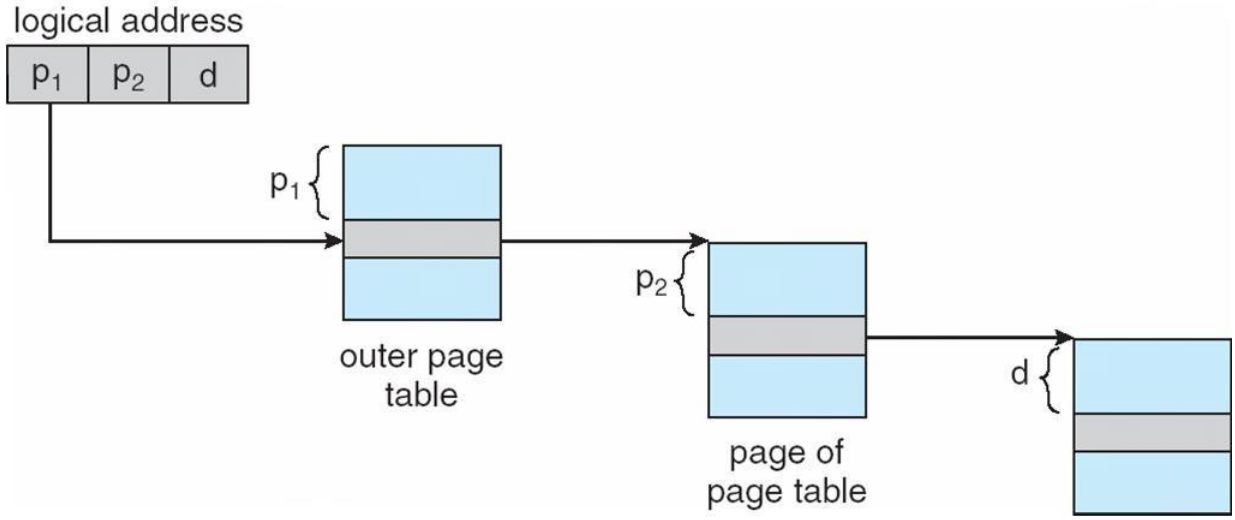
Two-Level Paging Example

- A logical address (on 32-bit machine with 1K page size) is divided into:
- a page number consisting of 22 bits
- a page offset consisting of 10 bits
- Since the page table is paged, the page number is further divided into:
- a 12-bit page number
- a 10-bit page offset
- Thus, a logical address is as follows:

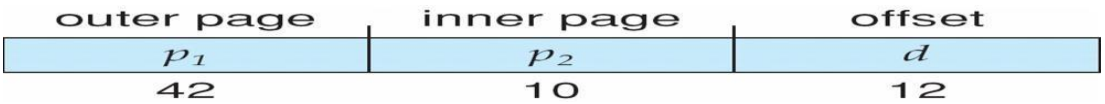
  where *pi* is an index into the outer page table, and *p2* is the displacement within the page of the outer page table

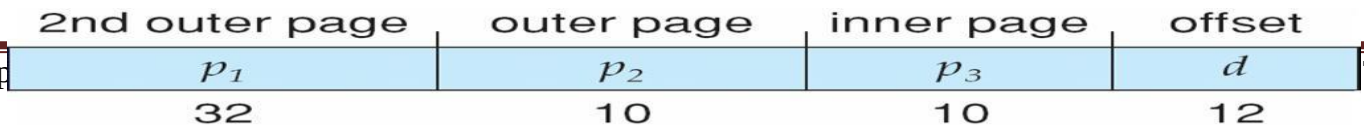


Address-Translation Scheme



Three-level Paging Scheme

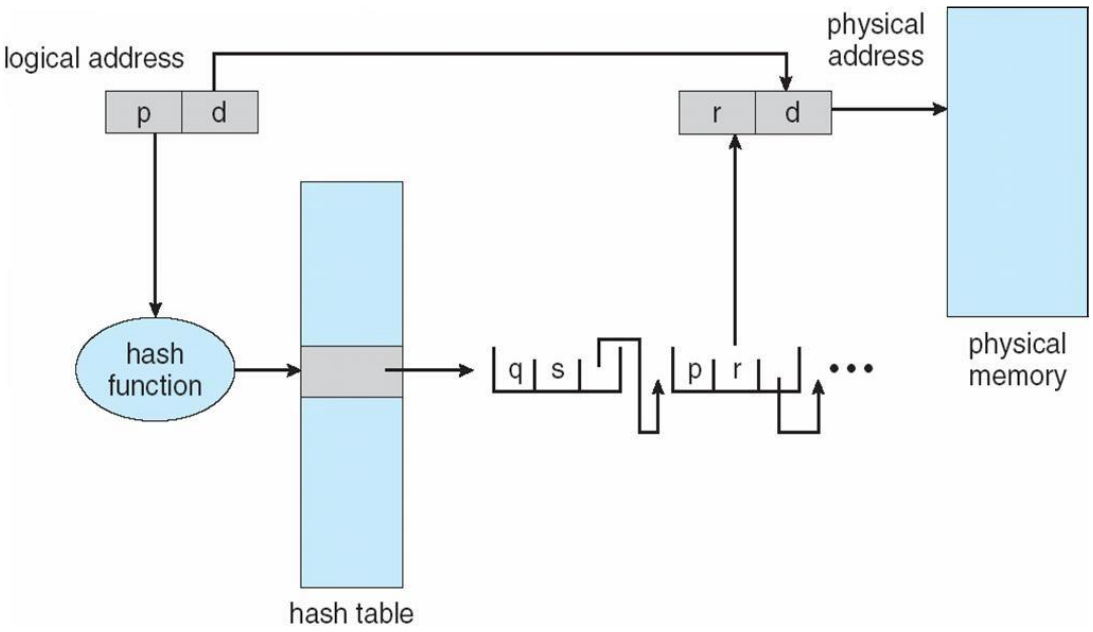




Hashed Page Tables

- Common in address spaces > 32 bits
- The virtual page number is hashed into a page table
- This page table contains a chain of elements hashing to the same location
- Virtual page numbers are compared in this chain searching for a match
- If a match is found, the corresponding physical frame is extracted

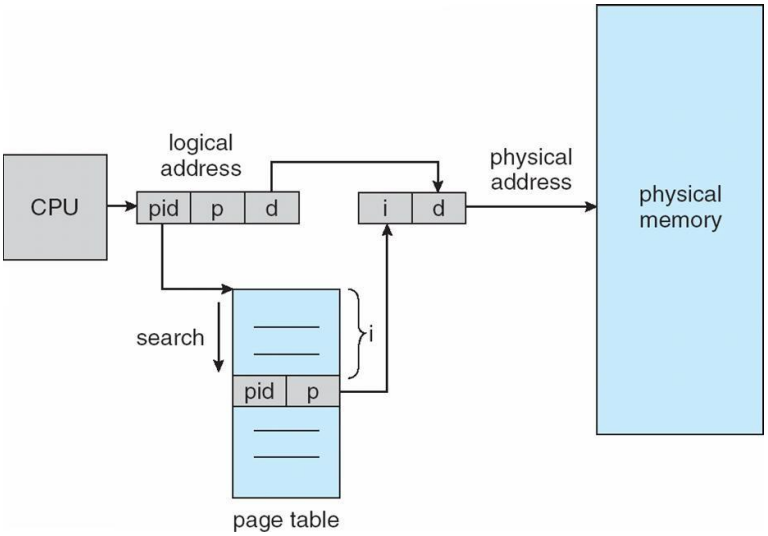
Hashed Page Table



Inverted Page Table

- One entry for each real page of memory
- Entry consists of the virtual address of the page stored in that real memory location, with information about the process that owns that page
- Decreases memory needed to store each page table, but increases time needed to search the table when a page reference occurs
- Use hash table to limit the search to one — or at most a few — page-table entries

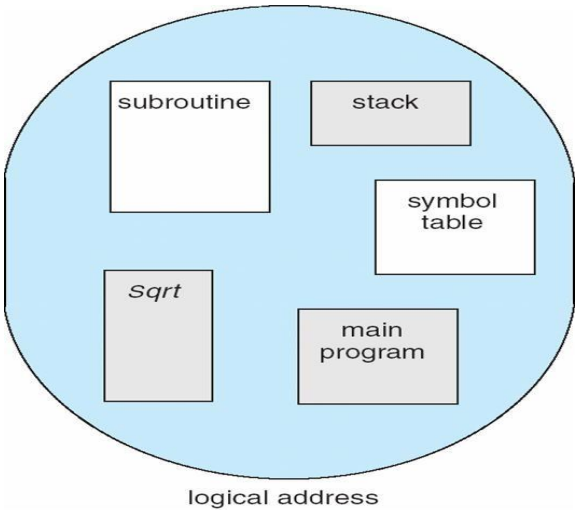
Inverted Page Table Architecture



Segmentation

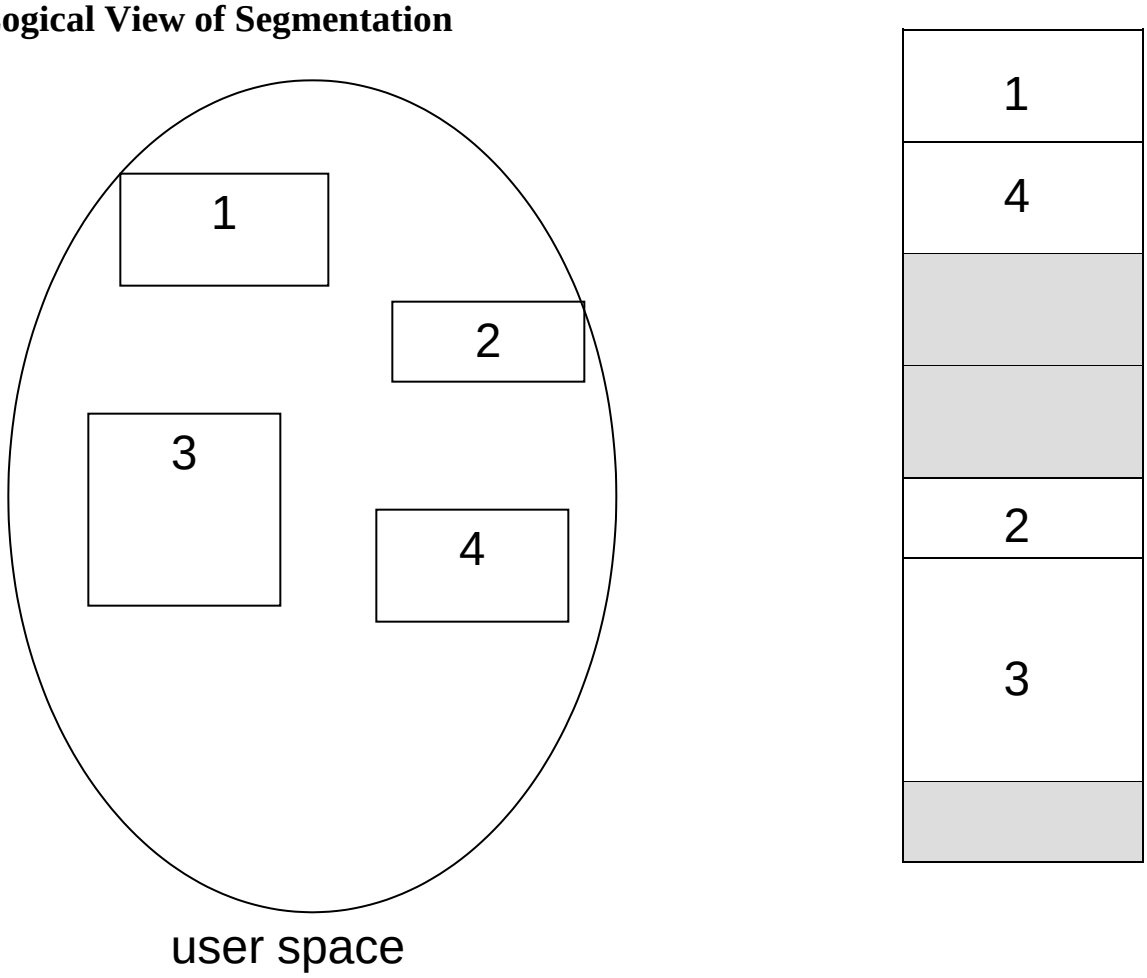
Memory-management scheme that supports user view of memory

- A program is a collection of segments
- A segment is a logical unit such as:
- main program
- procedure function
- method
- object
- local variables, global variables
- common block
- stack
- symbol table
- arrays



User's View of a Program

Logical View of Segmentation



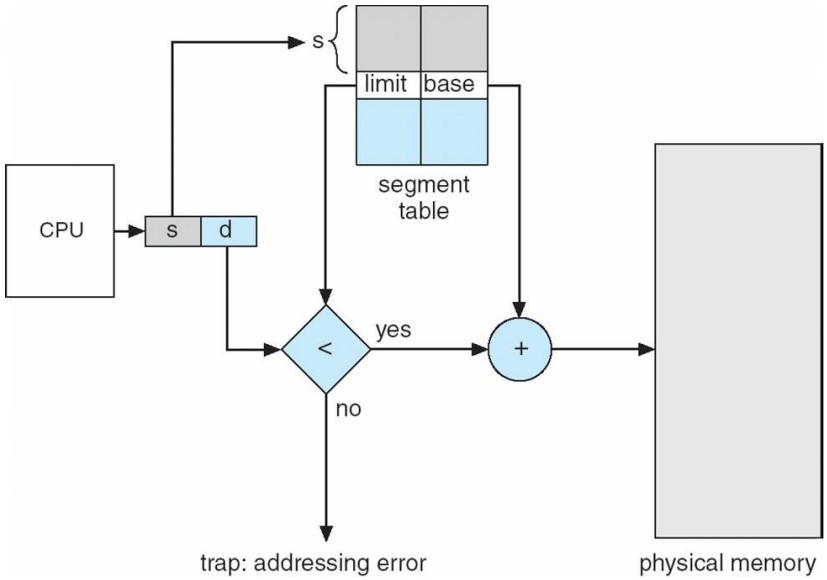
Segmentation Architecture

- Logical address consists of a two tuple:
  - <segment-number, offset>,
- **Segment table** – maps two-dimensional physical addresses; each table entry has:
- **base** – contains the starting physical address where the segments reside in memory
- **limit** – specifies the length of the segment
- **Segment-table base register (STBR)** points to the segment table's location in memory
- **Segment-table length register (STLR)** indicates number of segments used by a program;

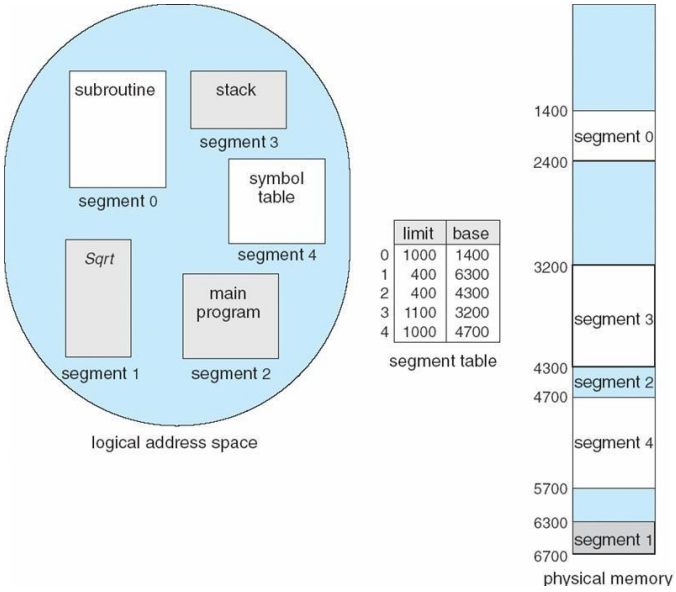
segment number ***s*** is legal if ***s*** < **STLR**

- Protection
- With each entry in segment table associate:
- □validation bit = 0 Þ illegal segment
- □read/write/execute privileges
- Protection bits associated with segments; code sharing occurs at segment level
- Since segments vary in length, memory allocation is a dynamic storage-allocation problem
- A segmentation example is shown in the following diagram

Segmentation Hardware



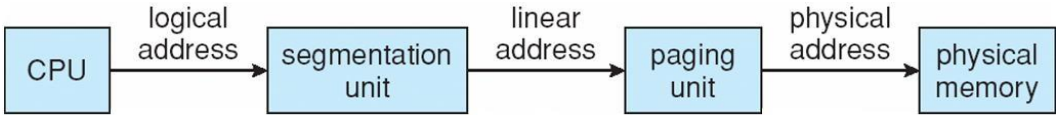
Example of Segmentation

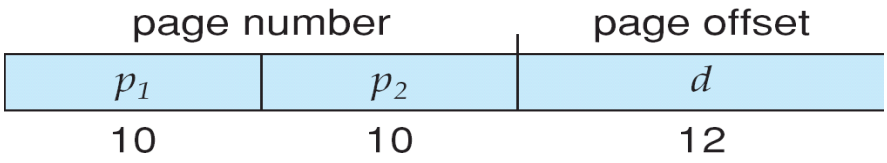


Example: The Intel Pentium

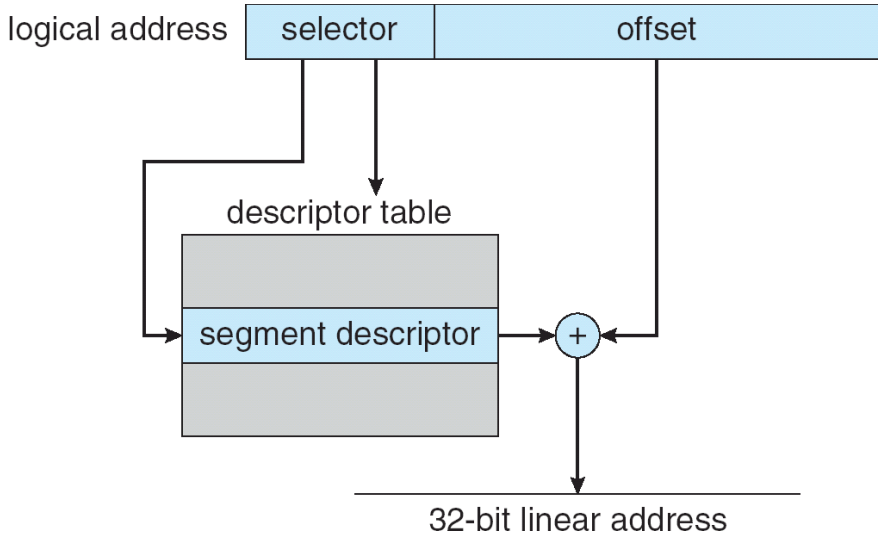
- Supports both segmentation and segmentation with paging
- CPU generates logical address
- Given to segmentation unit
  - Which produces linear addresses
- Linear address given to paging unit
  - Which generates physical address in main memory
  - Paging units form equivalent of MMU

Logical to Physical Address Translation in Pentium

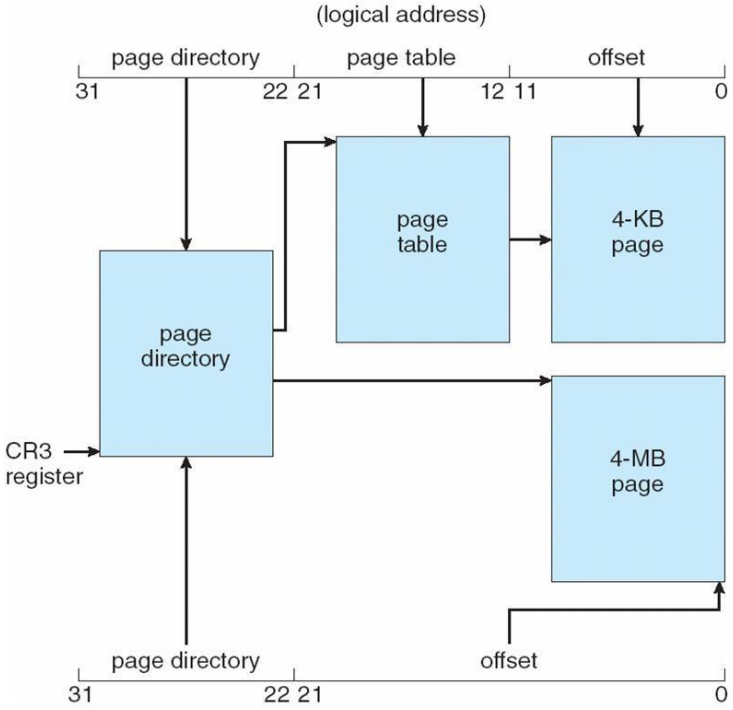




Intel Pentium Segmentation

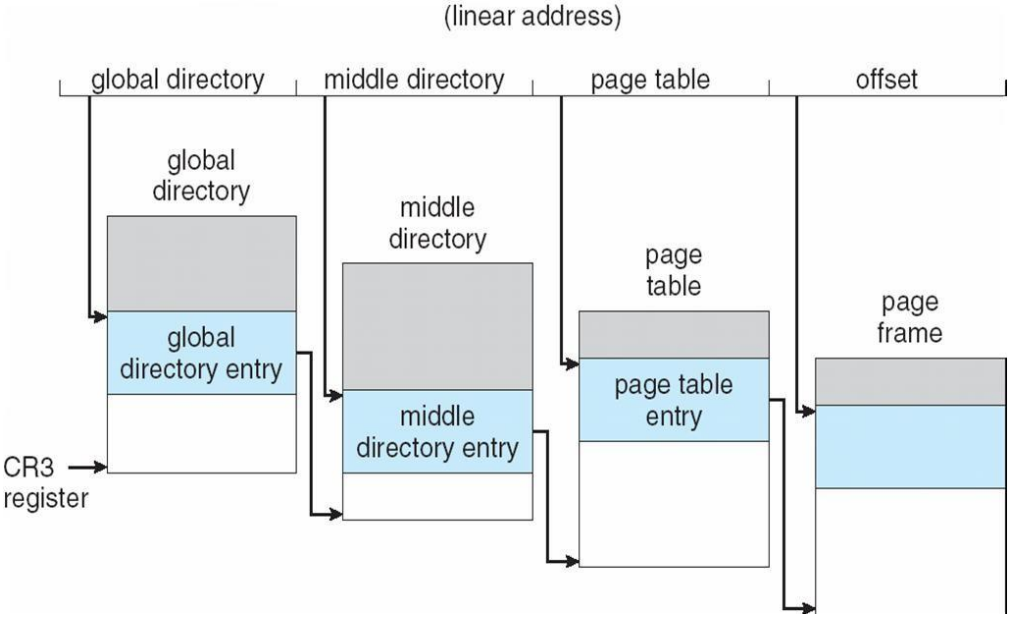


Pentium Paging Architecture



Linear Address in Linux

Three-level Paging in Linux



VIRTUAL MEMORY

Virtual Memory

- Virtual memory is a technique that allows the execution of process that may not be completely in memory. The main visible advantage of this scheme is that programs can be larger than physical memory.

- Virtual memory is the separation of user logical memory from physical memory this separation allows an extremely large virtual memory to be provided for programmers when only a smaller physical memory is available (Fig).
- Following are the situations, when entire program is not required to load fully.

1. User written error handling routines are used only when an error occurs in the data or computation.
2. Certain options and features of a program may be used rarely.
3. 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.

1. Less number of I/O would be needed to load or swap each user program into memory.
2. A program would no longer be constrained by the amount of physical memory that is available.
3. 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.

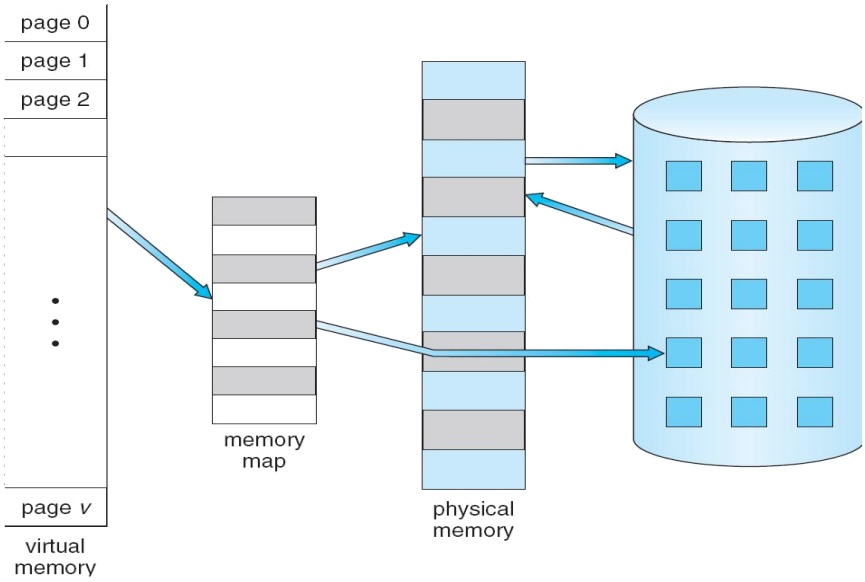


Fig. Diagram showing virtual memory that is larger than physical memory.

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 is similar to a paging system with swapping(Fig 5.2). When we want to execute a process, we swap it into memory. Rather than swapping the entire process into memory.

When a process is to be swapped in, the pager guesses which pages will be used before the process is swapped out again Instead of swapping in a whole process, the pager brings only those necessary pages into memory. Thus, it avoids reading into memory pages that will not be used in anyway, decreasing the swap time and the amount of physical memory needed.

Hardware support is required to distinguish between those pages that are in memory and those pages that are on the disk using the valid-invalid bit scheme. Where valid and invalid pages can be checked checking the bit and marking a page will have no effect if the process never attempts to access the pages. While the process executes and accesses pages that are memory resident, execution proceeds normally.

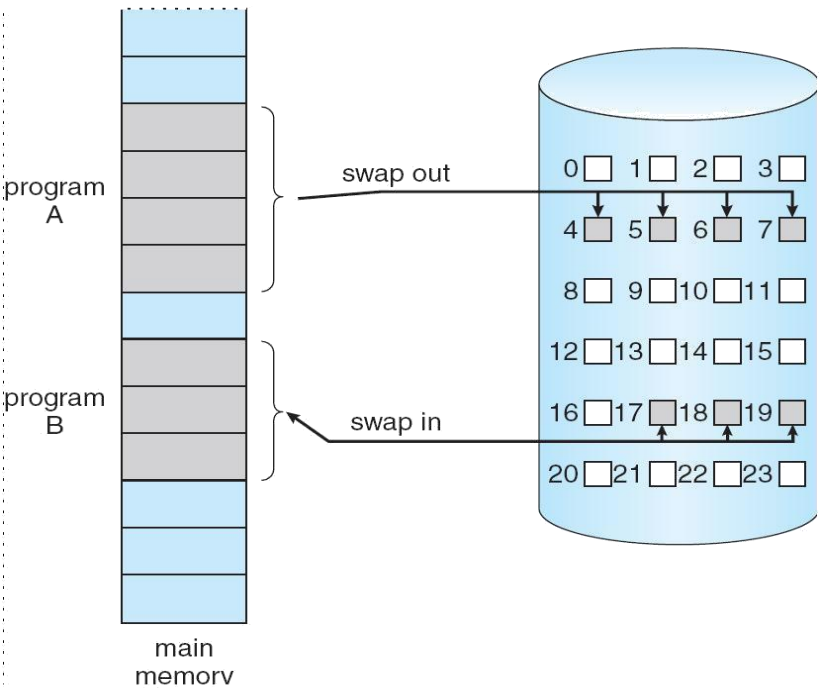


Fig. Transfer of a paged memory to continuous disk space

Access to a page marked invalid causes a page-fault trap. This trap is the result of the operating system's failure to bring the desired page into memory. But page fault can be handled as following (Fig 5.3):

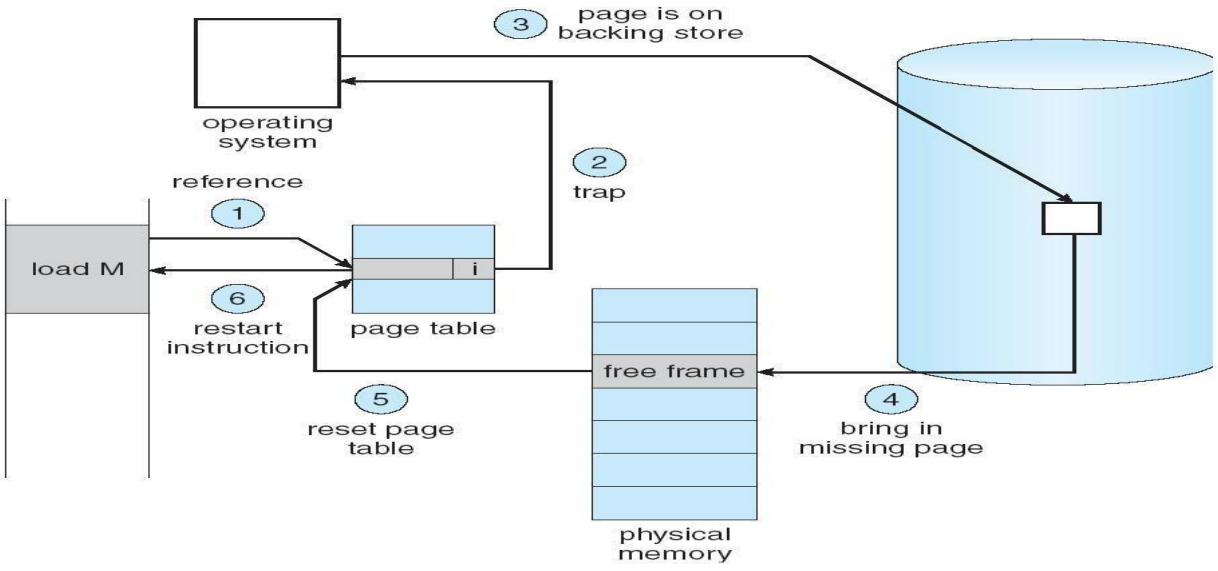


Fig. Steps in handling a page fault

1. We check an internal table for this process to determine whether the reference was a valid or invalid memory access.
2. If the reference was invalid, we terminate the process. If .it was valid, but we have not yet brought in that page, we now page in the latter.
3. We find a free frame.

4. We schedule a disk operation to read the desired page into the newly allocated frame.

5. When the disk read is complete, we modify the internal table kept with the process and the page table to indicate that the page is now in memory.

6. We restart the instruction that was interrupted by the illegal address trap. The process can now access the page as though it had always been memory.

Therefore, the operating system reads the desired page into memory and restarts the process as though the page had always been in memory.

The page replacement is used to make the frame free if they are not in used. If no frame is free then other process is called in.

Advantages of Demand Paging:

1. Large virtual memory.
2. More efficient use of memory.
3. Unconstrained multiprogramming. There is no limit on degree of multiprogramming.

Disadvantages of Demand Paging:

4. Number of tables and amount of processor over head for handling page interrupts are greater than in the case of the simple paged management techniques.
5. due to the lack of an explicit constraints on a jobs address space size.

Page Replacement Algorithm

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. 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.

1. For a given page size we need to consider only the page number, not the entire address.

2. 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.

Eg:- consider the address sequence

0100, 0432, 0101, 0612, 0102, 0103, 0104, 0101, 0611, 0102, 0103, 0104, 0101, 0610, 0102,

0103, 0104, 0104, 0101, 0609, 0102, 0105
and reduce to 1, 4, 1, 6,1, 6, 1, 6, 1, 6, 1

To determine the number of page faults for a particular reference string and page replacement algorithm, we also need to know the number of page frames available. As the number of frames available increase, the number of page faults will decrease.

FIFO Algorithm

The simplest page-replacement algorithm is a FIFO algorithm. A FIFO replacement algorithm associates with each page the time when that page was brought into memory. When a page must be replaced, the oldest page is chosen. We can create a FIFO queue to hold all pages in memory.

The first three references (7, 0, 1) cause page faults, and are brought into these empty eg. 7, 0, 1, 2, 0, 3, 0, 4, 2, 3, 0, 3, 2, 1, 2, 0, 1 and consider 3 frames. This replacement means that the next reference to 0 will fault. Page 1 is then replaced by page 0.

Optimal 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. It is simply

Replace the page that will not be used for the longest
period of time.

Now consider the same string with 3 empty frames.

The reference to page 2 replaces page 7, because 7 will not be used until reference 15, whereas page 0 will be used at 5, and page 1 at 14. The reference to page 3 replaces page 1, as page 1 will be the last of the three pages in memory to be referenced again. Optimal replacement is much better than a FIFO.

The optimal page-replacement algorithm is difficult to implement, because it requires future knowledge of the reference string.

LRU Algorithm

The FIFO algorithm uses the time when a page was brought into memory; the OPT algorithm uses the time when a page is to be used. In LRU replace the page that has not been used for the longest period of time.

LRU replacement associates with each page the time of that page's last use. When a page must be replaced, LRU chooses that page that has not been used for the longest period of time.

Let S^R be the reverse of a reference string S, then the page-fault rate for the OPT algorithm on S is the same as the page-fault rate for the OPT algorithm on S^R.

LRU Approximation Algorithms

Some systems provide no hardware support, and other page-replacement algorithm. Many systems provide some help, however, in the form of a reference bit. The reference bit for a page is set, by the hardware, whenever that page is referenced. Reference bits are associated with each entry in the page table Initially, all bits are cleared (to 0) by the operating system. As a user process executes, the bit associated with each page referenced is set (to 1) by the hardware.

Additional-Reference-Bits Algorithm

The operating system shifts the reference bit for each page into the high-order or of its 5-bit byte, shifting the other bits right 1 bit, discarding the low-order bit.

These 5-bit shift registers contain the history of page use for the last eight time periods. If the shift register contains 00000000, then the page has not been

used for eight time periods; a page that is used at least once each period would have a shift register value of 11111111.

Second-Chance Algorithm

The basic algorithm of second-chance replacement is a FIFO replacement algorithm. When a page gets a second chance, its reference bit is cleared and its arrival e is reset to the current time.

Enhanced Second-Chance Algorithm

The second-chance algorithm described above can be enhanced by considering troth the reference bit and the modify bit as an ordered pair.

1. (0,0) neither recently used nor modified best page to replace.
2. (0,1) not recently used but modified not quite as good, because the page will need to be written out before replacement.
3. (1,0) recently used but clean probably will be used again soon.
4. (1,1) recently used and modified probably will be used again, and write out will be needed before replacing it

Counting Algorithms

There are many other algorithms that can be used for page replacement.

• **LFU Algorithm:** The least frequently used (LFU) page-replacement algorithm requires that the page with the smallest count be replaced. 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.

• **MFU Algorithm:** The most frequently used (MFU) page-replacement algorithm is based on the argument that the page with the smallest count was probably just brought in and has yet to be used.

Page Buffering Algorithm

When a page fault occurs, a victim frame is chosen as before. However, the desired page is read into a free frame from the pool before the victim is written out.

This procedure allows the process to restart as soon as possible, without waiting for the victim page to be written out. When the victim is later written out, its frame is added to the free-frame pool.

When the FIFO replacement algorithm mistakenly replaces a page mistakenly replaces a page that is still in active use, that page is quickly retrieved from the free-frame buffer, and no I/O is necessary. The free-frame buffer provides protection against the relatively poor, but simple, FIFO replacement algorithm.

Disk scheduling is done by operating systems to schedule I/O requests arriving for the disk. Disk scheduling is also known as I/O scheduling.

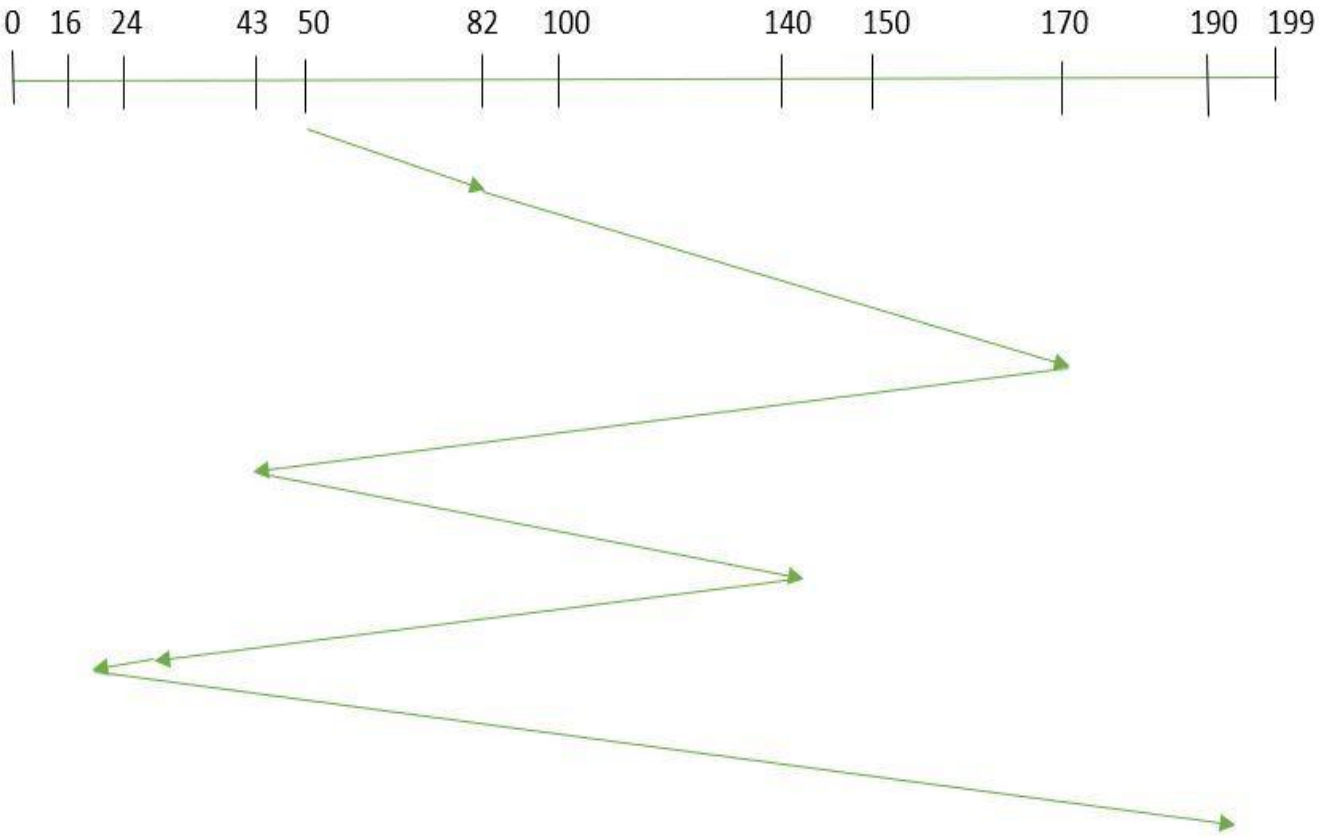
The purpose of disk scheduling algorithms is to reduce the total seek time.

Disk scheduling is important because:

- Multiple I/O requests may arrive by different processes and only one I/O request can be served at a time by the disk controller. Thus other I/O requests need to wait in the waiting queue and need to be scheduled.
- Two or more request may be far from each other so can result in greater disk arm movement.
- Hard drives are one of the slowest parts of the computer system and thus need to be accessed in an efficient manner
- .

1. **FCFS:** FCFS is the simplest of all the Disk Scheduling Algorithms. In FCFS, the requests are addressed in the order they arrive in the disk queue.Let us understand this with the help of an example.

   Example:
   Suppose the order of request is- (82,170,43,140,24,16,190)
   And current position of Read/Write head is : 50



So, total seek time:
=(82-50)+(170-82)+(170-43)+(140-43)+(140-24)+(24-16)+(190-16)
=642

Advantages:

- Every request gets a fair chance
- No indefinite postponement

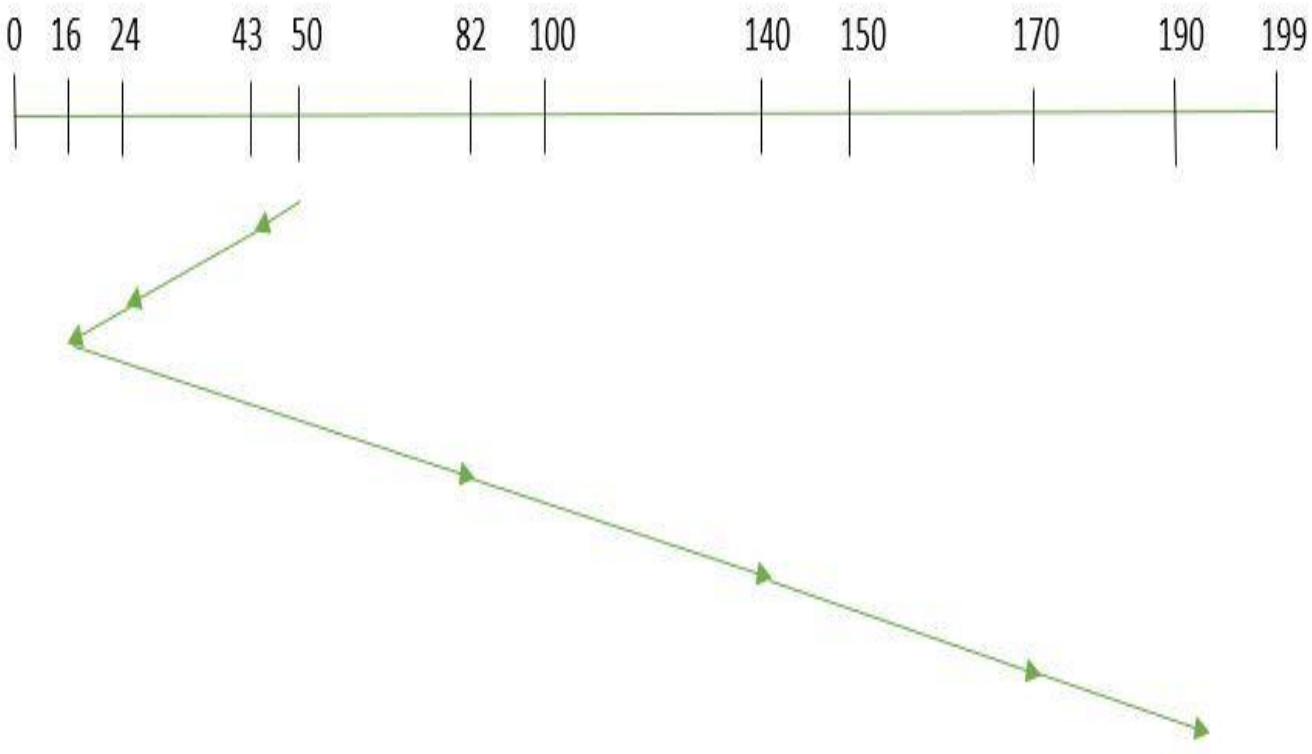
Disadvantages:

- Does not try to optimize seek time
- May not provide the best possible service

2. **SSTF:** In SSTF (Shortest Seek Time First), requests having shortest seek time are executed first. So, the seek time of every request is calculated in advance in the queue and then they are scheduled according to their calculated seek time. As a result, the request near the disk arm will get executed first. SSTF is certainly an improvement over FCFS as it decreases the average response time and increases the throughput of system.Let us understand this with the help of an example.

   Example:

Suppose the order of request is- (82,170,43,140,24,16,190)
And current position of Read/Write head is : 50



So, total seek time:

=(50-43)+(43-24)+(24-16)+(82-16)+(140-82)+(170-40)+(190-170)
=208

Advantages:

- Average Response Time decreases
- Throughput increases

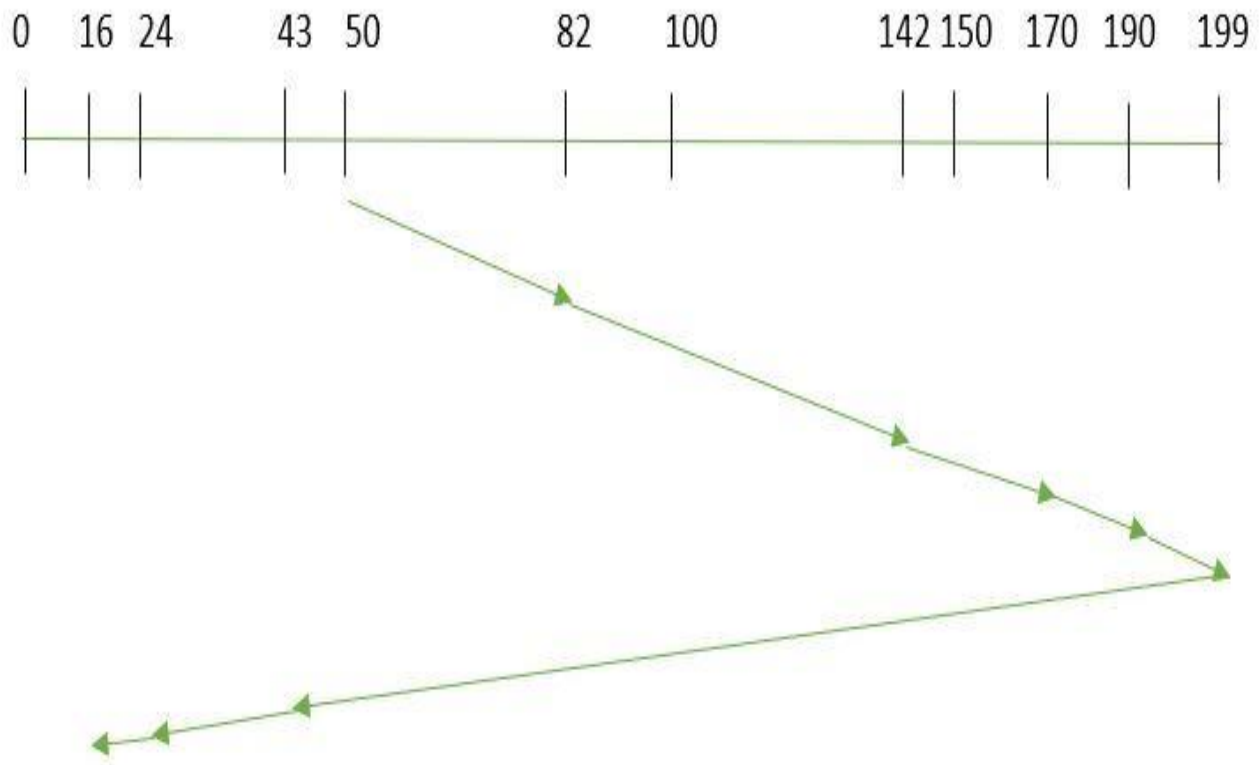
Disadvantages:

- Overhead to calculate seek time in advance
- Can cause Starvation for a request if it has higher seek time as compared to incoming requests
- High variance of response time as SSTF favours only some requests

3. **SCAN:** In SCAN algorithm the disk arm moves into a particular direction and services the requests coming in its path and after reaching the end of disk, it reverses its direction and again services the request arriving in its path. So, this algorithm works as an elevator and hence also known as **elevator algorithm.** As a result, the requests at the midrange are serviced more and

those arriving behind the disk arm will have to wait.

Example:
Suppose the requests to be addressed are-82,170,43,140,24,16,190. And the Read/Write arm is at 50, and it is also given that the disk arm should move **“towards the larger value”.**



Therefore, the seek time is calculated as:

=(199-50)+(199-16)
=332

Advantages:

- High throughput
- Low variance of response time
- Average response time

Disadvantages:

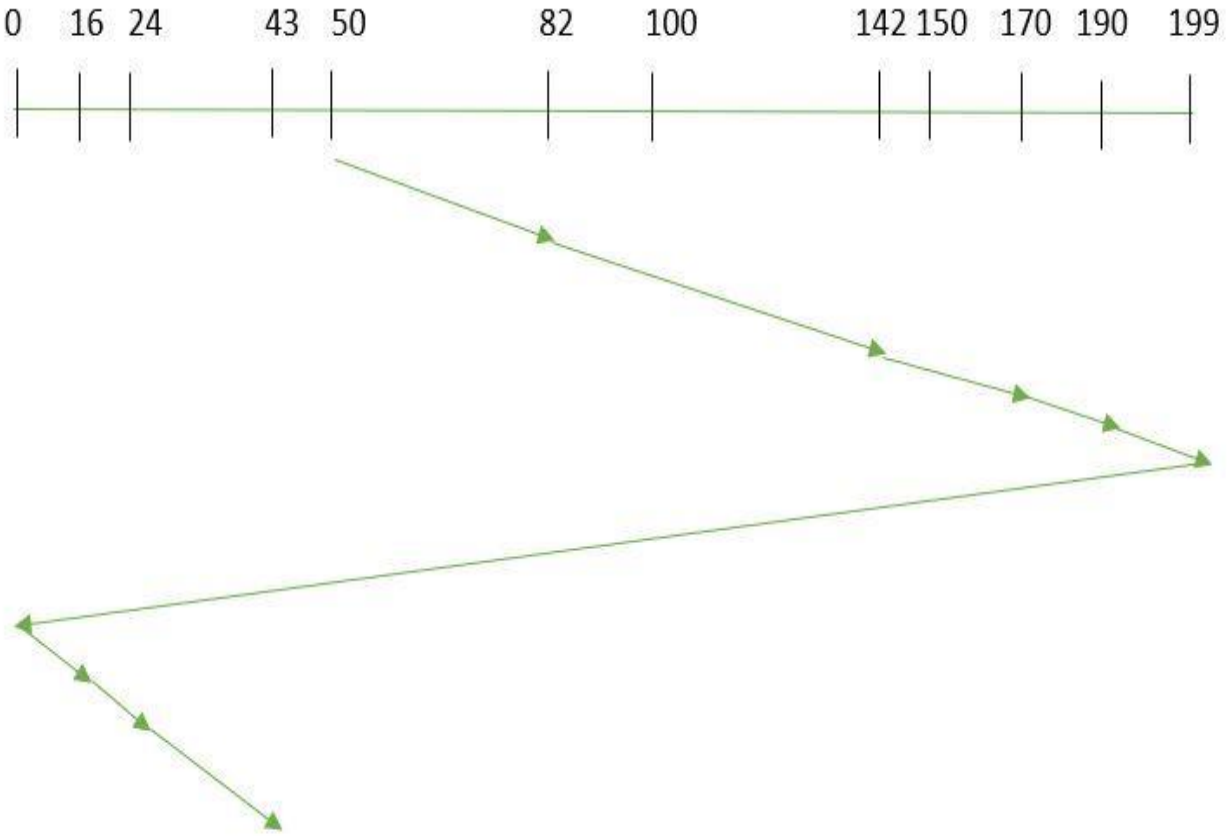
- Long waiting time for requests for locations just visited by disk arm

4. **CSCAN**: In SCAN algorithm, the disk arm again scans the path that has been scanned, after reversing its direction. So, it may be possible that too many requests are waiting at the other end or there may be zero or few requests pending at the scanned area.

These situations are avoided in *CSCAN* algorithm in which the disk arm instead of reversing its direction goes to the other end of the disk and starts servicing the requests from there. So, the disk arm moves in a circular fashion and this algorithm is also similar to SCAN algorithm and hence it is known as C-SCAN (Circular SCAN).

Example:

Suppose the requests to be addressed are-82,170,43,140,24,16,190. And the Read/Write arm is at 50, and it is also given that the disk arm should move **"towards the larger value".**



Seek time is calculated as:

=(199-50)+(199-0)+(43-0)
=391

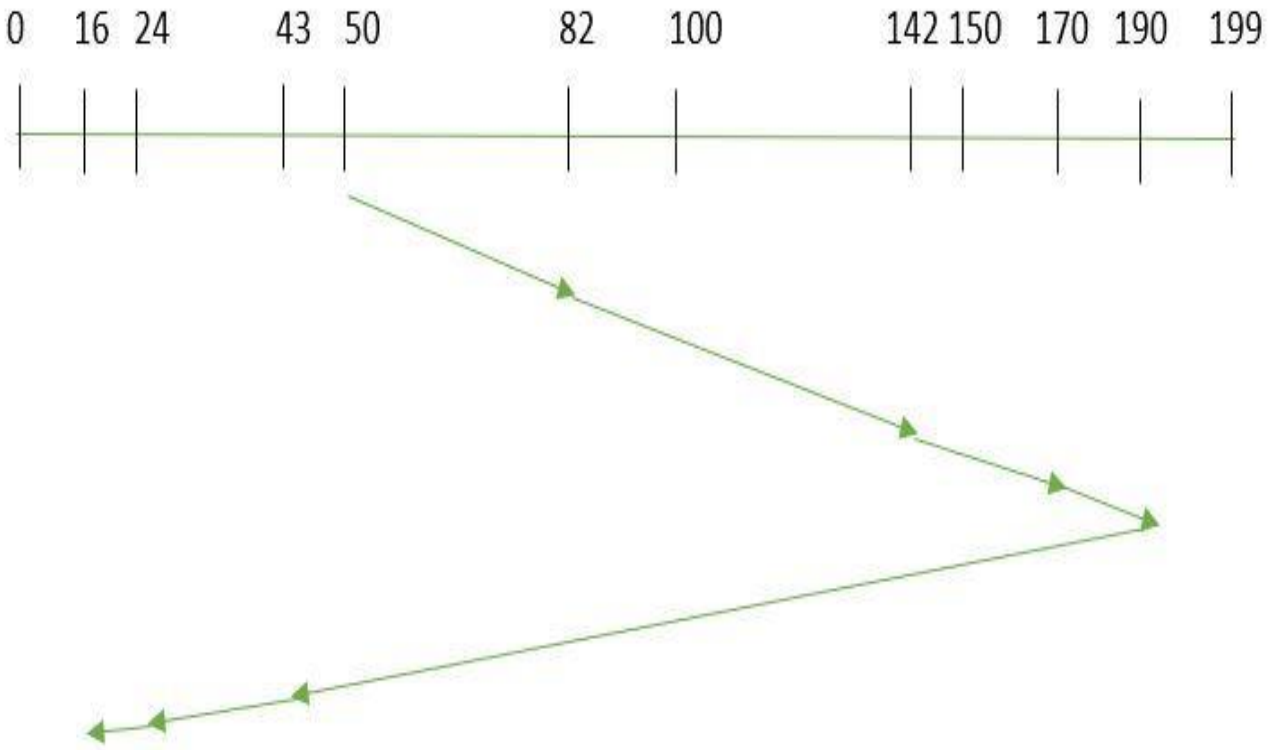
Advantages:

- Provides more uniform wait time compared to SCAN

5. **LOOK:** It is similar to the SCAN disk scheduling algorithm except for the difference that the disk arm in spite of going to the end of the disk goes only to the last request to be serviced in front of

the head and then reverses its direction from there only. Thus it prevents the extra delay which occurred due to unnecessary traversal to the end of the disk.

Example:
Suppose the requests to be addressed are-82,170,43,140,24,16,190. And the Read/Write arm is at 50, and it is also given that the disk arm should move **"towards the larger value".**



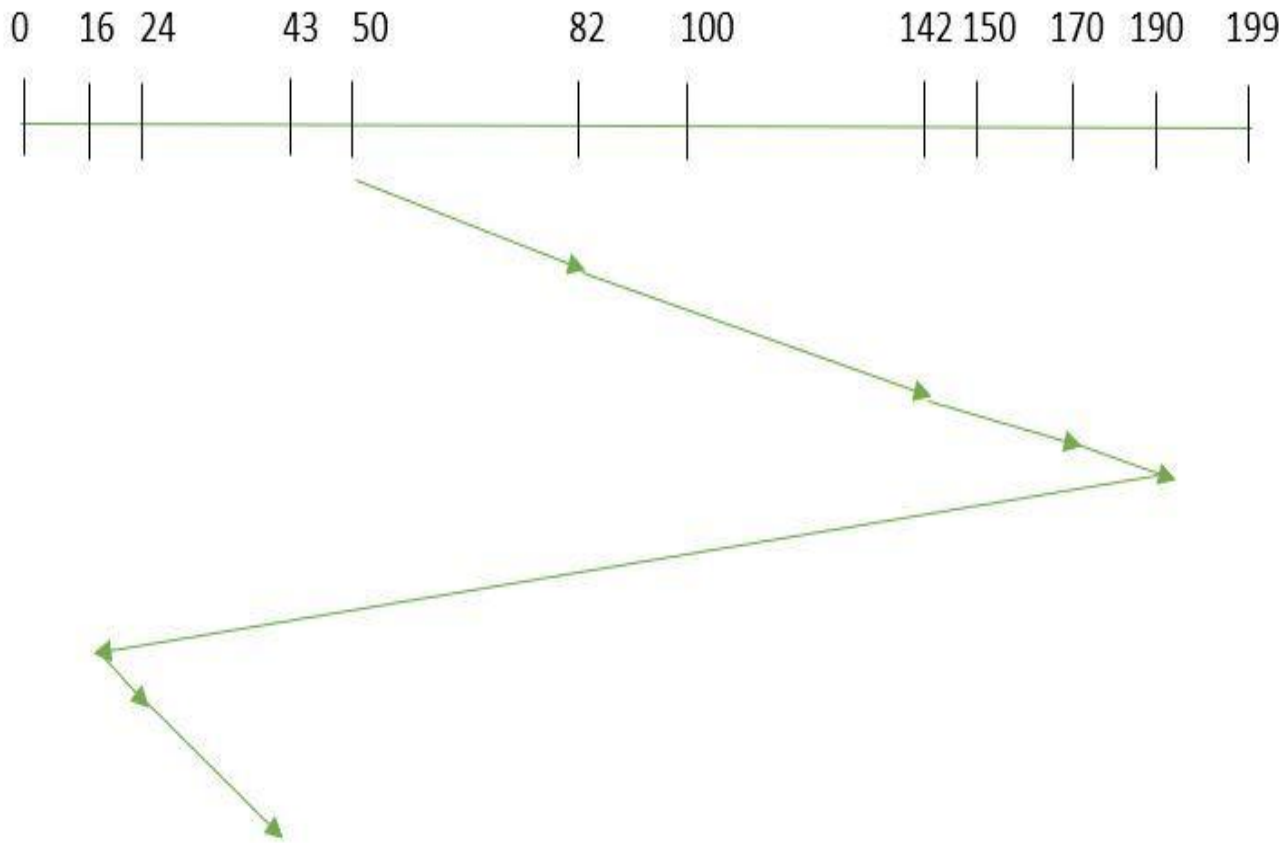
So, the seek time is calculated as:

=(190-50)+(190-16)
=314

6. **CLOOK:** As LOOK is similar to SCAN algorithm, in similar way, CLOOK is similar to CSCAN disk scheduling algorithm. In CLOOK, the disk arm in spite of going to the end goes only to the last request to be serviced in front of the head and then from there goes to the other end's last request. Thus, it also prevents the extra delay which occurred due to unnecessary traversal to the end of the disk.

   Example:

Suppose the requests to be addressed are-82,170,43,140,24,16,190. And the Read/Write arm is at 50, and it is also given that the disk arm should move **“towards the larger value”**



So, the seek time is calculated as:

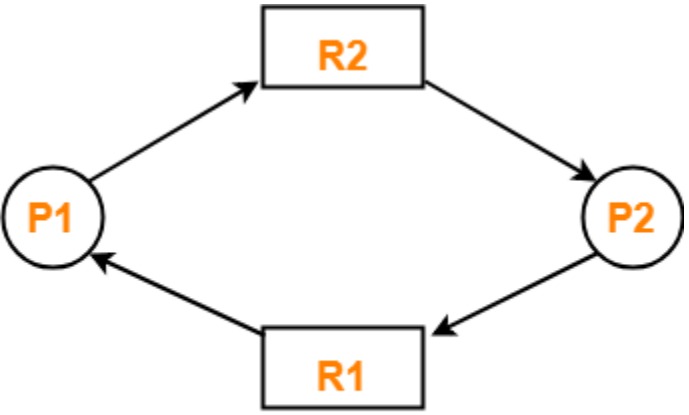
=(190-50)+(190-16)+(43-16)
=341

Deadlock in OS-

Deadlock is a situation where-

The execution of two or more processes is blocked because each process holds some resource and waits for another resource held by some other process.

Example-



Example of a deadlock

Here

Process P1 holds resource R1 and waits for resource R2 which is held by process P2.
Process P2 holds resource R2 and waits for resource R1 which is held by process P1.
None of the two processes can complete and release their resource.
Thus, both the processes keep waiting infinitely.

Conditions For Deadlock-

There are following 4 necessary conditions for the occurrence of deadlock-

. Mutual Exclusion
. Hold and Wait
. No preemption
. Circular wait

1. Mutual Exclusion-

By this condition,

There must exist at least one resource in the system which can be used by only one process at a time.
If there exists no such resource, then deadlock will never occur.
Printer is an example of a resource that can be used by only one process at a time.

2. Hold and Wait-

By this condition,

There must exist a process which holds some resource and waits for another resource held by some other process.

3. No Preemption-

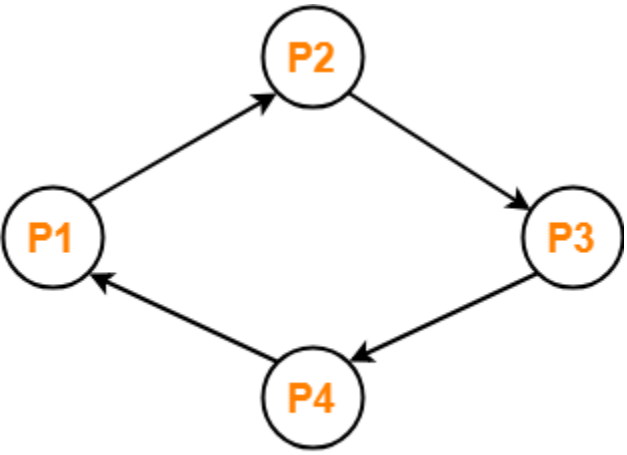
By this condition,

Once the resource has been allocated to the process, it can not be preempted.
It means resource can not be snatched forcefully from one process and given to the other process.
The process must release the resource voluntarily by itself.

4. Circular Wait-

By this condition,

All the processes must wait for the resource in a cyclic manner where the last process waits for the resource held by the first process.



Circular Wait

Here,

Process P1 waits for a resource held by process P2.
Process P2 waits for a resource held by process P3.
Process P3 waits for a resource held by process P4.
Process P4 waits for a resource held by process P1.

Important Note-

All these 4 conditions must hold simultaneously for the occurrence of deadlock.
If any of these conditions fail, then the system can be ensured deadlock free

System Protection in Operating System

Last Updated : 21 Aug, 2019

Protection refers to a mechanism which controls the access of programs, processes, or users to the resources defined by a computer system. We can take protection as a helper to multi programming operating system, so that many users might safely share a common logical name space such as directory or files.

Need of Protection:

- To prevent the access of unauthorized users and
- To ensure that each active programs or processes in the system uses resources only as the stated policy,
- To improve reliability by detecting latent errors.

Role of Protection:

The role of protection is to provide a mechanism that implement policies which defines the uses of resources in the computer system.Some policies are defined at the time of design of the system, some are designed by management of the system and some are defined by the users of the system to protect their own files and programs.

Every application has different policies for use of the resources and they may change over time so protection of the system is not only concern of the designer of the operating system. Application programmer should also design the protection mechanism to protect their system against misuse.

Policy is different from mechanism. Mechanisms determine how something will be done and policies determine what will be done.Policies are changed over time and place to place. Separation of mechanism and policy is important for the flexibility of the system

SECURITY IN OS

Security refers to providing a protection system to computer system resources such as CPU, memory, disk, software programs and most importantly data/information stored in the computer system. If a computer program is run by an unauthorized user, then he/she may cause severe damage to computer or data stored in it. So a computer system must be protected against unauthorized access, malicious access to system memory, viruses, worms etc.

It is the responsibility of the Operating System to create a protection system which ensures that a user who is running a particular program is authentic. Operating Systems generally identifies/authenticates users using following three ways −

- **Username / Password** − User need to enter a registered username and password with Operating system to login into the system.
- **User card/key** − User need to punch card in card slot, or enter key generated by key generator in option provided by operating system to login into the system.
- **User attribute - fingerprint/ eye retina pattern/ signature** − User need to pass his/her attribute via designated input device used by operating system to login into the system.

One Time passwords

One-time passwords provide additional security along with normal authentication. In One-Time Password system, a unique password is required every time user tries to login into the system. Once a one-time password is used, then it cannot be used again. One-time password are implemented in various ways.

- **Random numbers** − Users are provided cards having numbers printed along with corresponding alphabets. System asks for numbers corresponding to few alphabets randomly chosen.
- **Secret key** − User are provided a hardware device which can create a secret id mapped with user id. System asks for such secret id which is to be generated every time prior to login.
- **Network password** − Some commercial applications send one-time passwords to user on registered mobiles or emils which prior to login.

ACCESS CONTROL

Access control for an operating system determines how the operating system implements accesses to system resources by satisfying the security objectives of integrity, availability, and secrecy. Such a mechanism authorizes subjects (e.g., processes and users) to perform certain operations (e.g., read, write) on objects and resources of the OS (e.g., files, sockets).

Operating system is the main software between the users and the computing system resources that manage tasks and programs. Resources may include files, sockets, CPU, memory, disks, timers, network, etc. System administrators, developers, regular users, guests, and even hackers could be the users of the computing system. Information security is an important issue for an operating system due to its...

Access control

Access control is about ensuring that authorized users can do what they are permitted to do … and no more than that. In the real world, we rely on keys, badges, guards, and policy rules for enforcing access control. In the computer world, we achieve access control through a combination of hardware, operating systems, web servers, databases, and other multi-access software, and polices.

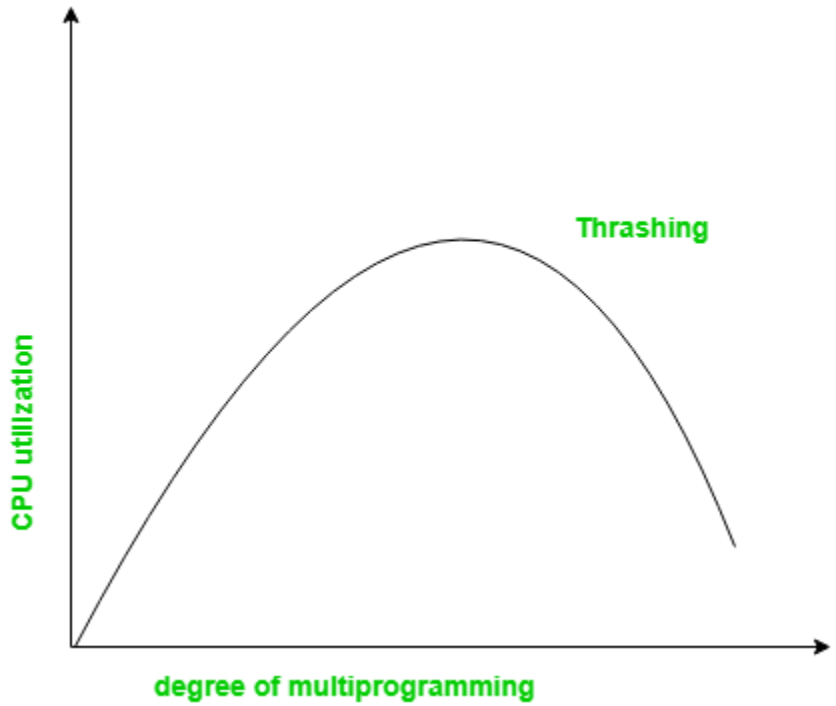
Access control and the operating system

In its most basic sense, an operating system is responsible for controlling access to system resources. These resources include the processor, memory, files and devices, and the network. The operating system needs to be protected from applications. If not, an operation may, accidentally or maliciously, destroy the integrity of the operating system. Applications also need to be protected from each other so that one application cannot read another's memory (enforce **confidentiality**) or modify them (enforce **integrity**). We also need to make sure that the operating system always stays in control. A process

should not be able to take over the computer and keep the operating system or other processes from running.

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.

What is Demand Paging

Definition: Demand paging is a process of swapping in the **Virtual Memory** system. In this process, all data is not moved from hard drive to **main memory** because while using this demand paging, when some programs are getting demand then data will be transferred. But, if required data is already existed into memory then not need to copy of data. The demand paging system is done with swapping from auxiliary storage to **primary memory**, so it is known as "Lazy Evaluation".

Diagram of Demand Paging

Some **Page Replacement Algorithms** are used in the **demand paging concept** to replace different pages – such as FIFO, LIFO, Optimal Algorithm, LRU Page, and Random Replacement Page Replacement Algorithms.

How Does Demand Paging Working

Demand paging system is totally depend on the page table implementation because page table helps to maps logical memory to physical memory. Bitwise operators are implemented in the page table to indication that pages are ok or not (valid or invalid). All valid pages are existed into **primary memory**, and other side invalid pages are existed into **secondary memory**.

Now all process go ahead to access all pages, then some things will be happened. Such as –

Attempt to currently access page.

If page is ok (Valid), then all processing instructions work as normal.

If, anyone page is found as invalid, then page- fault issue is arise.

Now memory reference is determined that valid reference is existed on the auxiliary memory or not. If not existed, then process is terminated, otherwise needed pages are paged in.

Now disk operations are implemented to fetch the required page into **primary memory**.

Example of Demand Paging

Memory Access Time = 200 nanoseconds

Average Page Fault Service Time = 8 milliseconds

EAT = (1-p)*200+p(8 milliseconds)
= (1-p)*200+p*8000000

= 200+p*7999800

EAT means direct proportional to the page fault rate.

Advantages of Demand Paging

Memory can be utilized with better efficiently.
We have to right for scaling of **virtual memory**.
If, any program is larger to physical memory then It helps to run this **program**.
No need of compaction.
Easy to share all pages
Partition management is more simply.
It is more useful in **time sharing system**.
It has no any limitations on level of **multi-programming**.
Discards external fragmentation
Easy to swap all pages
It allows pre-paging concept.
Easy to swap out page least likely to be used
All pages can be mapped appropriately.
All data can be collected over PM

Disadvantages of Demand Paging

It has more probability of internal fragmentation.
Its memory access time is longer.
Page Table Length Register (PTLR) has limit for **virtual memory**
Page map table is needed additional memory and **registers**.

Pure Demand Paging

In this section, we will discuss about **difference between demand paging and pure demand paging**.

In the initially stage, if anyone page is not loaded into **primary memory** then page faults are occurred, and then paged are loaded with on demanding of the process. This process is known as “Pure Demand Paging”.

Pure demand paging is not able to load single page into **main memory**, otherwise it will be fired the Page-Fault.

In pure demand paging, when process will be started up then all memory is swapped from auxiliary memory to primary memory.

Demand Segmentation in OS

Operating system implements demand segmentation like demand paging. While using "Demand Paging", if it to get lack of **hardware resources**, then OS implements the demand segmentation.

Segment table keeps all information related to demand segmentation such as valid bit because on the behalf of valid bit can be specified that segment has existed in the physical memory or not. If, anytime physical memory is not capable to store their segments then to get segment fault, and then it try to fetch required segments from physical memory. Similar to **page fault**.

Demand segmentation helps to decrease the number of **page faults** in the paging system.

Cryptography and its Types

Last Updated : 08 Jan, 2020

Cryptography is technique of securing information and communications through use of codes so that only those person for whom the information is intended can understand it and process it. Thus preventing unauthorized access to information. The prefix "crypt" means "hidden" and suffix graphy means "writing".

In Cryptography the techniques which are use to protect information are obtained from mathematical concepts and a set of rule based calculations known as algorithms to convert messages in ways that make it hard to decode it. These algorithms are used for cryptographic key generation, digital signing, verification to protect data privacy, web browsing on internet and to protect confidential transactions such as credit card and debit card transactions.

Techniques used For Cryptography:

In today's age of computers cryptography is often associated with the process where an ordinary plain text is converted to cipher text which is the text made such that intended receiver of the text can only decode it and hence this process is known as encryption. The process of conversion of cipher text to plain text this is known as decryption.

Features Of Cryptography are as follows:

1. **Confidentiality:**
   Information can only be accessed by the person for whom it is intended and no other person except him can access it.
2. **Integrity:**
   Information cannot be modified in storage or transition between sender and intended receiver without any addition to information being detected.
3. **Non-repudiation:**
   The creator/sender of information cannot deny his or her intention to send information at later stage.

4. **Authentication:**
   The identities of sender and receiver are confirmed. As well as destination/origin of information is confirmed.

Types Of Cryptography:

In general there are three types Of cryptography:

1. **Symmetric Key Cryptography:**
   It is an encryption system where the sender and receiver of message use a single common key to encrypt and decrypt messages. Symmetric Key Systems are faster and simpler but the problem is that sender and receiver have to somehow exchange key in a secure manner. The most popular symmetric key cryptography system is Data Encryption System(DES).
2. **Hash Functions:**
   There is no usage of any key in this algorithm. A hash value with fixed length is calculated as per the plain text which makes it impossible for contents of plain text to be recovered. Many operating systems use hash functions to encrypt passwords.
3. **Asymmetric Key Cryptography:**
   Under this system a pair of keys is used to encrypt and decrypt information. A public key is used for encryption and a private key is used for decryption. Public key and Private Key are different. Even if the public key is known by everyone the intended receiver can only decode it because he alone knows the private key.

FCFS Scheduling

First come first serve (FCFS) scheduling algorithm simply schedules the jobs according to their arrival time. The job which comes first in the ready queue will get the CPU first. The lesser the arrival time of the job, the sooner will the job get the CPU. FCFS scheduling may cause the problem of starvation if the burst time of the first process is the longest among all the jobs.

Advantages of FCFS

- Simple
- Easy
- First come, First serv

Disadvantages of FCFS

1. The scheduling method is non preemptive, the process will run to the completion.
2. Due to the non-preemptive nature of the algorithm, the problem of starvation may occur.

3. Although it is easy to implement, but it is poor in performance since the average waiting time is higher as compare to other scheduling algorithms.

Example

Let's take an example of The FCFS scheduling algorithm. In the Following schedule, there are 5 processes with process ID **P0, P1, P2, P3 and P4**. P0 arrives at time 0, P1 at time 1, P2 at time 2, P3 arrives at time 3 and Process P4 arrives at time 4 in the ready queue. The processes and their respective Arrival and Burst time are given in the following table.

The Turnaround time and the waiting time are calculated by using the following formula.

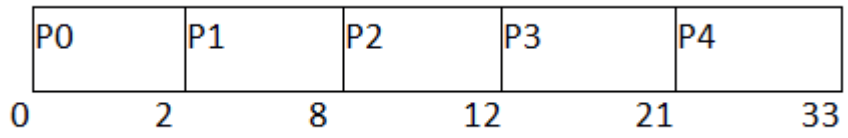
Turn Around Time = Completion Time - Arrival Time

Waiting Time = Turnaround time - Burst Time

The average waiting Time is determined by summing the respective waiting time of all the processes and divided the sum by the total number of processes.

Process ID	Arrival Time	Burst Time	Completion Time	Turn Around Time	Waiting Time
0	0	2	2	2	0
1	1	6	8	7	1
2	2	4	12	8	4
3	3	9	21	18	9
4	4	12	33	29	17

Avg Waiting Time=31/5



(Gantt chart)

Deadlocks

7.1 System Model

- For the purposes of deadlock discussion, a system can be modeled as a collection of limited resources, which can be partitioned into different categories, to be allocated to a number of processes, each having different needs.
- Resource categories may include memory, printers, CPUs, open files, tape drives, CD-ROMS, etc.
- By definition, all the resources within a category are equivalent, and a request of this category can be equally satisfied by any one of the resources in that category. If this is not the case (i.e. if there is some difference between the resources within a category), then that category needs to be further divided into separate categories. For example, "printers" may need to be separated into "laser printers" and "color inkjet printers".
- Some categories may have a single resource.
- In normal operation a process must request a resource before using it, and release it when it is done, in the following sequence:
    1. Request - If the request cannot be immediately granted, then the process must wait until the resource(s) it needs become available. For example the system calls open( ), malloc( ), new( ), and request( ).
    2. Use - The process uses the resource, e.g. prints to the printer or reads from the file.
    3. Release - The process relinquishes the resource. so that it becomes available for other processes. For example, close( ), free( ), delete( ), and release( ).
- For all kernel-managed resources, the kernel keeps track of what resources are free and which are allocated, to which process they are allocated, and a queue of processes waiting for this resource to become available. Application-managed resources can be controlled using mutexes or wait( ) and signal( ) calls, (i.e. binary or counting semaphores.)
- A set of processes is deadlocked when every process in the set is waiting for a resource that is currently allocated to another process in the set (and which can only be released when that other waiting process makes progress.)

DEADLOCK WITH MUTEX LOCKS

Let's see how deadlock can occur in a multithreaded Pthread program using mutex locks. The `pthread_mutex_init()` function initializes an unlocked mutex. Mutex locks are acquired and released using `pthread_mutex_lock()` and `pthread_mutex_unlock()`, respectively. If a thread attempts to acquire a locked mutex, the call to `pthread_mutex_lock()` blocks the thread until the owner of the mutex lock invokes `pthread_mutex_unlock()`.

Two mutex locks are created in the following code example:

```
/* Create and initialize the mutex locks */
pthread_mutex_t first_mutex;
pthread_mutex_t second_mutex;

pthread_mutex_init(&first_mutex,NULL);
pthread_mutex_init(&second_mutex,NULL);
```

Next, two threads—`thread_one` and `thread_two`—are created, and both these threads have access to both mutex locks. `thread_one` and `thread_two` run in the functions `do_work_one()` and `do_work_two()`, respectively, as shown below:

```
/* thread_one runs in this function */
void *do_work_one(void *param)
{
   pthread_mutex_lock(&first_mutex);
   pthread_mutex_lock(&second_mutex);
   /**
    * Do some work
    */
   pthread_mutex_unlock(&second_mutex);
   pthread_mutex_unlock(&first_mutex);

   pthread_exit(0);
}

/* thread_two runs in this function */
void *do_work_two(void *param)
{
   pthread_mutex_lock(&second_mutex);
   pthread_mutex_lock(&first_mutex);
   /**
    * Do some work
    */
   pthread_mutex_unlock(&first_mutex);
   pthread_mutex_unlock(&second_mutex);

   pthread_exit(0);
}
```

In this example, `thread_one` attempts to acquire the mutex locks in the order (1) `first_mutex`, (2) `second_mutex`, while `thread_two` attempts to acquire the mutex locks in the order (1) `second_mutex`, (2) `first_mutex`. Deadlock is possible if `thread_one` acquires `first_mutex` while `thread_two` acquires `second_mutex`.

Note that, even though deadlock is possible, it will not occur if `thread_one` can acquire and release the mutex locks for `first_mutex` and `second_mutex` before `thread_two` attempts to acquire the locks. And, of course, the order in which the threads run depends on how they are scheduled by the CPU scheduler. This example illustrates a problem with handling deadlocks: it is difficult to identify and test for deadlocks that may occur only under certain scheduling circumstances.

New Sidebar in Ninth Edition

7.2.1 Necessary Conditions

- There are four conditions that are necessary to achieve deadlock:
    1. **Mutual Exclusion** - At least one resource must be held in a non-sharable mode; If any other process requests this resource, then that process must wait for the resource to be released.
    2. **Hold and Wait** - A process must be simultaneously holding at least one resource and waiting for at least one resource that is currently being held by some other process.
    3. **No preemption** - Once a process is holding a resource (i.e. once its request has been granted), then that resource cannot be taken away from that process until the process voluntarily releases it.
    4. **Circular Wait** - A set of processes { P0, P1, P2, . . ., PN } must exist such that every P[i] is waiting for P[(i + 1) % (N + 1)]. (Note that this condition implies the hold-and-wait condition, but it is easier to deal with the conditions if the four are considered separately.)

7.2.2 Resource-Allocation Graph

- In some cases deadlocks can be understood more clearly through the use of **Resource-Allocation Graphs**, having the following properties:
    - A set of resource categories, { R1, R2, R3, . . ., RN }, which appear as square nodes on the graph. Dots inside the resource nodes indicate

specific instances of the resource. (E.g. two dots might represent two laser printers.)

- A set of processes, { P1, P2, P3, . . ., PN }
- **Request Edges -** A set of directed arcs from Pi to Rj, indicating that process Pi has requested Rj, and is currently waiting for that resource to become available.
- **Assignment Edges -** A set of directed arcs from Rj to Pi indicating that resource Rj has been allocated to process Pi, and that Pi is currently holding resource Rj.
- Note that a **request edge** can be converted into an **assignment edge** by reversing the direction of the arc when the request is granted. (However note also that request edges point to the category box, whereas assignment edges emanate from a particular instance dot within the box.)
- For example:

Figure 7.1 - Resource allocation graph

- If a resource-allocation graph contains no cycles, then the system is not deadlocked. (When looking for cycles, remember that these are ***directed*** graphs.) See the example in Figure 7.2 above.
- If a resource-allocation graph does contain cycles **AND** each resource category contains only a single instance, then a deadlock exists.
- If a resource category contains more than one instance, then the presence of a cycle in the resource-allocation graph indicates the *possibility* of a deadlock, but does not guarantee one. Consider, for example, Figures 7.3 and 7.4 below:

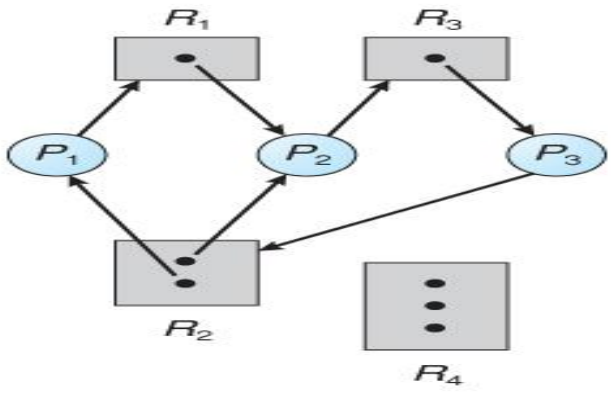


Figure 7.2 - Resource allocation graph with a deadlock

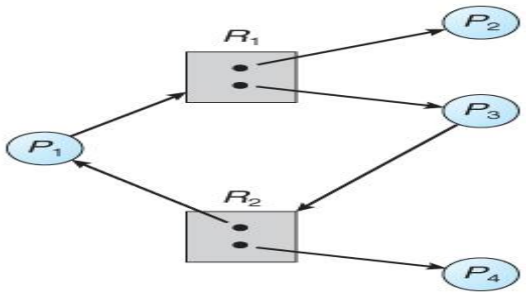


Figure 7.3 - Resource allocation graph with a cycle but no deadlock

7.3 Methods for Handling Deadlocks

- Generally speaking there are three ways of handling deadlocks:
    1. Deadlock prevention or avoidance - Do not allow the system to get into a deadlocked state.
    2. Deadlock detection and recovery - Abort a process or preempt some resources when deadlocks are detected.
    3. Ignore the problem all together - If deadlocks only occur once a year or so, it may be better to simply let them happen and reboot as necessary than to incur the constant overhead and system performance penalties associated with deadlock prevention or detection. This is the approach that both Windows and UNIX take.
- In order to avoid deadlocks, the system must have additional information about all processes. In particular, the system must know what resources a process will or may request in the future. (Ranging from a simple worst-case maximum to a complete resource request and release plan for each process, depending on the particular algorithm.)
- Deadlock detection is fairly straightforward, but deadlock recovery requires either aborting processes or preempting resources, neither of which is an attractive alternative.
- If deadlocks are neither prevented nor detected, then when a deadlock occurs the system will gradually slow down, as more and more processes become stuck waiting for resources currently held by the deadlock and by other waiting processes. Unfortunately this slowdown can be indistinguishable from a general system slowdown when a real-time process has heavy computing needs.

7.4 Deadlock Prevention

- Deadlocks can be prevented by preventing at least one of the four required conditions:

7.4.1 Mutual Exclusion

- Shared resources such as read-only files do not lead to deadlocks.
- Unfortunately some resources, such as printers and tape drives, require exclusive access by a single process.

7.4.2 Hold and Wait

- To prevent this condition processes must be prevented from holding one or more resources while simultaneously waiting for one or more others. There are several possibilities for this:
    - Require that all processes request all resources at one time. This can be wasteful of system resources if a process needs one resource early in its execution and doesn't need some other resource until much later.
    - Require that processes holding resources must release them before requesting new resources, and then re-acquire the released resources along with the new ones in a single new request. This can be a problem if a process has partially completed an operation using a resource and then fails to get it re-allocated after releasing it.
    - Either of the methods described above can lead to starvation if a process requires one or more popular resources.

7.4.3 No Preemption

- Preemption of process resource allocations can prevent this condition of deadlocks, when it is possible.
    - One approach is that if a process is forced to wait when requesting a new resource, then all other resources previously held by this process are implicitly released, (preempted), forcing this process to re-acquire the old resources along with the new resources in a single request, similar to the previous discussion.
    - Another approach is that when a resource is requested and not available, then the system looks to see what other processes currently have those resources *and* are themselves blocked waiting for some other resource. If such a process is found, then some of their resources may get preempted and added to the list of resources for which the process is waiting.
    - Either of these approaches may be applicable for resources whose states are easily saved and restored, such as registers and memory, but are generally not applicable to other devices such as printers and tape drives.

7.4.4 Circular Wait

- One way to avoid circular wait is to number all resources, and to require that processes request resources only in strictly increasing (or decreasing) order.
- In other words, in order to request resource Rj, a process must first release all Ri such that i >= j.
- One big challenge in this scheme is determining the relative ordering of the different resources

7.5 Deadlock Avoidance

- The general idea behind deadlock avoidance is to prevent deadlocks from ever happening, by preventing at least one of the aforementioned conditions.
- This requires more information about each process, AND tends to lead to low device utilization. (I.e. it is a conservative approach.)
- In some algorithms the scheduler only needs to know the *maximum* number of each resource that a process might potentially use. In more complex algorithms the scheduler can also take advantage of the *schedule* of exactly what resources may be needed in what order.
- When a scheduler sees that starting a process or granting resource requests may lead to future deadlocks, then that process is just not started or the request is not granted.
- A resource allocation ***state*** is defined by the number of available and allocated resources, and the maximum requirements of all processes in the system.

7.5.1 Safe State

- A state is ***safe*** if the system can allocate all resources requested by all processes (up to their stated maximums) without entering a deadlock state.
- More formally, a state is safe if there exists a ***safe sequence*** of processes { P0, P1, P2, ..., PN } such that all of the resource requests for Pi can be granted using the resources currently allocated to Pi and all processes Pj where j < i. (I.e. if all the processes prior to Pi finish and free up their resources, then Pi will be able to finish also, using the resources that they have freed up.)
- If a safe sequence does not exist, then the system is in an unsafe state, which ***MAY*** lead to deadlock. (All safe states are deadlock free, but not all unsafe states lead to deadlocks.)

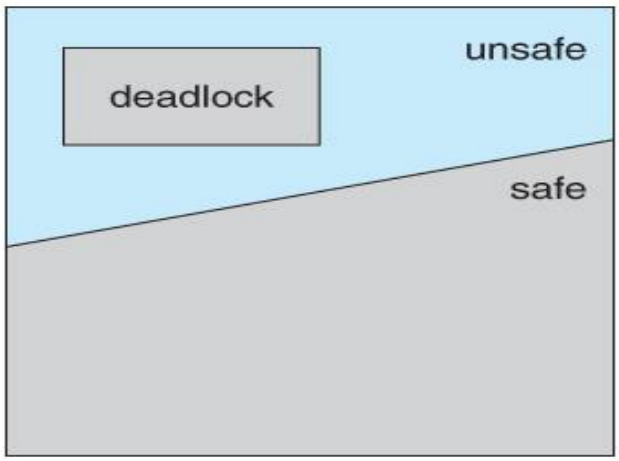


Figure 7.6 - Safe, unsafe, and deadlocked state spaces.

- For example, consider a system with 12 tape drives, allocated as follows. Is this a safe state? What is the safe sequence?
-

	Maximum Needs	Current Allocation
P0	10	5
P1	4	2
P2	9	2

What happens to the above table if process P2 requests and is granted one more tape drive?

- Key to the safe state approach is that when a request is made for resources, the request is granted only if the resulting allocation state is a safe one.

7.5.2 Resource-Allocation Graph Algorithm

- If resource categories have only single instances of their resources, then deadlock states can be detected by cycles in the resource-allocation graphs.
- In this case, unsafe states can be recognized and avoided by augmenting the resource-allocation graph with ***claim edges***, noted by dashed lines, which point from a process to a resource that it may request in the future.
- In order for this technique to work, all claim edges must be added to the graph for any particular process before that process is allowed to request any resources. (Alternatively, processes may only make requests for resources for

which they have already established claim edges, and claim edges cannot be added to any process that is currently holding resources.)

- When a process makes a request, the claim edge Pi->Rj is converted to a request edge. Similarly when a resource is released, the assignment reverts back to a claim edge.
- This approach works by denying requests that would produce cycles in the resource-allocation graph, taking claim edges into effect.
- Consider for example what happens when process P2 requests resource R2:

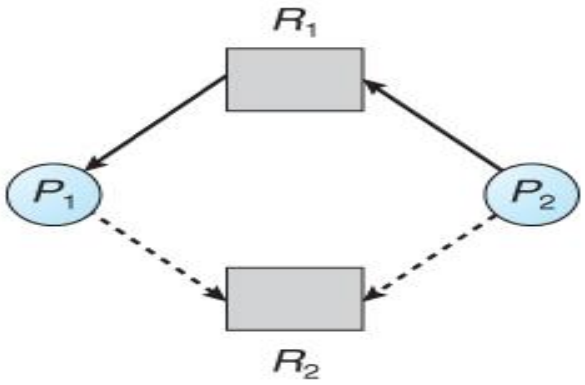


Figure 7.7 - Resource allocation graph for deadlock avoidance

- The resulting resource-allocation graph would have a cycle in it, and so the request cannot be granted.

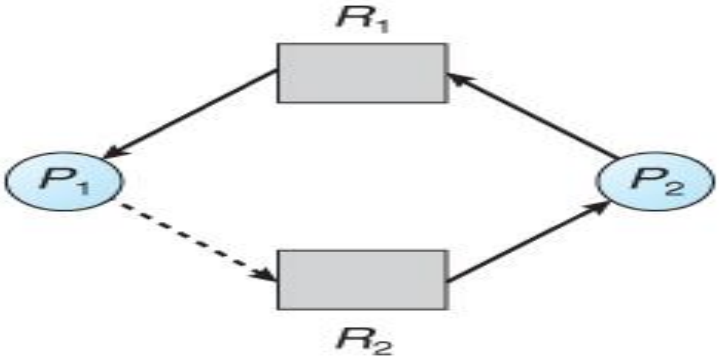


Figure 7.8 - An unsafe state in a resource allocation graph

7.5.3 Banker's Algorithm

- For resource categories that contain more than one instance the resource-allocation graph method does not work, and more complex (and less efficient) methods must be chosen.

- The Banker's Algorithm gets its name because it is a method that bankers could use to assure that when they lend out resources they will still be able to satisfy all their clients. (A banker won't loan out a little money to start building a house unless they are assured that they will later be able to loan out the rest of the money to finish the house.)
- When a process starts up, it must state in advance the maximum allocation of resources it may request, up to the amount available on the system.
- When a request is made, the scheduler determines whether granting the request would leave the system in a safe state. If not, then the process must wait until the request can be granted safely.
- The banker's algorithm relies on several key data structures: (where n is the number of processes and m is the number of resource categories.)
    - Available[m] indicates how many resources are currently available of each type.
    - Max[n][m] indicates the maximum demand of each process of each resource.
    - Allocation[n][m] indicates the number of each resource category allocated to each process.
    - Need[n][m] indicates the remaining resources needed of each type for each process. (Note that Need[i][j] = Max[i][j] - Allocation[i][j] for all i, j.)
- For simplification of discussions, we make the following notations / observations:
    - One row of the Need vector, Need[i], can be treated as a vector corresponding to the needs of process i, and similarly for Allocation and Max.
    - A vector X is considered to be <= a vector Y if X[i] <= Y[i] for all i.

7.5.3.1 Safety Algorithm

- In order to apply the Banker's algorithm, we first need an algorithm for determining whether or not a particular state is safe.
- This algorithm determines if the current state of a system is safe, according to the following steps:
    1. Let Work and Finish be vectors of length m and n respectively.
        - Work is a working copy of the available resources, which will be modified during the analysis.
        - Finish is a vector of booleans indicating whether a particular process can finish. (or has finished so far in the analysis.)

        - Initialize Work to Available, and Finish to false for all elements.
    2. Find an i such that both (A) Finish[i] == false, and (B) Need[i] < Work. This process has not finished, but could with the given available working set. If no such i exists, go to step 4.
    3. Set Work = Work + Allocation[i], and set Finish[i] to true. This corresponds to process i finishing up and releasing its resources back into the work pool. Then loop back to step 2.
    4. If finish[i] == true for all i, then the state is a safe state, because a safe sequence has been found.
- (JTB's Modification:
    1. In step 1. instead of making Finish an array of booleans initialized to false, make it an array of ints initialized to 0. Also initialize an int s = 0 as a step counter.
    2. In step 2, look for Finish[i] == 0.
    3. In step 3, set Finish[i] to ++s. S is counting the number of finished processes.
    4. For step 4, the test can be either Finish[i] > 0 for all i, or s >= n. The benefit of this method is that if a safe state exists, then Finish[ ] indicates one safe sequence (of possibly many.))

7.5.3.2 Resource-Request Algorithm (The Bankers Algorithm)

- Now that we have a tool for determining if a particular state is safe or not, we are now ready to look at the Banker's algorithm itself.
- This algorithm determines if a new request is safe, and grants it only if it is safe to do so.
- When a request is made (that does not exceed currently available resources), pretend it has been granted, and then see if the resulting state is a safe one. If so, grant the request, and if not, deny the request, as follows:
    1. Let Request[n][m] indicate the number of resources of each type currently requested by processes. If Request[i] > Need[i] for any process i, raise an error condition.
    2. If Request[i] > Available for any process i, then that process must wait for resources to become available. Otherwise the process can continue to step 3.
    3. Check to see if the request can be granted safely, by pretending it has been granted and then seeing if the resulting state is safe. If so, grant the request, and if not, then the process must wait until its request can be

granted safely.The procedure for granting a request (or pretending to for testing purposes) is:

- Available = Available - Request
- Allocation = Allocation + Request
- Need = Need - Request

7.5.3.3 An Illustrative Example

- Consider the following situation:

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

- And now consider what happens if process P1 requests 1 instance of A and 2 instances of C. (Request[1] = (1, 0, 2))

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

- What about requests of (3, 3,0) by P4? or (0, 2, 0) by P0? Can these be safely granted? Why or why not?

7.6 Deadlock Detection

- If deadlocks are not avoided, then another approach is to detect when they have occurred and recover somehow.
- In addition to the performance hit of constantly checking for deadlocks, a policy / algorithm must be in place for recovering from deadlocks, and there is potential for lost work when processes must be aborted or have their resources preempted.

7.6.1 Single Instance of Each Resource Type

- If each resource category has a single instance, then we can use a variation of the resource-allocation graph known as a ***wait-for graph***.
- A wait-for graph can be constructed from a resource-allocation graph by eliminating the resources and collapsing the associated edges, as shown in the figure below.
- An arc from Pi to Pj in a wait-for graph indicates that process Pi is waiting for a resource that process Pj is currently holding.

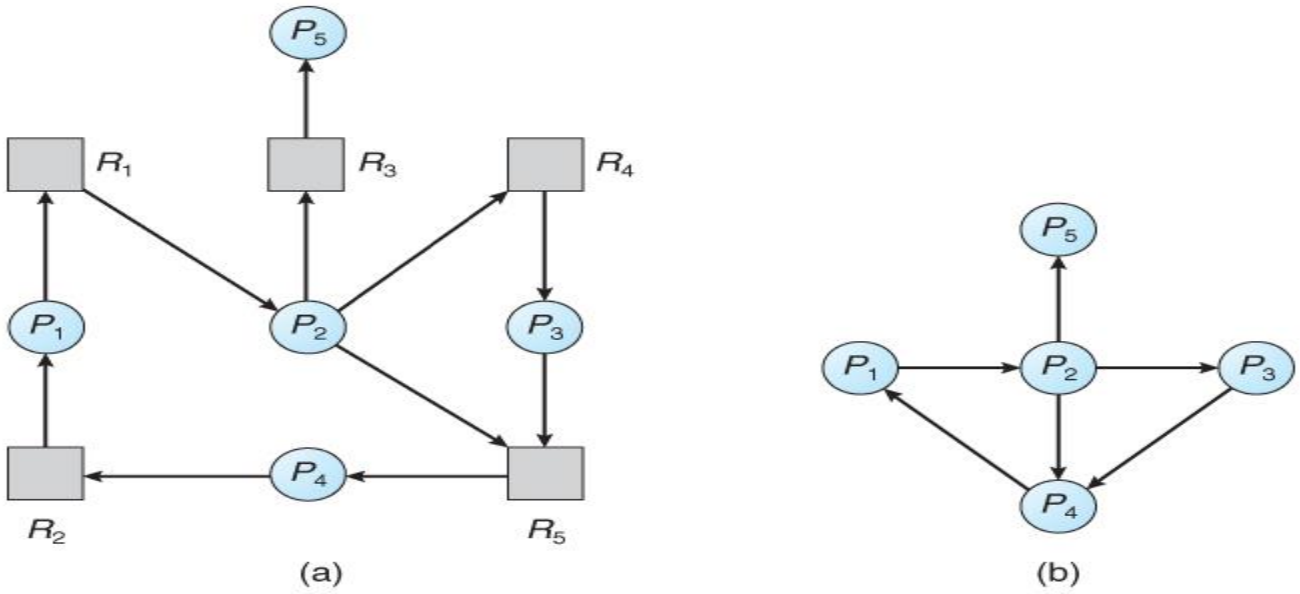


Figure 7.9 - (a) Resource allocation graph. (b) Corresponding wait-for graph

- As before, cycles in the wait-for graph indicate deadlocks.
- This algorithm must maintain the wait-for graph, and periodically search it for cycles.

7.6.2 Several Instances of a Resource Type

- The detection algorithm outlined here is essentially the same as the Banker's algorithm, with two subtle differences:
    - In step 1, the Banker's Algorithm sets Finish[i] to false for all i. The algorithm presented here sets Finish[i] to false only if Allocation[i] is not zero. If the currently allocated resources for this process are zero, the algorithm sets Finish[i] to true. This is essentially assuming that IF all of the other processes can finish, then this process can finish also. Furthermore, this algorithm is specifically looking for which processes are involved in a deadlock situation, and a process that does not have any resources allocated cannot be involved in a deadlock, and so can be removed from any further consideration.
    - Steps 2 and 3 are unchanged
    - In step 4, the basic Banker's Algorithm says that if Finish[i] == true for all i, that there is no deadlock. This algorithm is more specific, by stating that if Finish[i] == false for any process Pi, then that process is specifically involved in the deadlock which has been detected.
- (Note: An alternative method was presented above, in which Finish held integers instead of booleans. This vector would be initialized to all zeros, and then filled with increasing integers as processes are detected which can finish. If any processes are left at zero when the algorithm completes, then there is a deadlock, and if not, then the integers in finish describe a safe sequence. To modify this algorithm to match this section of the text, processes with allocation = zero could be filled in with N, N - 1, N - 2, etc. in step 1, and any processes left with Finish = 0 in step 4 are the deadlocked processes.)
- Consider, for example, the following state, and determine if it is currently deadlocked:

	Allocation	*Request*	*Available*
	A B C	*A B C*	*A B C*
P_0	0 1 0	0 0 0	0 0 0
P_1	2 0 0	2 0 2	
P_2	3 0 3	0 0 0	
P_3	2 1 1	1 0 0	
P_4	0 0 2	0 0 2	

- Now suppose that process P2 makes a request for an additional instance of type C, yielding the state shown below. Is the system now deadlocked?

	Allocation	*Request*	*Available*
	A B C	*A B C*	*A B C*
P_0	0 1 0	0 0 0	0 0 0
P_1	2 0 0	2 0 2	
P_2	3 0 3	0 0 1	
P_3	2 1 1	1 0 0	
P_4	0 0 2	0 0 2	

7.6.3 Detection-Algorithm Usage

- When should the deadlock detection be done? Frequently, or infrequently?
- The answer may depend on how frequently deadlocks are expected to occur, as well as the possible consequences of not catching them immediately. (If deadlocks are not removed immediately when they occur, then more and more processes can "back up" behind the deadlock, making the eventual task of unblocking the system more difficult and possibly damaging to more processes.)
- There are two obvious approaches, each with trade-offs:
    1. Do deadlock detection after every resource allocation which cannot be immediately granted. This has the advantage of detecting the deadlock right away, while the minimum number of processes are involved in the deadlock. (One might consider that the process whose request triggered the deadlock condition is the "cause" of the deadlock, but realistically all of the processes in the cycle are equally responsible for the resulting deadlock.) The down side of this approach is the extensive overhead and performance hit caused by checking for deadlocks so frequently.
    2. Do deadlock detection only when there is some clue that a deadlock may have occurred, such as when CPU utilization reduces to 40% or some other magic number. The advantage is that deadlock detection is done much less frequently, but the down side is that it becomes impossible to detect the processes involved in the original deadlock, and so deadlock recovery can be more complicated and damaging to more processes.
    3. (As I write this, a third alternative comes to mind: Keep a historical log of resource allocations, since that last known time of no deadlocks. Do

deadlock checks periodically (once an hour or when CPU usage is low?), and then use the historical log to trace through and determine when the deadlock occurred and what processes caused the initial deadlock. Unfortunately I'm not certain that breaking the original deadlock would then free up the resulting log jam.)

7.7 Recovery From Deadlock

- There are three basic approaches to recovery from deadlock:
    1. Inform the system operator, and allow him/her to take manual intervention.
    2. Terminate one or more processes involved in the deadlock
    3. Preempt resources.

7.7.1 Process Termination

- Two basic approaches, both of which recover resources allocated to terminated processes:
    - Terminate all processes involved in the deadlock. This definitely solves the deadlock, but at the expense of terminating more processes than would be absolutely necessary.
    - Terminate processes one by one until the deadlock is broken. This is more conservative, but requires doing deadlock detection after each step.
- In the latter case there are many factors that can go into deciding which processes to terminate next:
    1. Process priorities.
    2. How long the process has been running, and how close it is to finishing.
    3. How many and what type of resources is the process holding. (Are they easy to preempt and restore?)
    4. How many more resources does the process need to complete.
    5. How many processes will need to be terminated
    6. Whether the process is interactive or batch.
    7. (Whether or not the process has made non-restorable changes to any resource.)

7.7.2 Resource Preemption

- When preempting resources to relieve deadlock, there are three important issues to be addressed:

1. **Selecting a victim** - Deciding which resources to preempt from which processes involves many of the same decision criteria outlined above.
2. **Rollback** - Ideally one would like to roll back a preempted process to a safe state prior to the point at which that resource was originally allocated to the process. Unfortunately it can be difficult or impossible to determine what such a safe state is, and so the only safe rollback is to roll back all the way back to the beginning. (I.e. abort the process and make it start over.)
3. **Starvation** - How do you guarantee that a process won't starve because its resources are constantly being preempted? One option would be to use a priority system, and increase the priority of a process every time its resources get preempted. Eventually it should get a high enough priority that it won't get preempted any more.

File-System Implementation

12.1 File-System Structure

- Hard disks have two important properties that make them suitable for secondary storage of files in file systems: (1) Blocks of data can be rewritten in place, and (2) they are direct access, allowing any block of data to be accessed with only (relatively) minor movements of the disk heads and rotational latency. (See Chapter 12)
- Disks are usually accessed in physical blocks, rather than a byte at a time. Block sizes may range from 512 bytes to 4K or larger.
- File systems organize storage on disk drives, and can be viewed as a layered design:
    - At the lowest layer are the physical devices, consisting of the magnetic media, motors & controls, and the electronics connected to them and controlling them. Modern disk put more and more of the electronic controls directly on the disk drive itself, leaving relatively little work for the disk controller card to perform.
    - ***I/O Control*** consists of ***device drivers***, special software programs (often written in assembly) which communicate with the devices by reading and writing special codes directly to and from memory addresses corresponding to the controller card's registers. Each controller card (device) on a system has a different set of addresses (registers,

a.k.a. ***ports***) that it listens to, and a unique set of command codes and results codes that it understands.
    - The ***basic file system*** level works directly with the device drivers in terms of retrieving and storing raw blocks of data, without any consideration for what is in each block. Depending on the system, blocks may be referred to with a single block number, (e.g. block # 234234), or with head-sector-cylinder combinations.
    - The ***file organization module*** knows about files and their logical blocks, and how they map to physical blocks on the disk. In addition to translating from logical to physical blocks, the file organization module also maintains the list of free blocks, and allocates free blocks to files as needed.
    - The ***logical file system*** deals with all of the meta data associated with a file (UID, GID, mode, dates, etc), i.e. everything about the file except the data itself. This level manages the directory structure and the mapping of file names to ***file control blocks, FCBs***, which contain all of the meta data as well as block number information for finding the data on the disk.
- The layered approach to file systems means that much of the code can be used uniformly for a wide variety of different file systems, and only certain layers need to be filesystem specific. Common file systems in use include the UNIX file system, UFS, the Berkeley Fast File System, FFS, Windows systems FAT, FAT32, NTFS, CD-ROM systems ISO 9660, and for Linux the extended file systems ext2 and ext3 (among 40 others supported.)

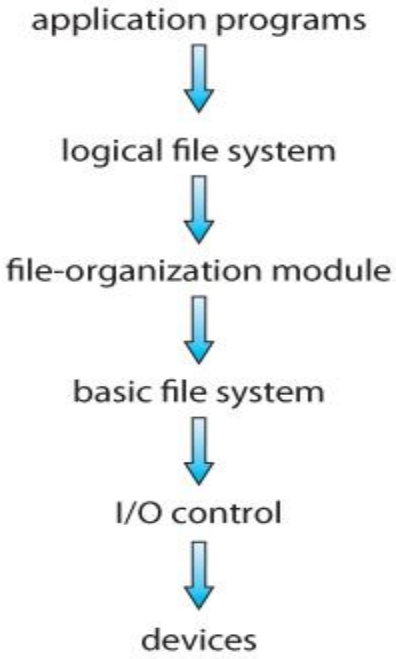


Figure 12.1 - Layered file system.

12.2 File-System Implementation

12.2.1 Overview

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

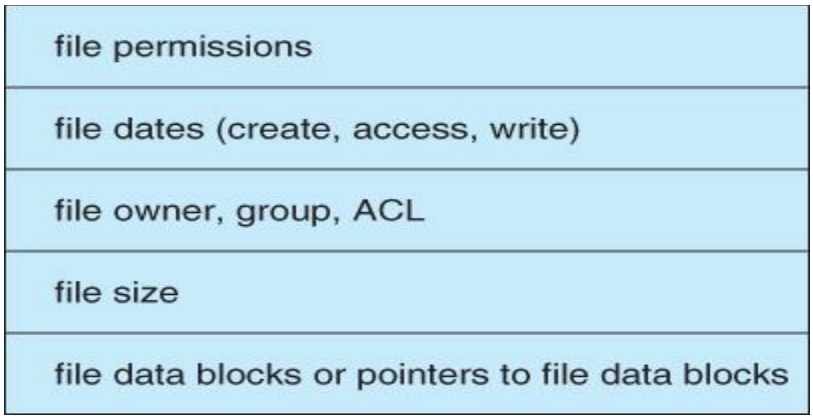
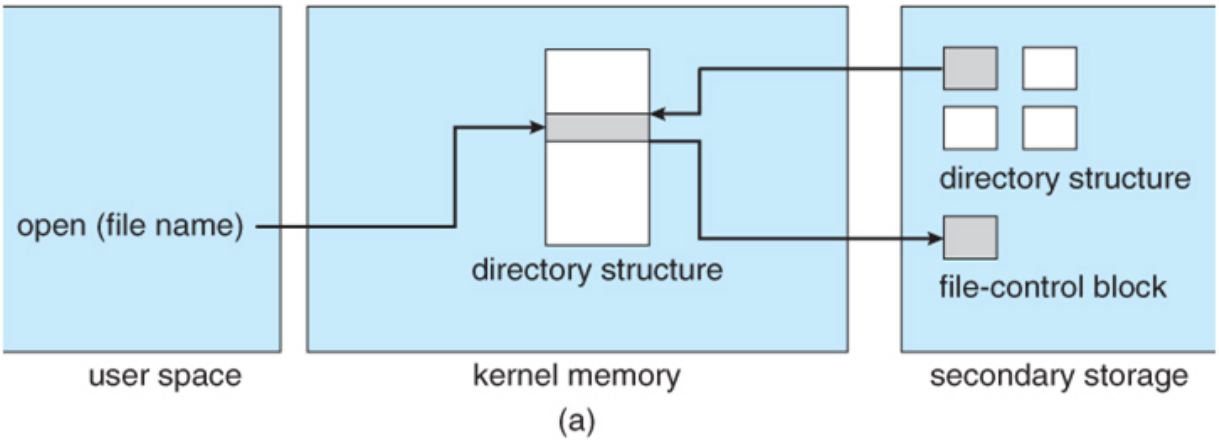


Figure 12.2 - A typical file-control block.

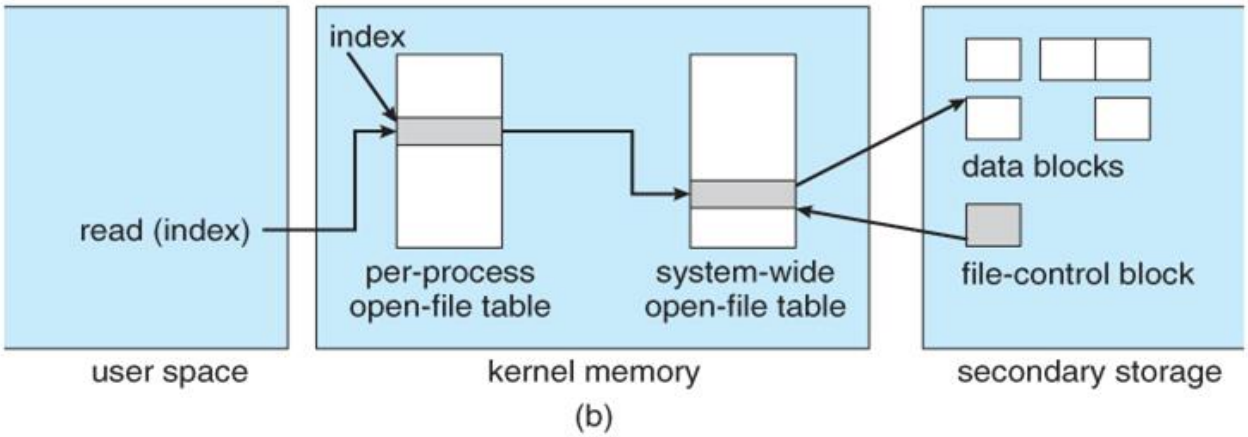
- There are also several key data structures stored in memory:
  - An in-memory mount table.
  - An in-memory directory cache of recently accessed directory information.
  - ***A system-wide open file table***, containing a copy of the FCB for every currently open file in the system, as well as some other related information.

- ***A per-process open file table,*** containing a pointer to the system open file table as well as some other information. (For example the current file position pointer may be either here or in the system file table, depending on the implementation and whether the file is being shared or not.)

- Figure 12.3 illustrates some of the interactions of file system components when files are created and/or used:
  - When a new file is created, a new FCB is allocated and filled out with important information regarding the new file. The appropriate directory is modified with the new file name and FCB information.
  - When a file is accessed during a program, the open( ) system call reads in the FCB information from disk, and stores it in the system-wide open file table. An entry is added to the per-process open file table referencing the system-wide table, and an index into the per-process table is returned by the open( ) system call. UNIX refers to this index as a ***file descriptor***, and Windows refers to it as a ***file handle***.
  - If another process already has a file open when a new request comes in for the same file, and it is sharable, then a counter in the system-wide table is incremented and the per-process table is adjusted to point to the existing entry in the system-wide table.
  - When a file is closed, the per-process table entry is freed, and the counter in the system-wide table is decremented. If that counter reaches zero, then the system wide table is also freed. Any data currently stored in memory cache for this file is written out to disk if necessary.



(a)



2.3 - In-memory file-system structures. (a) File open. (b) File read.

12.2.2 Partitions and Mounting

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

properly the last time they were used, or just for general principals. Filesystems may be mounted either automatically or manually. In UNIX a mount point is indicated by setting a flag in the in-memory copy of the inode, so all future references to that inode get re-directed to the root directory of the mounted filesystem.

12.2.3 Virtual File Systems

- ***Virtual File Systems, VFS***, provide a common interface to multiple different filesystem types. In addition, it provides for a unique identifier (vnode) for files across the entire space, including across all filesystems of different types. (UNIX inodes are unique only across a single filesystem, and certainly do not carry across networked file systems.)
- The VFS in Linux is based upon four key object types:
  - The ***inode*** object, representing an individual file
  - The ***file*** object, representing an open file.
  - The ***superblock*** object, representing a filesystem.
  - The ***dentry*** object, representing a directory entry.
- Linux VFS provides a set of common functionalities for each filesystem, using function pointers accessed through a table. The same functionality is accessed through the same table position for all filesystem types, though the actual functions pointed to by the pointers may be filesystem-specific. See /usr/include/linux/fs.h for full details. Common operations provided include open( ), read( ), write( ), and mmap( ).

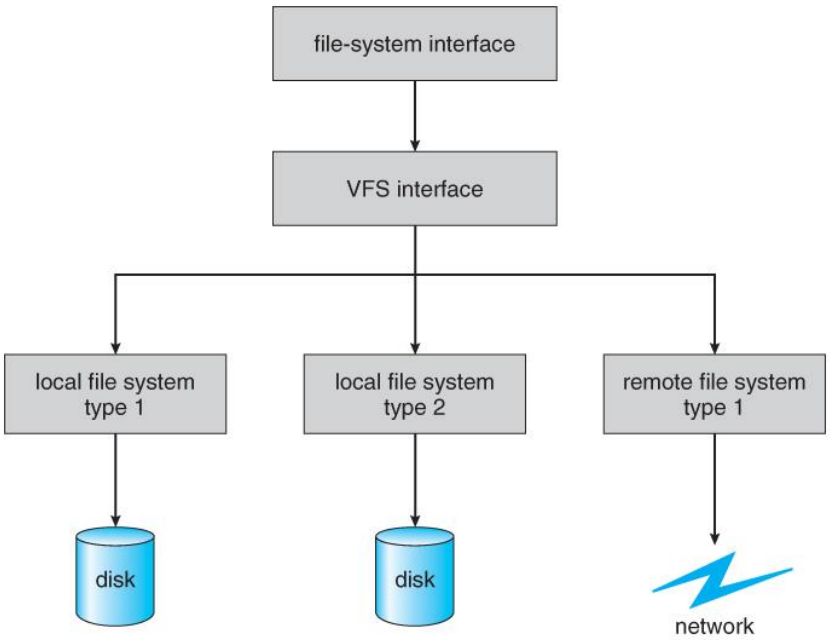


Figure 12.4 - Schematic view of a virtual file system.

12.3 Directory Implementation

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

12.3.1 Linear List

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

12.3.2 Hash Table

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

12.4 Allocation Methods

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

12.4.1 Contiguous Allocation

- ***Contiguous Allocation*** requires that all blocks of a file be kept together contiguously.
- Performance is very fast, because reading successive blocks of the same file generally requires no movement of the disk heads, or at most one small step to the next adjacent cylinder.
- Storage allocation involves the same issues discussed earlier for the allocation of contiguous blocks of memory (first fit, best fit, fragmentation problems, etc.) The distinction is that the high time penalty required for moving the disk heads from spot to spot may now justify the benefits of keeping files contiguously when possible.

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

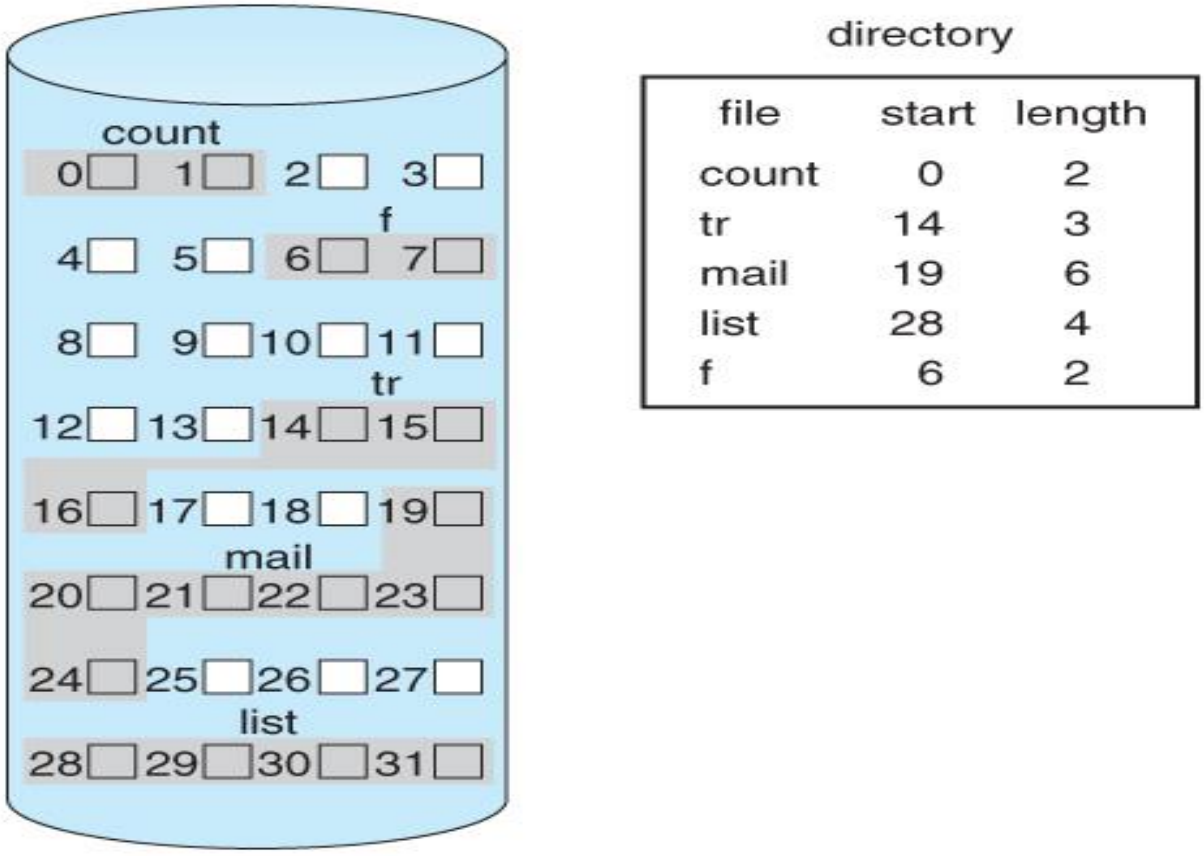


Figure 12.5 - Contiguous allocation of disk space.

12.4.2 Linked Allocation

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

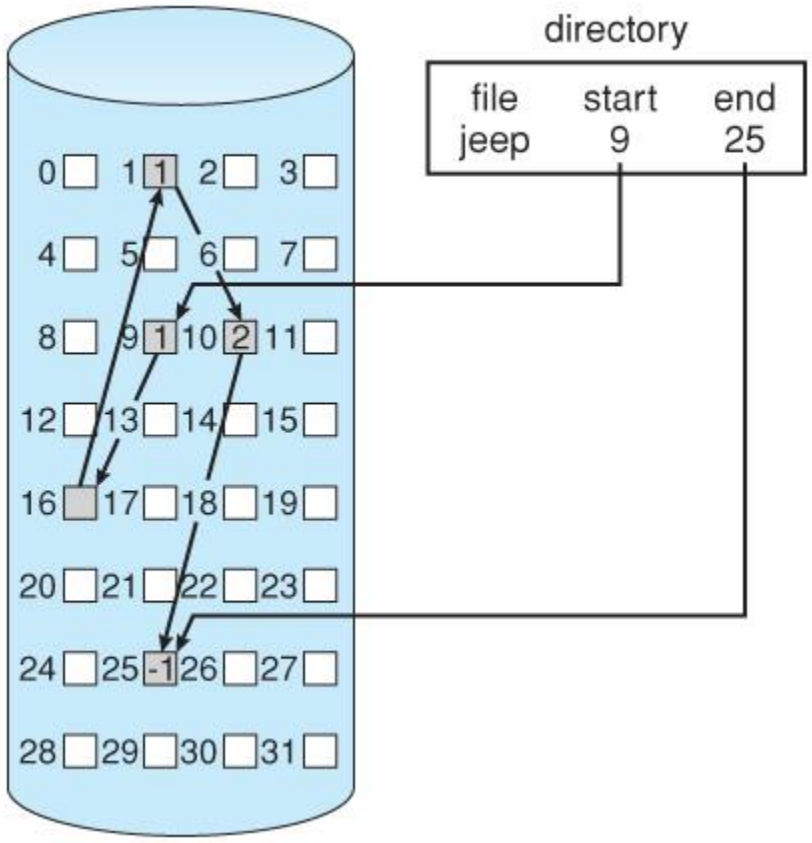


Figure 12.6 - Linked allocation of disk space.

- The ***File Allocation Table, FAT,*** used by DOS is a variation of linked allocation, where all the links are stored in a separate table at the beginning

of the disk. The benefit of this approach is that the FAT table can be cached in memory, greatly improving random access speeds.

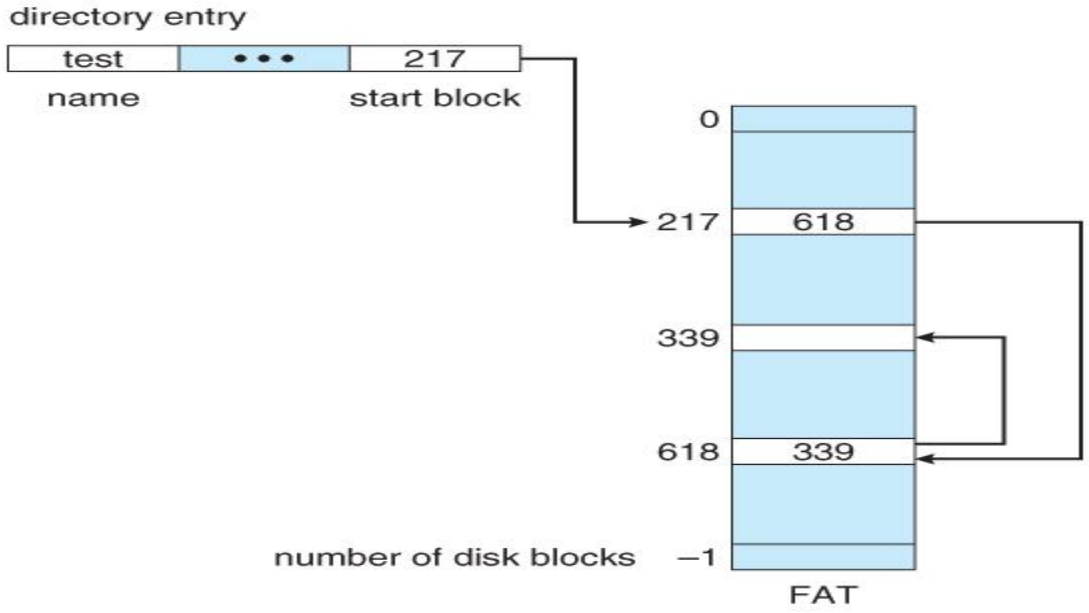


Figure 12.7 File-allocation table.

12.4.3 Indexed Allocation

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

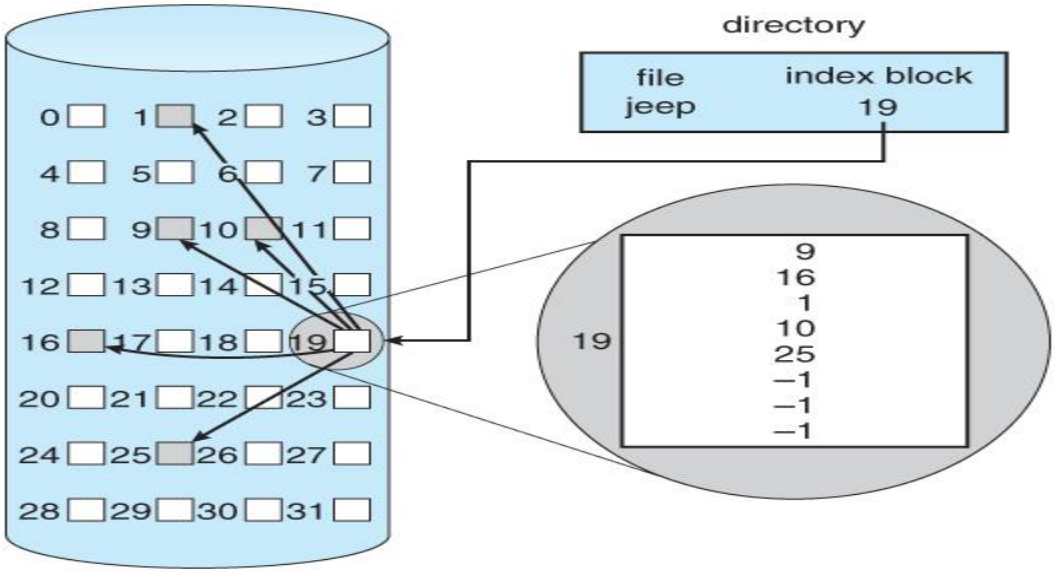


Figure 12.8 - Indexed allocation of disk space.

- Some disk space is wasted (relative to linked lists or FAT tables) because an entire index block must be allocated for each file, regardless of how many data blocks the file contains. This leads to questions of how big the index block should be, and how it should be implemented. There are several approaches:
    - **Linked Scheme -** An index block is one disk block, which can be read and written in a single disk operation. The first index block contains some header information, the first N block addresses, and if necessary a pointer to additional linked index blocks.
    - **Multi-Level Index -** The first index block contains a set of pointers to secondary index blocks, which in turn contain pointers to the actual data blocks.
    - **Combined Scheme -** This is the scheme used in UNIX inodes, in which the first 12 or so data block pointers are stored directly in the inode, and then singly, doubly, and triply indirect pointers provide access to more data blocks as needed. (See below.) The advantage of this scheme is that for small files (which many are), the data blocks are readily accessible (up to 48K with 4K block sizes); files up to about 4144K (using 4K blocks) are accessible with only a single indirect block (which can be cached), and huge files are still accessible using a relatively small number of disk accesses (larger in theory than can be addressed by a 32-bit address, which is why some systems have moved to 64-bit file pointers.)

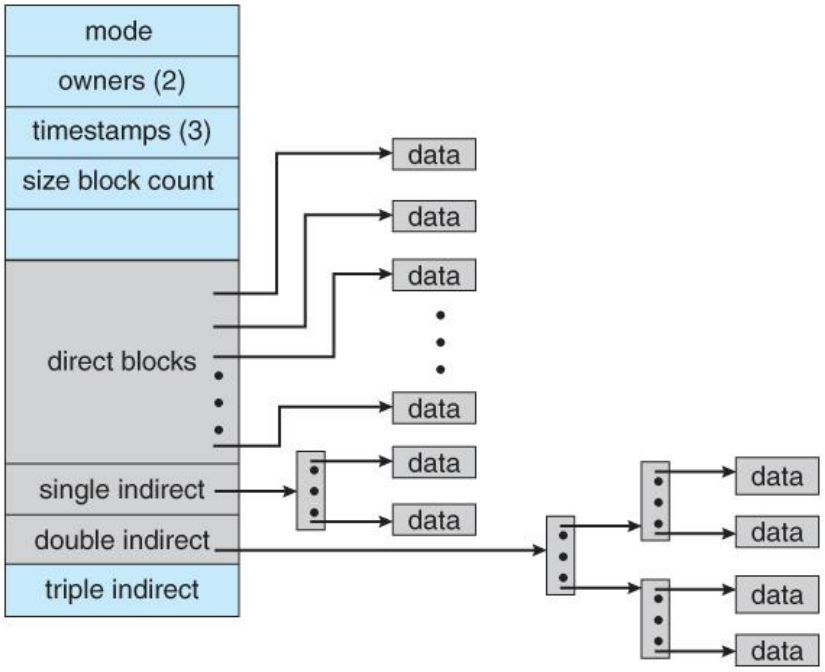


Figure 12.9 - The UNIX inode.

12.4.4 Performance

- The optimal allocation method is different for sequential access files than for random access files, and is also different for small files than for large files.
- Some systems support more than one allocation method, which may require specifying how the file is to be used (sequential or random access) at the time it is allocated. Such systems also provide conversion utilities.
- Some systems have been known to use contiguous access for small files, and automatically switch to an indexed scheme when file sizes surpass a certain threshold.
- And of course some systems adjust their allocation schemes (e.g. block sizes) to best match the characteristics of the hardware for optimum performance.

12.5 Free-Space Management

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

12.5.1 Bit Vector

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

12.5.2 Linked List

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

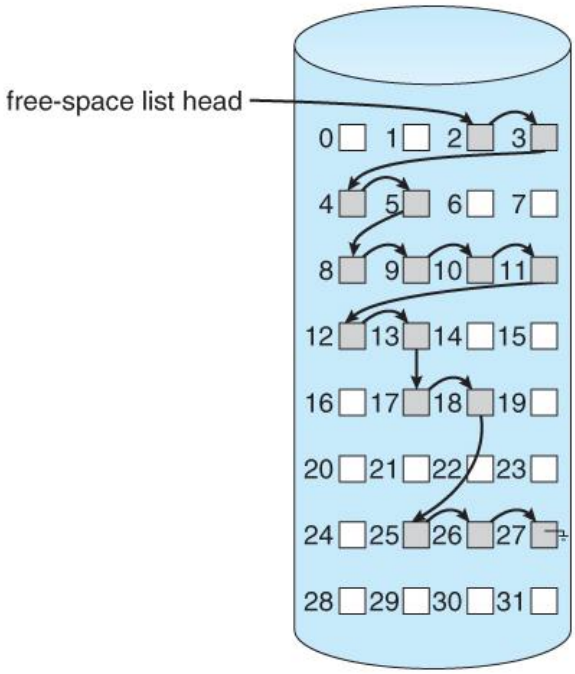


Figure 12.10 - Linked free-space list on disk.

12.5.3 Grouping

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

12.5.4 Counting

- When there are multiple contiguous blocks of free space then the system can keep track of the starting address of the group and the number of contiguous free blocks. As long as the average length of a contiguous group of free blocks is greater than two this offers a savings in space needed for the free list. (Similar to compression techniques used for graphics images when a group of pixels all the same color is encountered.)

12.5.5 Space Maps

- Sun's ZFS file system was designed for HUGE numbers and sizes of files, directories, and even file systems.
- The resulting data structures could be VERY inefficient if not implemented carefully. For example, freeing up a 1 GB file on a 1 TB file

system could involve updating thousands of blocks of free list bit maps if the file was spread across the disk.

- ZFS uses a combination of techniques, starting with dividing the disk up into (hundreds of) ***metaslabs*** of a manageable size, each having their own space map.
- Free blocks are managed using the counting technique, but rather than write the information to a table, it is recorded in a log-structured transaction record. Adjacent free blocks are also coalesced into a larger single free block.
- An in-memory space map is constructed using a balanced tree data structure, constructed from the log data.
- The combination of the in-memory tree and the on-disk log provide for very fast and efficient management of these very large files and free blocks.

12.6 Efficiency and Performance

12.6.1 Efficiency

- UNIX pre-allocates inodes, which occupies space even before any files are created.
- UNIX also distributes inodes across the disk, and tries to store data files near their inode, to reduce the distance of disk seeks between the inodes and the data.
- Some systems use variable size clusters depending on the file size.
- The more data that is stored in a directory (e.g. last access time), the more often the directory blocks have to be re-written.
- As technology advances, addressing schemes have had to grow as well.
    - Sun's ZFS file system uses 128-bit pointers, which should theoretically never need to be expanded. (The mass required to store 2^128 bytes with atomic storage would be at least 272 trillion kilograms!)
- Kernel table sizes used to be fixed, and could only be changed by rebuilding the kernels. Modern tables are dynamically allocated, but that requires more complicated algorithms for accessing them.

12.6.2 Performance

- Disk controllers generally include on-board caching. When a seek is requested, the heads are moved into place, and then an entire track is read, starting from whatever sector is currently under the heads (reducing

latency.) The requested sector is returned and the unrequested portion of the track is cached in the disk's electronics.

- Some OSes cache disk blocks they expect to need again in a ***buffer cache.***
- A ***page cache*** connected to the virtual memory system is actually more efficient as memory addresses do not need to be converted to disk block addresses and back again.
- Some systems (Solaris, Linux, Windows 2000, NT, XP) use page caching for both process pages and file data in a ***unified virtual memory.***
- Figures 11.11 and 11.12 show the advantages of the ***unified buffer cache*** found in some versions of UNIX and Linux - Data does not need to be stored twice, and problems of inconsistent buffer information are avoided.

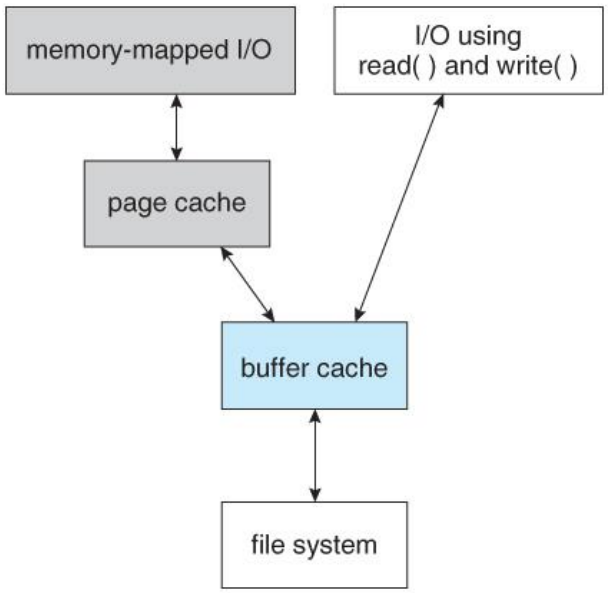


Figure 12.11 - I/O without a unified buffer cache.

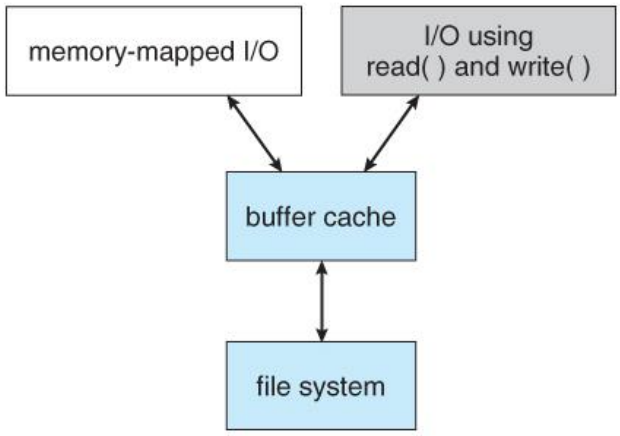


Figure 12.12 - I/O using a unified buffer cache.

- Page replacement strategies can be complicated with a unified cache, as one needs to decide whether to replace process or file pages, and how many pages to guarantee to each category of pages. Solaris, for example, has gone through many variations, resulting in ***priority paging*** giving process pages priority over file I/O pages, and setting limits so that neither can knock the other completely out of memory.
- Another issue affecting performance is the question of whether to implement ***synchronous writes*** or ***asynchronous writes.*** Synchronous writes occur in the order in which the disk subsystem receives them, without caching; Asynchronous writes are cached, allowing the disk subsystem to schedule writes in a more efficient order (See Chapter 12.) Metadata writes are often done synchronously. Some systems support flags to the open call requiring that writes be synchronous, for example for the benefit of database systems that require their writes be performed in a required order.
- The type of file access can also have an impact on optimal page replacement policies. For example, LRU is not necessarily a good policy for sequential access files. For these types of files progression normally goes in a forward direction only, and the most recently used page will not be needed again until after the file has been rewound and re-read from the beginning, (if it is ever needed at all.) On the other hand, we can expect to need the next page in the file fairly soon. For this reason sequential access files often take advantage of two special policies:
    - ***Free-behind*** frees up a page as soon as the next page in the file is requested, with the assumption that we are now done with the old page and won't need it again for a long time.
    - ***Read-ahead*** reads the requested page and several subsequent pages at the same time, with the assumption that those pages will be needed in the near future. This is similar to the track caching that is already performed by the disk controller, except it saves the future latency of transferring data from the disk controller memory into motherboard main memory.
- The caching system and asynchronous writes speed up disk writes considerably, because the disk subsystem can schedule physical writes to the disk to minimize head movement and disk seek times. (See Chapter 12.) Reads, on the other hand, must be done more synchronously in spite of the caching system, with the result that disk writes can counter-intuitively be much faster on average than disk reads.

12.7 Recovery

12.7.1 Consistency Checking

- The storing of certain data structures (e.g. directories and inodes) in memory and the caching of disk operations can speed up performance, but what happens in the result of a system crash? All volatile memory structures are lost, and the information stored on the hard drive may be left in an inconsistent state.
- A ***Consistency Checker*** (fsck in UNIX, chkdsk or scandisk in Windows) is often run at boot time or mount time, particularly if a filesystem was not closed down properly. Some of the problems that these tools look for include:
    - Disk blocks allocated to files and also listed on the free list.
    - Disk blocks neither allocated to files nor on the free list.
    - Disk blocks allocated to more than one file.
    - The number of disk blocks allocated to a file inconsistent with the file's stated size.
    - Properly allocated files / inodes which do not appear in any directory entry.
    - Link counts for an inode not matching the number of references to that inode in the directory structure.
    - Two or more identical file names in the same directory.
    - Illegally linked directories, e.g. cyclical relationships where those are not allowed, or files/directories that are not accessible from the root of the directory tree.
    - Consistency checkers will often collect questionable disk blocks into new files with names such as chk00001.dat. These files may contain valuable information that would otherwise be lost, but in most cases they can be safely deleted, (returning those disk blocks to the free list.)
- UNIX caches directory information for reads, but any changes that affect space allocation or metadata changes are written synchronously, before any of the corresponding data blocks are written to.

12.7.2 Log-Structured File Systems (was 11.8)

- ***Log-based transaction-oriented*** (a.k.a. ***journaling***) filesystems borrow techniques developed for databases, guaranteeing that any given transaction either completes successfully or can be rolled back to a safe state before the transaction commenced:
    - All metadata changes are written sequentially to a log.
    - A set of changes for performing a specific task (e.g. moving a file) is a ***transaction***.
    - As changes are written to the log they are said to be ***committed,*** allowing the system to return to its work.

- In the meantime, the changes from the log are carried out on the actual filesystem, and a pointer keeps track of which changes in the log have been completed and which have not yet been completed.
- When all changes corresponding to a particular transaction have been completed, that transaction can be safely removed from the log.
- At any given time, the log will contain information pertaining to uncompleted transactions only, e.g. actions that were committed but for which the entire transaction has not yet been completed.
  - From the log, the remaining transactions can be completed,
  - or if the transaction was aborted, then the partially completed changes can be undone.

12.7.3 Other Solutions (New)

- Sun's ZFS and Network Appliance's WAFL file systems take a different approach to file system consistency.
- No blocks of data are ever over-written in place. Rather the new data is written into fresh new blocks, and after the transaction is complete, the metadata (data block pointers) is updated to point to the new blocks.
  - The old blocks can then be freed up for future use.
  - Alternatively, if the old blocks and old metadata are saved, then a ***snapshot*** of the system in its original state is preserved. This approach is taken by WAFL.
- ZFS combines this with check-summing of all metadata and data blocks, and RAID, to ensure that no inconsistencies are possible, and therefore ZFS does not incorporate a consistency checker.

12.7.4 Backup and Restore

- In order to recover lost data in the event of a disk crash, it is important to conduct backups regularly.
- Files should be copied to some removable medium, such as magnetic tapes, CDs, DVDs, or external removable hard drives.
- A full backup copies every file on a filesystem.
- Incremental backups copy only files which have changed since some previous time.
- A combination of full and incremental backups can offer a compromise between full recoverability, the number and size of backup tapes needed, and the number of tapes that need to be used to do a full restore. For example, one strategy might be:
  - At the beginning of the month do a full backup.

    - At the end of the first and again at the end of the second week, backup all files which have changed since the beginning of the month.
    - At the end of the third week, backup all files that have changed since the end of the second week.
    - Every day of the month not listed above, do an incremental backup of all files that have changed since the most recent of the weekly backups described above.
- Backup tapes are often reused, particularly for daily backups, but there are limits to how many times the same tape can be used.
- Every so often a full backup should be made that is kept "forever" and not overwritten.
- ***Backup tapes should be tested, to ensure that they are readable!***
- For optimal security, backup tapes should be kept off-premises, so that a fire or burglary cannot destroy both the system and the backups. There are companies (e.g. Iron Mountain) that specialize in the secure off-site storage of critical backup information.
- ***Keep your backup tapes secure - The easiest way for a thief to steal all your data is to simply pocket your backup tapes!***
- Storing important files on more than one computer can be an alternate though less reliable form of backup.
- Note that incremental backups can also help users to get back a previous version of a file that they have since changed in some way.
- Beware that backups can help forensic investigators recover e-mails and other files that users had though they had deleted!

12.8 NFS (Optional)

12.8.1 Overview

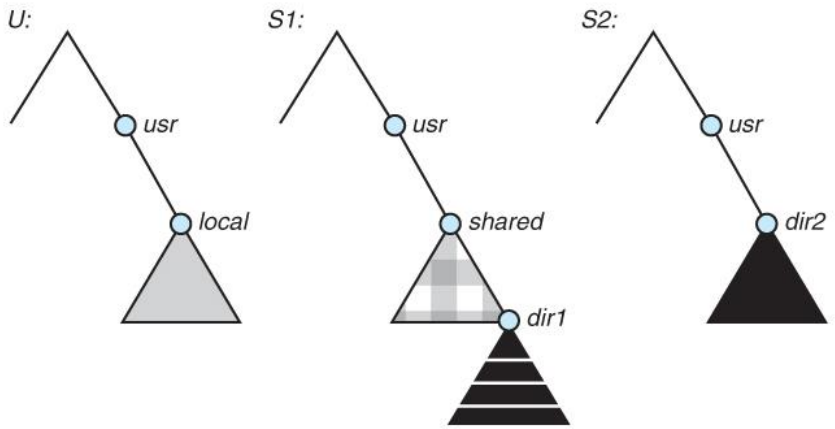


Figure 12.13 - Three independent file systems.

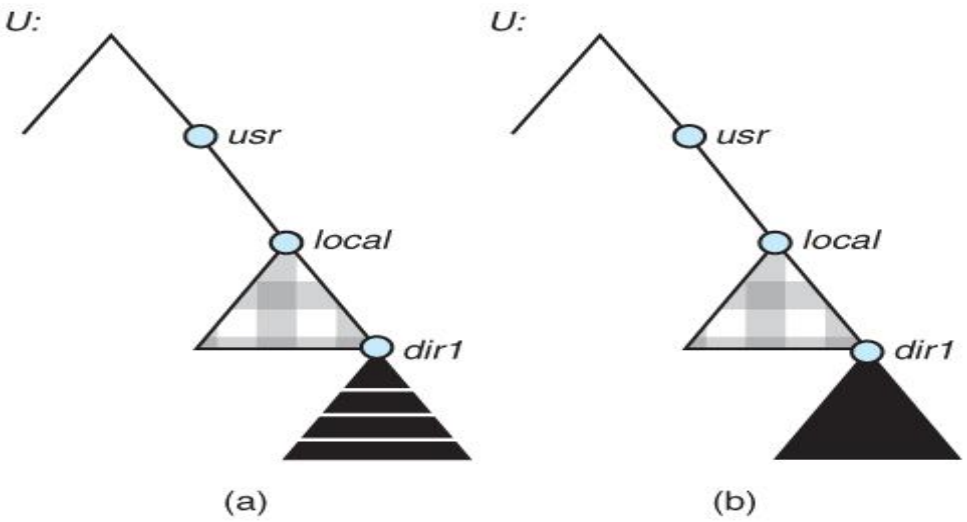


Figure 12.14 - Mounting in NFS. (a) Mounts. (b) Cascading mounts.

12.8.2 The Mount Protocol

- The NFS mount protocol is similar to the local mount protocol, establishing a connection between a specific local directory (the mount point) and a specific device from a remote system.
- Each server maintains an ***export list*** of the local filesystems (directory sub-trees) which are exportable, who they are exportable to, and what restrictions apply (e.g. read-only access.)
- The server also maintains a list of currently connected clients, so that they can be notified in the event of the server going down and for other reasons.
- Automount and autounmount are supported.

12.8.3 The NFS Protocol

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

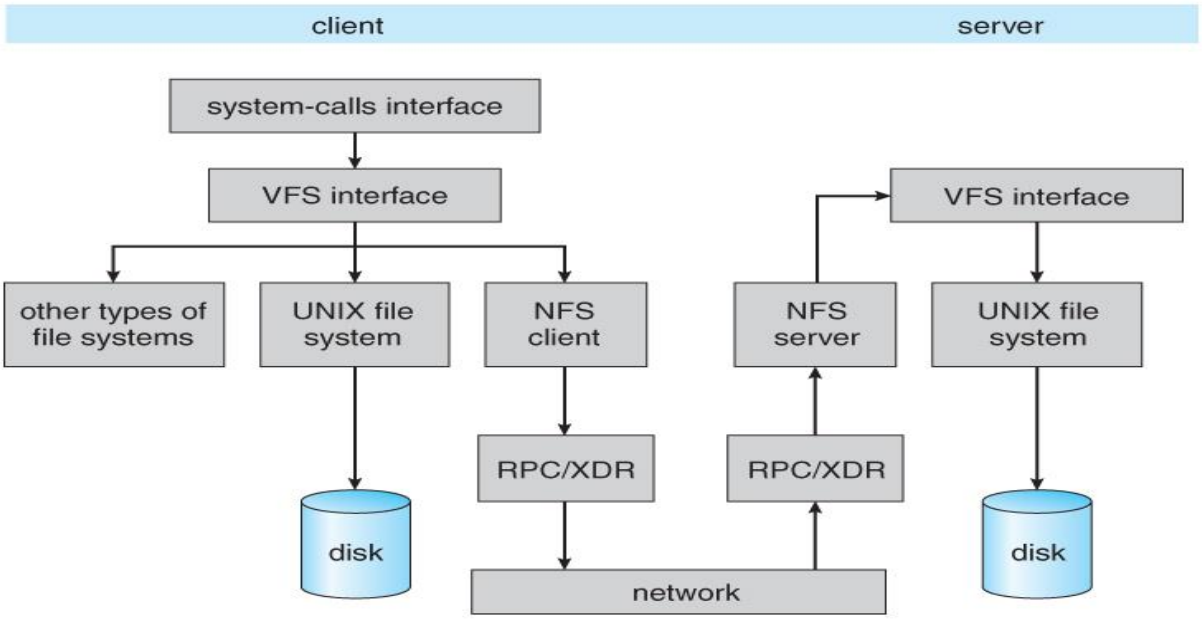


Figure 12.15 - Schematic view of the NFS architecture.

12.8.4 Path-Name Translation

11.8.5 Remote Operations

- Buffering and caching improve performance, but can cause a disparity in local versus remote views of the same file(s).

12.9 Example: The WAFL File System (Optional)

- Write Anywhere File Layout
- Designed for a specific hardware architecture.
- ***Snapshots*** record the state of the system at regular or irregular intervals.
  - The snapshot just copies the inode pointers, not the actual data.
  - Used pages are not overwritten, so updates are fast.
  - Blocks keep counters for how many snapshots are pointing to that block - When the counter reaches zero, then the block is considered free.

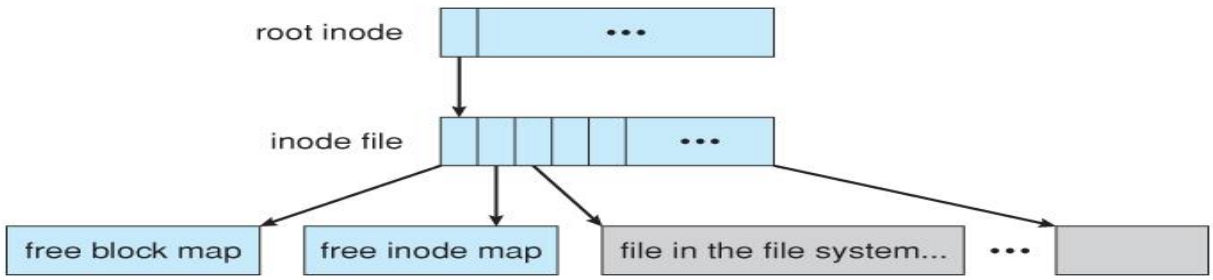
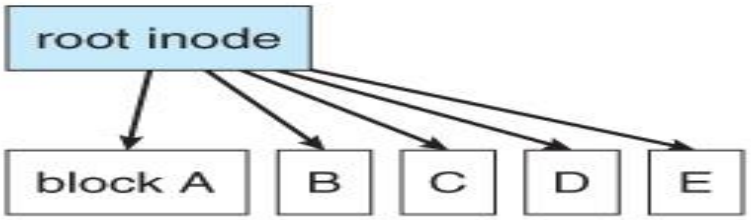
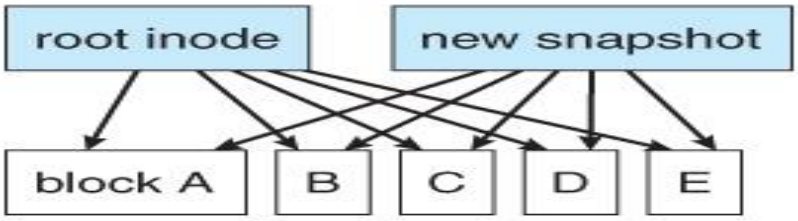


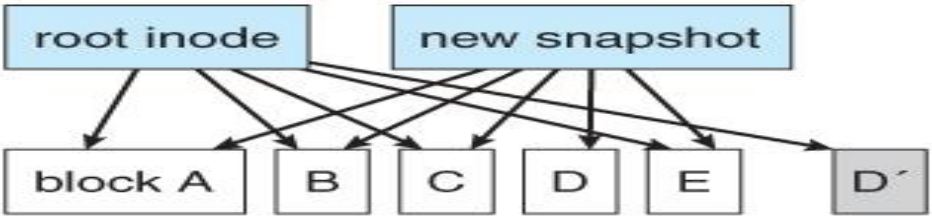
Figure 12.16 - The WAFL file layout.



(a) Before a snapshot.



(b) After a snapshot, before any blocks change.



(c) After block D has changed to D´.

Figure 12.17 - Snapshots in WAFL

Mass-Storage Structure

10.1 Overview of Mass-Storage Structure

10.1.1 Magnetic Disks

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

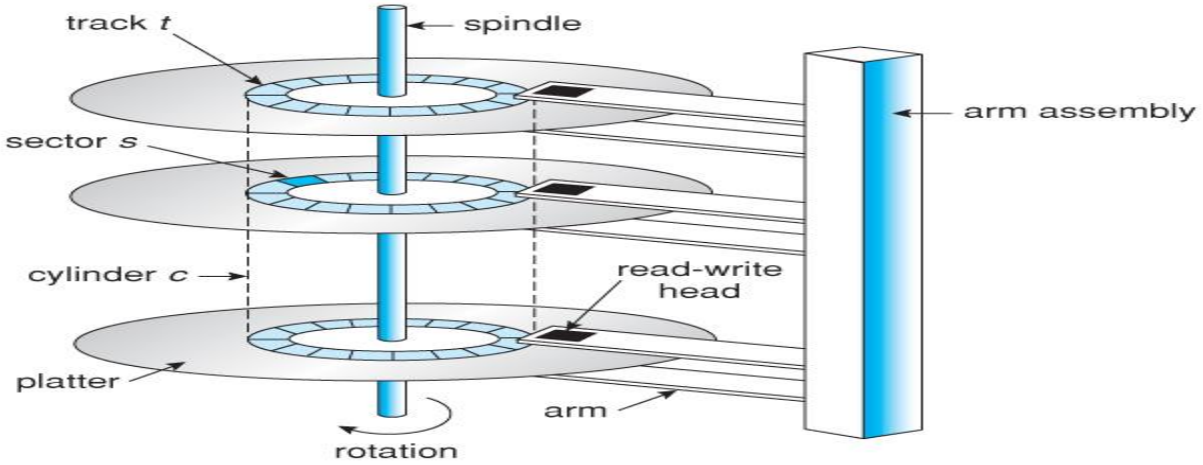


Figure 10.1 - Moving-head disk mechanism.

- In operation the disk rotates at high speed, such as 7200 rpm (120 revolutions per second.) The rate at which data can be transferred from the disk to the computer is composed of several steps:
    - The ***positioning time***, a.k.a. the ***seek time*** or ***random access time*** is the time required to move the heads from one cylinder to another, and for the heads to settle down after the move. This is typically the slowest step in the process and the predominant bottleneck to overall transfer rates.
    - The ***rotational latency*** is the amount of time required for the desired sector to rotate around and come under the read-write head.This can range anywhere from zero to one full revolution, and on the average will equal one-half revolution. This is another physical step and is usually the second slowest step behind seek time. (For a disk rotating at 7200 rpm, the average rotational latency would be 1/2 revolution / 120 revolutions per second, or just over 4 milliseconds, a long time by computer standards.
    - The ***transfer rate***, which is the time required to move the data electronically from the disk to the computer. (Some authors may also use the term transfer rate to refer to the overall transfer rate, including seek time and rotational latency as well as the electronic data transfer rate.)
- Disk heads "fly" over the surface on a very thin cushion of air. If they should accidentally contact the disk, then a ***head crash*** occurs, which may or may not permanently damage the disk or even destroy it completely. For this reason it is normal to ***park*** the disk heads when turning a computer off, which means to move the heads off the disk or to an area of the disk where there is no data stored.
- Floppy disks are normally ***removable***. Hard drives can also be removable, and some are even ***hot-swappable***, meaning they can be removed while the computer is running, and a new hard drive inserted in their place.

- Disk drives are connected to the computer via a cable known as the ***I/O Bus.*** Some of the common interface formats include Enhanced Integrated Drive Electronics, EIDE; Advanced Technology Attachment, ATA; Serial ATA, SATA, Universal Serial Bus, USB; Fiber Channel, FC, and Small Computer Systems Interface, SCSI.

- The ***host controller*** is at the computer end of the I/O bus, and the ***disk controller*** is built into the disk itself. The CPU issues commands to the host controller via I/O ports. Data is transferred between the magnetic surface and onboard ***cache*** by the disk controller, and then the data is transferred from that cache to the host controller and the motherboard memory at electronic speeds.

10.1.2 Solid-State Disks - New

- As technologies improve and economics change, old technologies are often used in different ways. One example of this is the increasing used of ***solid state disks, or SSDs.***

- SSDs use memory technology as a small fast hard disk. Specific implementations may use either flash memory or DRAM chips protected by a battery to sustain the information through power cycles.

- Because SSDs have no moving parts they are much faster than traditional hard drives, and certain problems such as the scheduling of disk accesses simply do not apply.

- However SSDs also have their weaknesses: They are more expensive than hard drives, generally not as large, and may have shorter life spans.

- SSDs are especially useful as a high-speed cache of hard-disk information that must be accessed quickly. One example is to store filesystem meta-data, e.g. directory and inode information, that must be accessed quickly and often. Another variation is a boot disk containing the OS and some application executables, but no vital user data. SSDs are also used in laptops to make them smaller, faster, and lighter.

- Because SSDs are so much faster than traditional hard disks, the throughput of the bus can become a limiting factor, causing some SSDs to be connected directly to the system PCI bus for example.

10.1.3 Magnetic Tapes - was 12.1.2

- Magnetic tapes were once used for common secondary storage before the days of hard disk drives, but today are used primarily for backups.

- Accessing a particular spot on a magnetic tape can be slow, but once reading or writing commences, access speeds are comparable to disk drives.

- Capacities of tape drives can range from 20 to 200 GB, and compression can double that capacity.

10.2 Disk Structure

- The traditional head-sector-cylinder, HSC numbers are mapped to linear block addresses by numbering the first sector on the first head on the outermost track as sector 0. Numbering proceeds with the rest of the sectors on that same track, and then the rest of the tracks on the same cylinder before proceeding through the rest of the cylinders to the center of the disk. In modern practice these linear block addresses are used in place of the HSC numbers for a variety of reasons:

    1. The linear length of tracks near the outer edge of the disk is much longer than for those tracks located near the center, and therefore it is possible to squeeze many more sectors onto outer tracks than onto inner ones.

    2. All disks have some bad sectors, and therefore disks maintain a few spare sectors that can be used in place of the bad ones. The mapping of spare sectors to bad sectors in managed internally to the disk controller.

    3. Modern hard drives can have thousands of cylinders, and hundreds of sectors per track on their outermost tracks. These numbers exceed the range of HSC numbers for many (older) operating systems, and therefore disks can be configured for any convenient combination of HSC values that falls within the total number of sectors physically on the drive.

- There is a limit to how closely packed individual bits can be placed on a physical media, but that limit is growing increasingly more packed as technological advances are made.

- Modern disks pack many more sectors into outer cylinders than inner ones, using one of two approaches:

    - With ***Constant Linear Velocity, CLV,*** the density of bits is uniform from cylinder to cylinder. Because there are more sectors in outer cylinders, the disk spins slower when reading those cylinders, causing the rate of bits passing under the read-write head to remain constant. This is the approach used by modern CDs and DVDs.

    - With ***Constant Angular Velocity, CAV,*** the disk rotates at a constant angular speed, with the bit density decreasing on outer cylinders. (These disks would have a constant number of sectors per track on all cylinders.)

10.3 Disk Attachment

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

10.3.1 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.
- 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.)

10.3.2 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.

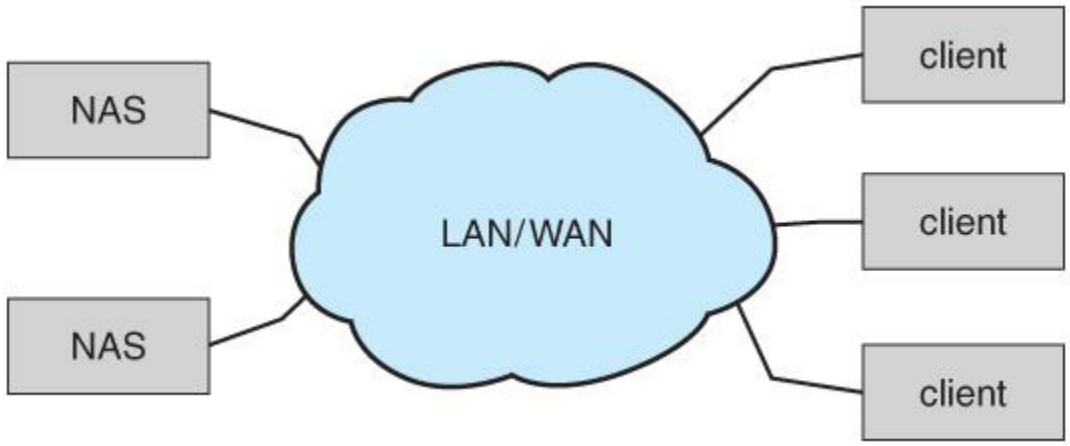


Figure 10.2 - Network-attached storage.

10.3.3 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.

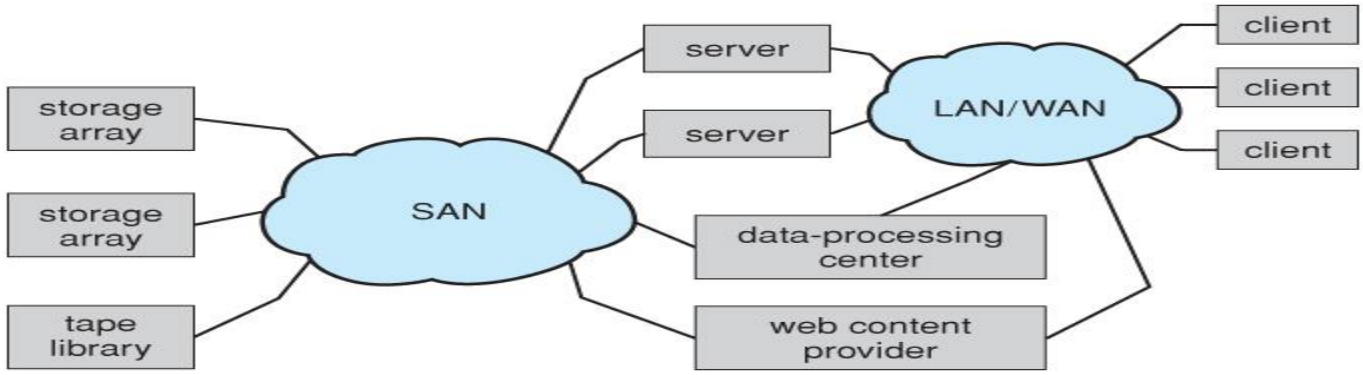


Figure 10.3 - Storage-area network.

10.4 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.

10.4.1 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:

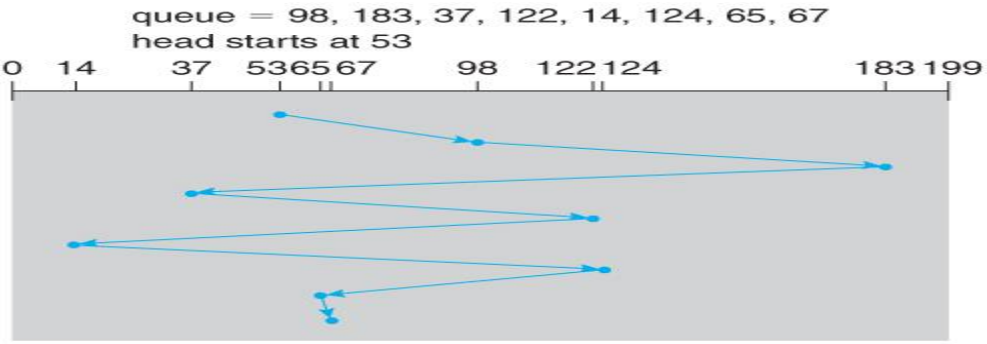


Figure 10.4 - FCFS disk scheduling.

10.4.2 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.

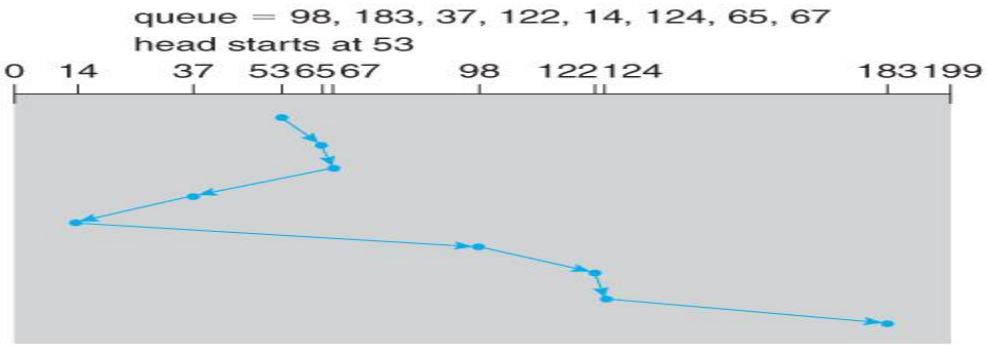


Figure 10.5 - SSTF disk scheduling.

10.4.3 SCAN Scheduling

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

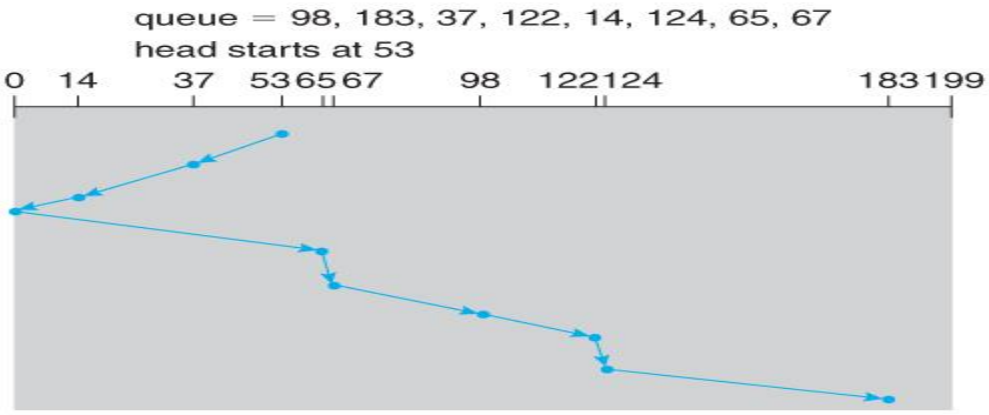


Figure 10.6 - SCAN disk scheduling.

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

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

10.4.4 C-SCAN Scheduling

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

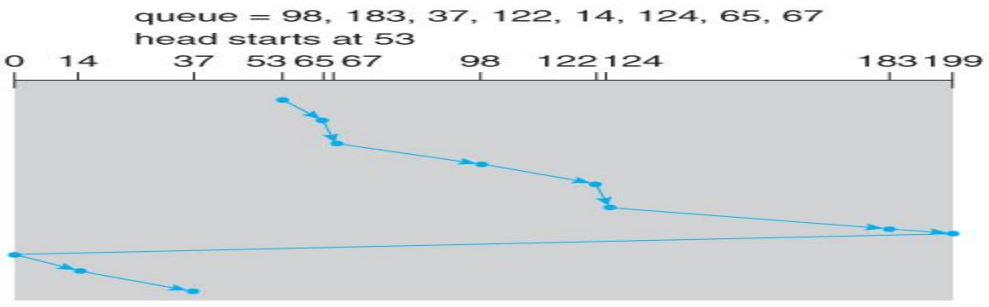


Figure 10.7 - C-SCAN disk scheduling.

12.4.5 LOOK Scheduling

- ***LOOK*** scheduling improves upon SCAN by looking ahead at the queue of pending requests, and not moving the heads any farther towards the end of the disk than is necessary. The following diagram illustrates the circular form of LOOK:

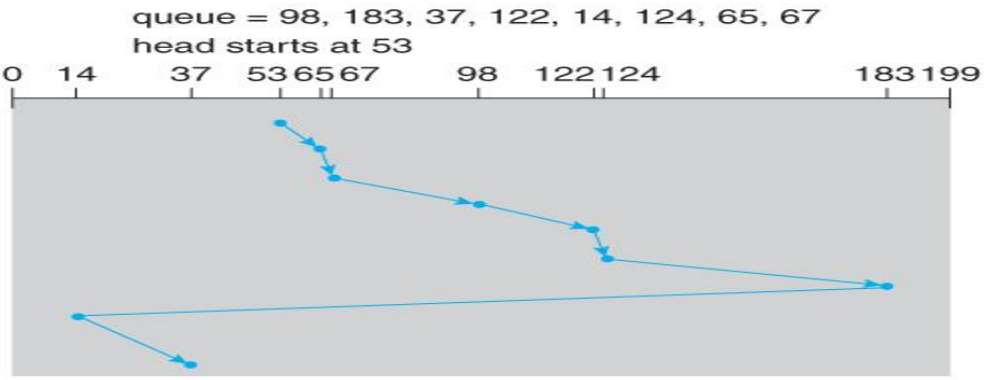


Figure 10.8 - C-LOOK disk scheduling.

10.4.6 Selection of a Disk-Scheduling Algorithm

- With very low loads all algorithms are equal, since there will normally only be one request to process at a time.
- For slightly larger loads, SSTF offers better performance than FCFS, but may lead to starvation when loads become heavy enough.
- For busier systems, SCAN and LOOK algorithms eliminate starvation problems.
- The actual optimal algorithm may be something even more complex than those discussed here, but the incremental improvements are generally not worth the additional overhead.
- Some improvement to overall filesystem access times can be made by intelligent placement of directory and/or inode information. If those structures are placed in the middle of the disk instead of at the beginning of the disk, then the maximum distance from those structures to data blocks is reduced to only one-half of the disk size. If those structures can be further distributed and furthermore have their data blocks stored as close as possible to the corresponding directory structures, then that reduces still further the overall time to find the disk block numbers and then access the corresponding data blocks.
- On modern disks the rotational latency can be almost as significant as the seek time, however it is not within the OSes control to account for that, because modern disks do not reveal their internal sector mapping schemes, (particularly when bad blocks have been remapped to spare sectors.)

- Some disk manufacturers provide for disk scheduling algorithms directly on their disk controllers, (which do know the actual geometry of the disk as well as any remapping), so that if a series of requests are sent from the computer to the controller then those requests can be processed in an optimal order.

- Unfortunately there are some considerations that the OS must take into account that are beyond the abilities of the on-board disk-scheduling algorithms, such as priorities of some requests over others, or the need to process certain requests in a particular order. For this reason OSes may elect to spoon-feed requests to the disk controller one at a time in certain situations.

10.7 RAID Structure

- The general idea behind RAID is to employ a group of hard drives together with some form of duplication, either to increase reliability or to speed up operations, (or sometimes both.)

- ***RAID*** originally stood for ***Redundant Array of Inexpensive Disks,*** and was designed to use a bunch of cheap small disks in place of one or two larger more expensive ones. Today RAID systems employ large possibly expensive disks as their components, switching the definition to ***Independent*** disks.

10.7.1 Improvement of Reliability via Redundancy

- The more disks a system has, the greater the likelihood that one of them will go bad at any given time. Hence increasing disks on a system actually ***decreases*** the **Mean Time To Failure, MTTF** of the system.

- If, however, the same data was copied onto multiple disks, then the data would not be lost unless **both** (or all) copies of the data were damaged simultaneously, which is a **MUCH** lower probability than for a single disk going bad. More specifically, the second disk would have to go bad before the first disk was repaired, which brings the **Mean Time To Repair** into play. For example if two disks were involved, each with a MTTF of 100,000 hours and a MTTR of 10 hours, then the **Mean Time to Data Loss** would be 500 * 10^6 hours, or 57,000 years!

- This is the basic idea behind disk ***mirroring***, in which a system contains identical data on two or more disks.

    - Note that a power failure during a write operation could cause both disks to contain corrupt data, if both disks were writing simultaneously at the time of the power failure. One solution is to write to the two disks in series, so that they will not both become corrupted (at least not in the same way) by a power failure. And alternate solution involves non-volatile RAM as a write cache, which is not lost in the event of a power failure and which is protected by error-correcting codes.

10.7.2 Improvement in Performance via Parallelism

- There is also a performance benefit to mirroring, particularly with respect to reads. Since every block of data is duplicated on multiple disks, read operations can be satisfied from any available copy, and multiple disks can be reading different data blocks simultaneously in parallel. (Writes could possibly be sped up as well through careful scheduling algorithms, but it would be complicated in practice.)

- Another way of improving disk access time is with ***striping***, which basically means spreading data out across multiple disks that can be accessed simultaneously.

    - With ***bit-level striping*** the bits of each byte are striped across multiple disks. For example if 8 disks were involved, then each 8-bit byte would be read in parallel by 8 heads on separate disks. A single disk read would access 8 * 512 bytes = 4K worth of data in the time normally required to read 512 bytes. Similarly if 4 disks were involved, then two bits of each byte could be stored on each disk, for 2K worth of disk access per read or write operation.

    - ***Block-level striping*** spreads a filesystem across multiple disks on a block-by-block basis, so if block N were located on disk 0, then block N + 1 would be on disk 1, and so on. This is particularly useful when filesystems are accessed in ***clusters*** of physical blocks. Other striping possibilities exist, with block-level striping being the most common.

10.7.3 RAID Levels

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

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

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

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

    4. ***Raid Level 3 -*** This level is similar to level 2, except that it takes advantage of the fact that each disk is still doing its own error-detection, so that when an error occurs, there is no question about which disk in the array has the bad data. As a result a single parity bit is all that is needed to recover the lost data from an array of disks. Level 3 also includes striping, which improves performance. The downside with the parity approach

is that every disk must take part in every disk access, and the parity bits must be constantly calculated and checked, reducing performance. Hardware-level parity calculations and NVRAM cache can help with both of those issues. In practice level 3 is greatly preferred over level 2.

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

6. ***Raid Level 5 -*** This level is similar to level 4, except the parity blocks are distributed over all disks, thereby more evenly balancing the load on the system. For any given block on the disk(s), one of the disks will hold the parity information for that block and the other N-1 disks will hold the data. Note that the same disk cannot hold both data and parity for the same block, as both would be lost in the event of a disk crash.

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

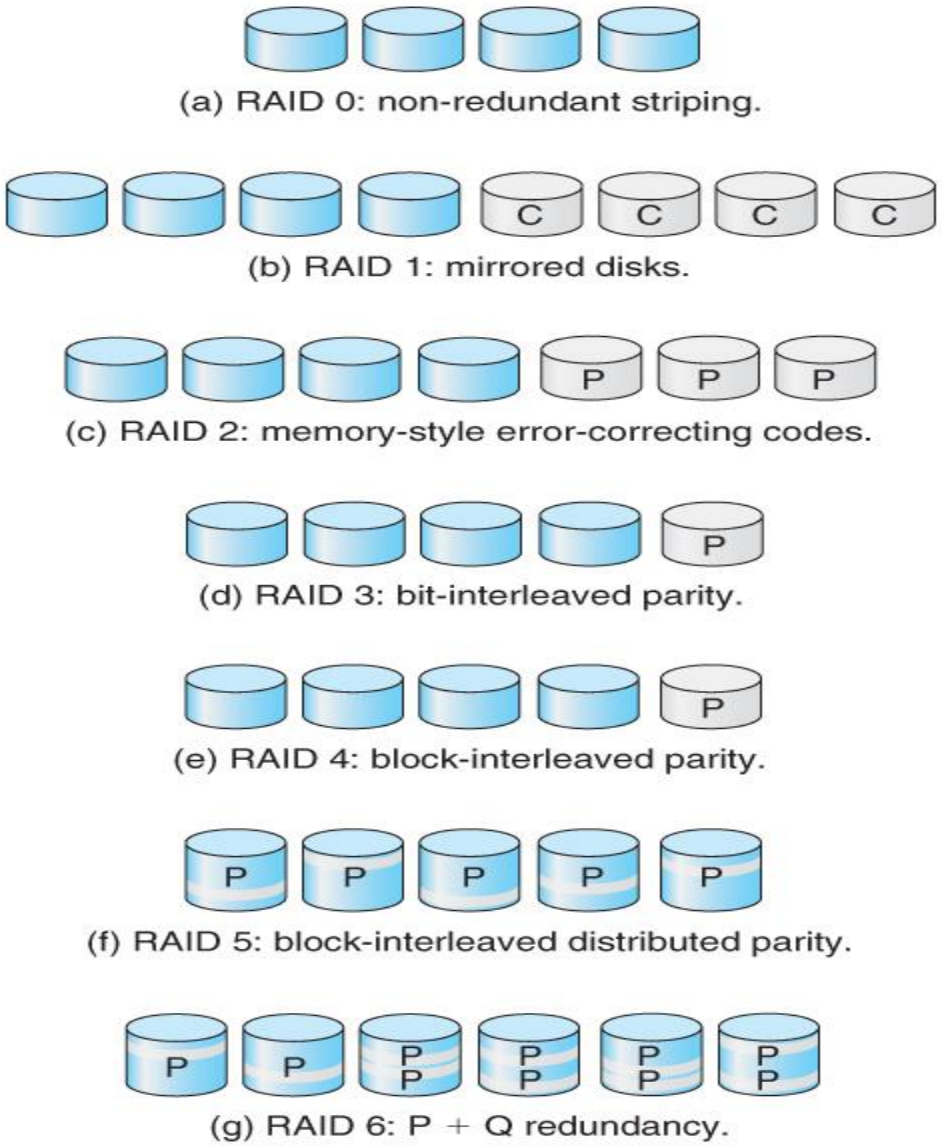


Figure 10.11 - RAID levels.

- There are also two RAID levels which combine RAID levels 0 and 1 (striping and mirroring) in different combinations, designed to provide both performance and reliability at the expense of increased cost.
    - **RAID level 0 + 1** disks are first striped, and then the striped disks mirrored to another set. This level generally provides better performance than RAID level 5.
    - **RAID level 1 + 0** mirrors disks in pairs, and then stripes the mirrored pairs. The storage capacity, performance, etc. are all the same, but there is an advantage to this approach in the event of multiple disk failures, as illustrated below:.
        - In diagram (a) below, the 8 disks have been divided into two sets of four, each of which is striped, and then one stripe set is used to mirror the other set.

- If a single disk fails, it wipes out the entire stripe set, but the system can keep on functioning using the remaining set.
- However if a second disk from the other stripe set now fails, then the entire system is lost, as a result of two disk failures.

- In diagram (b), the same 8 disks are divided into four sets of two, each of which is mirrored, and then the file system is striped across the four sets of mirrored disks.
  - If a single disk fails, then that mirror set is reduced to a single disk, but the system rolls on, and the other three mirror sets continue mirroring.
  - Now if a second disk fails, (that is not the mirror of the already failed disk), then another one of the mirror sets is reduced to a single disk, but the system can continue without data loss.
  - In fact the second arrangement could handle as many as four simultaneously failed disks, as long as no two of them were from the same mirror pair.

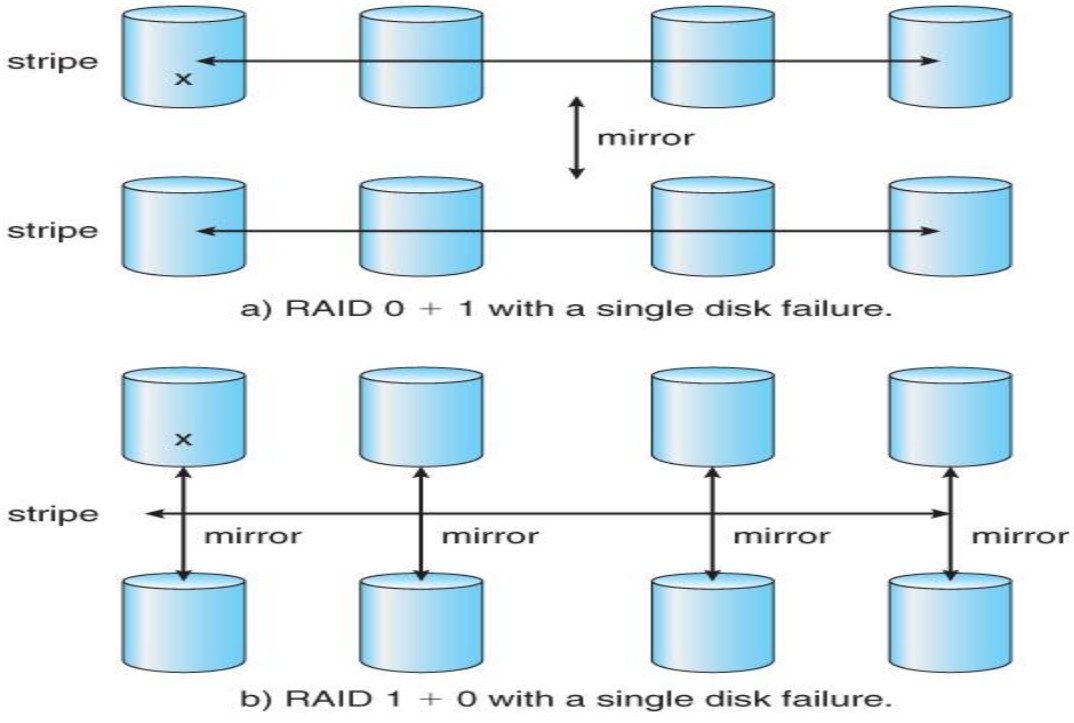


Figure 10.12 - RAID 0 + 1 and 1 + 0

10.7.4 Selecting a RAID Level

- Trade-offs in selecting the optimal RAID level for a particular application include cost, volume of data, need for reliability, need for performance, and rebuild time, the latter of which can affect the likelihood that a second disk will fail while the first failed disk is being rebuilt.

- Other decisions include how many disks are involved in a RAID set and how many disks to protect with a single parity bit. More disks in the set increases performance but increases cost. Protecting more disks per parity bit saves cost, but increases the likelihood that a second disk will fail before the first bad disk is repaired.

10.7.5 Extensions

- RAID concepts have been extended to tape drives (e.g. striping tapes for faster backups or parity checking tapes for reliability), and for broadcasting of data.

10.7.6 Problems with RAID

- RAID protects against physical errors, but not against any number of bugs or other errors that could write erroneous data.

- ZFS adds an extra level of protection by including data block checksums in all inodes along with the pointers to the data blocks. If data are mirrored and one copy has the correct checksum and the other does not, then the data with the bad checksum will be replaced with a copy of the data with the good checksum. This increases reliability greatly over RAID alone, at a cost of a performance hit that is acceptable because ZFS is so fast to begin with.

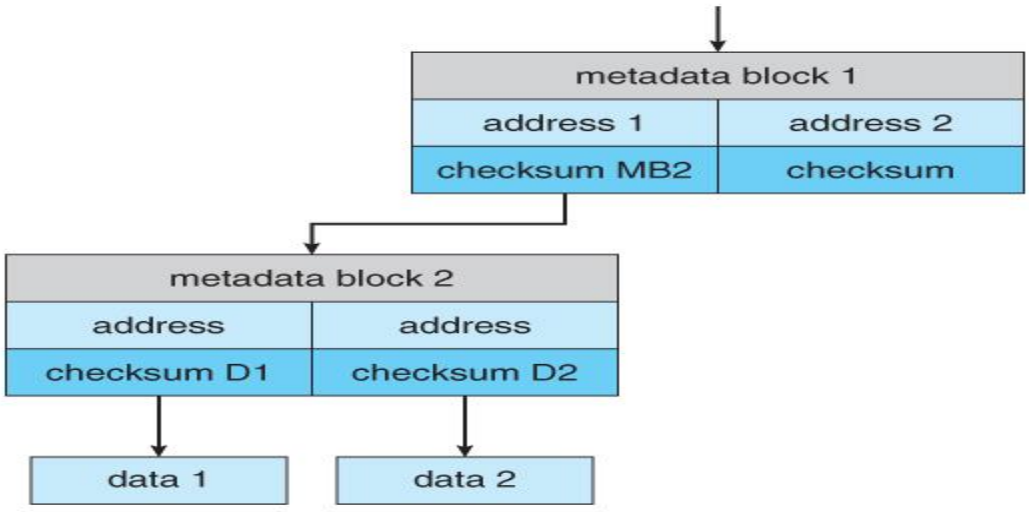


Figure 10.13 - ZFS checksums all metadata and data.

- Another problem with traditional filesystems is that the sizes are fixed, and relatively difficult to change. Where RAID sets are involved it becomes even harder to adjust filesystem sizes, because a filesystem cannot span across multiple filesystems.

- ZFS solves these problems by pooling RAID sets, and by dynamically allocating space to filesystems as needed. Filesystem sizes can be limited by quotas, and space can also be reserved to guarantee that a filesystem will be able to grow later, but these parameters can be changed at any time by the filesystem's owner. Otherwise filesystems grow and shrink dynamically as needed.

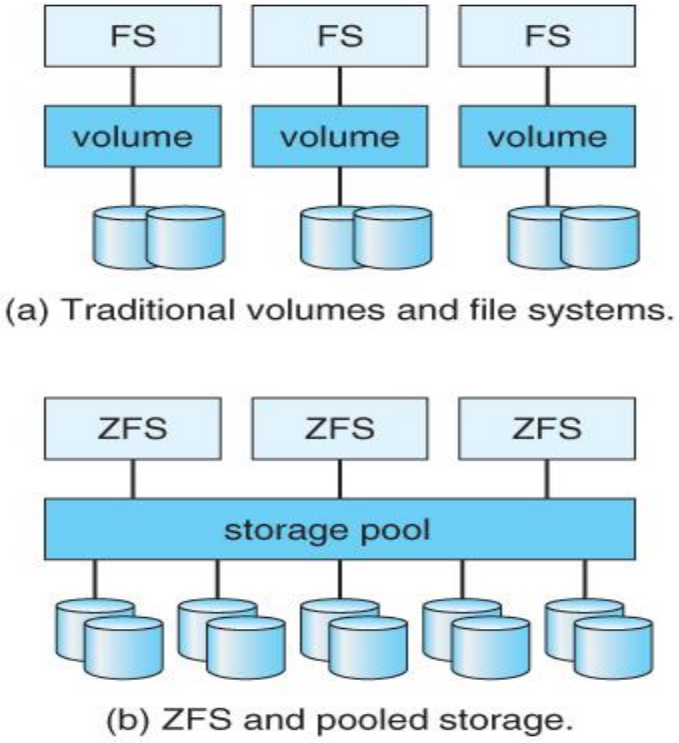


Figure 10.14 - (a) Traditional volumes and file systems. (b) a ZFS pool and file systems.

10.8 Stable-Storage Implementation (Optional)

- The concept of stable storage (first presented in chapter 6) involves a storage medium in which data is ***never*** lost, even in the face of equipment failure in the middle of a write operation.
- To implement this requires two (or more) copies of the data, with separate failure modes.
- An attempted disk write results in one of three possible outcomes:
    1. The data is successfully and completely written.
    2. The data is partially written, but not completely. The last block written may be garbled.
    3. No writing takes place at all.
- Whenever an equipment failure occurs during a write, the system must detect it, and return the system back to a consistent state. To do this requires two physical blocks for every logical block, and the following procedure:

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

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

Operating Systems
UNIT – V

UNIT -V

System Protection: Goals of protection, Principles and domain of protection, Access matrix, Access control, Revocation of access rights.

System Security: Introduction, Program threats, System and network threats, Cryptography for security, User authentication, Implementing security defenses, Firewalling to protect systems and networks, Computer security classification.

Case Studies: Linux, Microsoft Windows.

System Protection

Protection refers to a mechanism which controls the access of programs, processes, or users to the resources defined by a computer system.

Need of Protection:

- To prevent the access of unauthorized users
- To ensure that each active programs or processes in the system.
- To improve reliability by detecting errors.

Goals of Protection

- prevent malicious misuse of the system by users or programs.
- To ensure that each shared resource is used only in accordance with system *policies*.
- To ensure that errant programs cause the minimal amount of damage possible.
- protection systems only provide the *mechanisms* for enforcing policies and ensuring reliable systems.

Principles of Protection

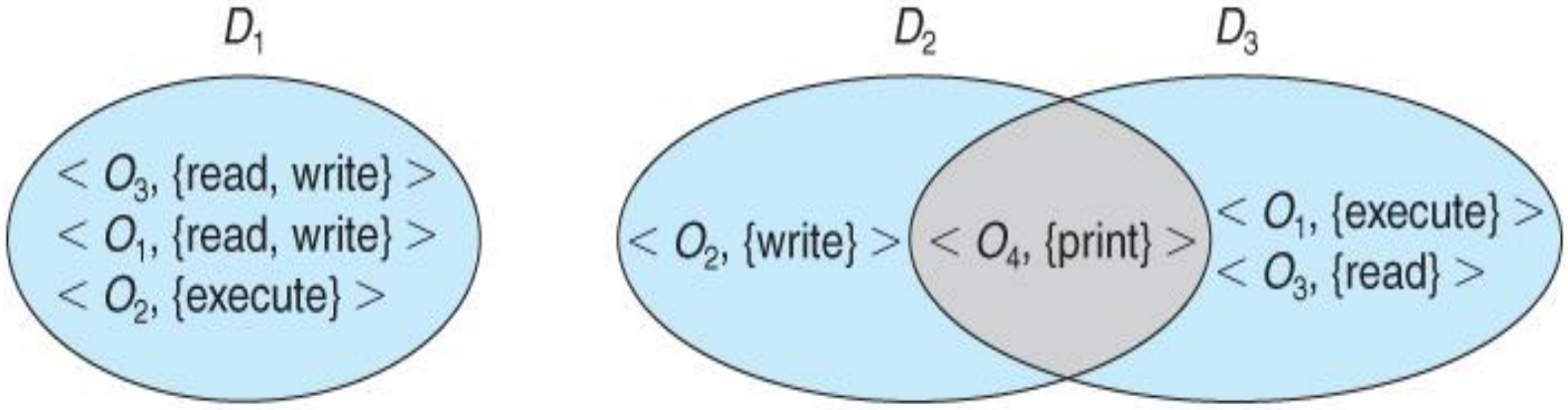
- The ***principle of least privilege*** dictates that programs, users, and systems be given just enough privileges to perform their tasks.
- This ensures that failures do the least amount of harm and allow the least of harm to be done.
- For example, if **a program needs special privileges to perform a task, it is better to make it a SGID program with group ownership of "network" or "backup".**
- 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 .

Domain of Protection

- A computer can be viewed as a collection of *processes* and *objects* (both HW & SW).

Domain Structure

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.



Access Matrix

- The model of protection that 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	

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

object / domain	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			

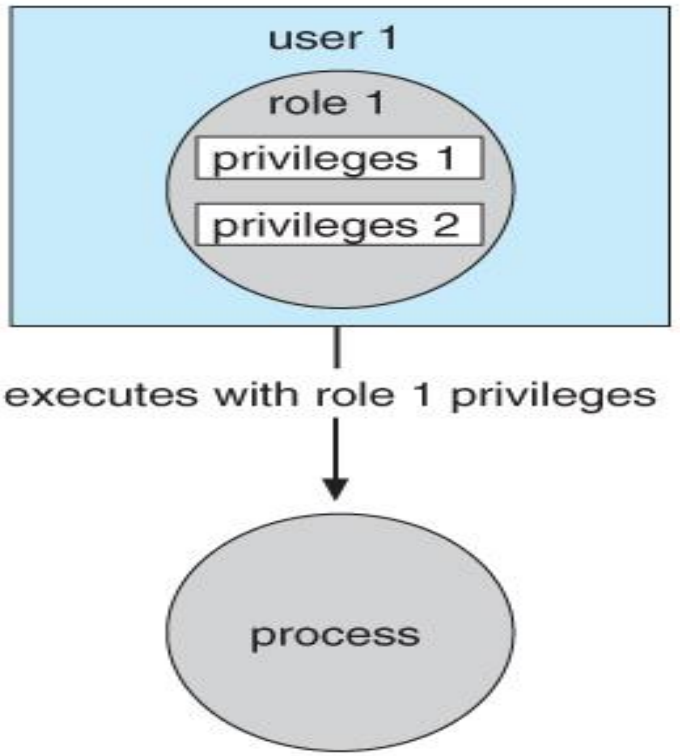
Implementation of Access Matrix

- Global Table
- Access Lists for Objects
- Capability Lists for Domains
- A Lock-Key Mechanism
- Comparison

Access Control

- *Role-Based Access Control*, ***RBAC,*** assigns privileges to users, programs. where "privileges" refer to the right to call certain system calls, or to use certain parameters with those calls.

Role-based access control in Solaris 10



Revocation of Access Rights

The need to revoke access rights dynamically raises several questions:

- Immediate versus delayed
- Selective versus general
- Partial versus total
- Temporary versus permanent

System Security

Security refers to providing a protection system to computer system resources such as **CPU, memory, disk, software programs and most importantly data/information stored in the computer system.**

- Authentication
- One Time passwords

Program Threats

If a user program made these process do malicious tasks, then it is known as **Program Threats**.

example of program threat is a program installed in a computer which can store and send user credentials via network to some hacker.

- **Trojan Horse** program traps ***user login credentials and stores them to send to malicious user.***
- **Trap Door** ***perform illegal action without knowledge of user.***
- **Logic Bomb** when a ***program misbehaves only when certain conditions*** met otherwise it works as a genuine program.
- **Virus** replicate themselves on computer system. They ***are highly dangerous and can modify/delete user files, crash systems.***

System AND Network Threats

System and network threats refers to misuse of system services and network connections to put user in trouble.

System threats can be used to launch program threats on a complete network called as program attack.

- **Worm** – A Worm process ***generates its multiple copies where each copy uses system resources***, prevents all other processes to get required resources. Worms processes can even shut down an entire network.
- **Port Scanning** – Port scanning is a mechanism or means by which a *hacker can detects system vulnerabilities to make an attack on the system.*
- **Denial of Service** – Denial of service attacks normally prevents user to make legitimate use of the system. For example, a *user may not be able to use internet if denial of service attacks browser's content settings.*

Computer Security Classifications

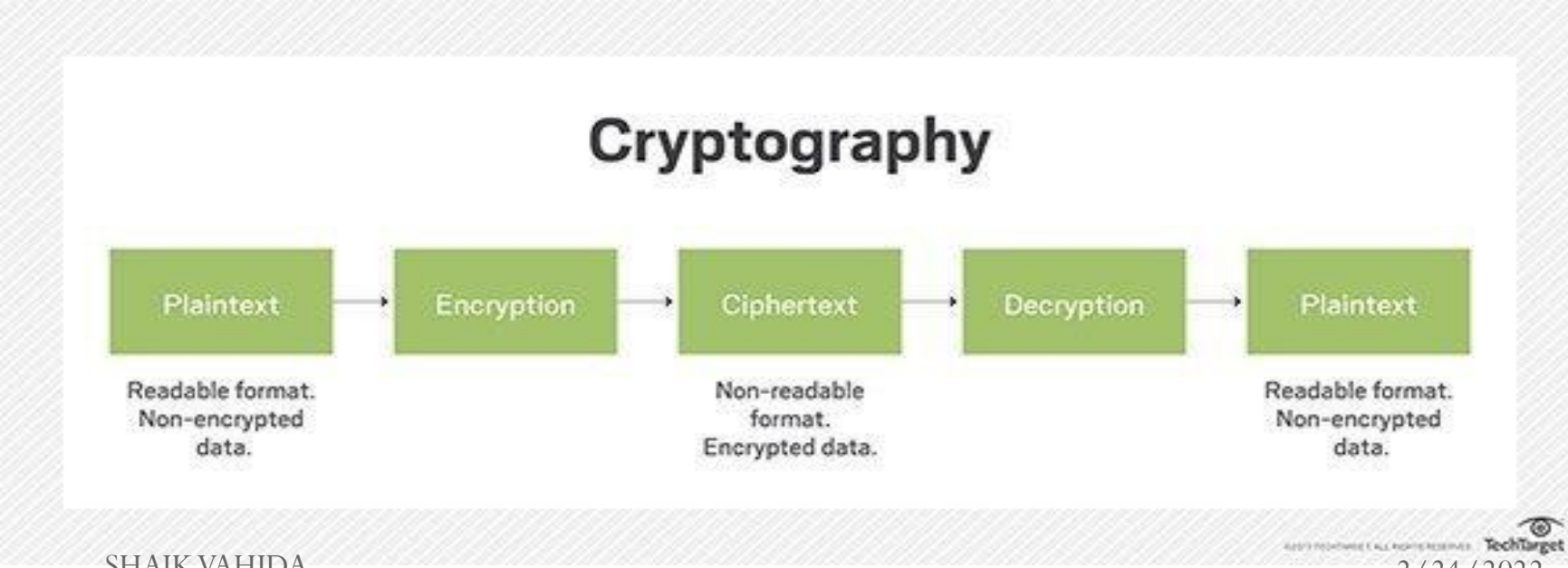
- As per the U.S. Department of Defence Trusted Computer System's Evaluation Criteria there are *four security classifications in computer systems: A, B, C, and D.*

S.N.	Classification Type & Description
1	**Type A** Highest Level. Uses formal design specifications and verification techniques. Grants a high degree of assurance of process security.
2	**Type B** Provides mandatory protection system. Have all the properties of a class C2 system. Attaches a sensitivity label to each object. It is of three types. ▫ **B1** – Maintains the security label of each object in the system. Label is used for making decisions to access control. ▫ **B2** – Extends the sensitivity labels to each system resource, such as storage objects, supports covert channels and auditing of events. ▫ **B3** – Allows creating lists or user groups for access-control to grant access or revoke access to a given named object.
3	**Type C** Provides protection and user accountability using audit capabilities. It is of two types. ▫ **C1** – Incorporates controls so that users can protect their private information and keep other users from accidentally reading / deleting their data. UNIX versions are mostly Cl class. ▫ **C2** – Adds an individual-level access control to the capabilities of a Cl level system.
4	**Type D** Lowest level. Minimum protection. MS-DOS, Window 3.1 fall in this category.

Cryptography for security

Cryptography is technique of securing information and communications through use of codes, so that only those person for whom the information is intended can understand it and process it.

Thus preventing unauthorized access to information.



Features Of Cryptography are as follows:

- **Confidentiality:**
  Information can only be accessed by the person for whom it is intended and no other person except him can access it.
- **Integrity:**
  Information cannot be modified in storage or transition between sender and intended receiver.
- **Non-repudiation:**
  The sender of information *cannot deny his intention to send information at later stage*.
- **Authentication:**
  The identities of sender and receiver are confirmed. As well as destination/origin of information is confirmed.

Types Of Cryptography:

In general there are three types Of cryptography:

1. **Symmetric Key Cryptography**
2. **Hash Functions**
3. **Asymmetric Key Cryptography**

- **Symmetric Key Cryptography:**
  It is an encryption system where the sender and receiver of message use a single common key to encrypt and decrypt messages.

Symmetric Key Systems are faster and simpler.

- **Hash Functions:**
  There is no usage of any key in this algorithm.

A hash value with fixed length is calculated as per the plain text which makes it impossible for contents of plain text to be recovered.

Many operating systems use hash functions to encrypt passwords.

- **Asymmetric Key Cryptography:** Under this system a pair of keys is used to encrypt and decrypt information.

A public key is used for encryption and a private key is used for decryption.

Public key and Private Key are different.

User authentication

- User authentication process is used to identify who the owner is or who the identified person is.
- In personal computer, generally, user authentication can be perform using **password**.

User can be authenticated through one of the following way:

- User authentication **using password**
- User authentication **using physical object**
- User authentication **using biometric**
- User authentication **using countermeasures**

User authentication **using password**

- Password should be minimum of eight characters
- Password should contain both uppercase and lowercase letters
- Password should contain at least one digit and one special characters
- Don't use dictionary words and known name such as stick, mouth, sun, albert etc.

User authentication **using physical object**

Here, physical object may refer to Bank's Automated Teller Machine (ATM) card or any other plastic card that is used to authenticate.

User authentication **using biometric**

- This method measures the physical characteristics of the user that are very hard to forge. These are called as biometrics.
- User authentication using biometric's example is a fingerprint, voiceprint, or retina scan reader in the terminal could verify the identity of the user.

User authentication **using countermeasures**

- For example, a company could have their policy that the employee working in the Computer Science (CS) department are only allowed to log in from 10 A.M. to 4 P.M., Monday to Saturday, and then only from a machine in the CS department connected to company's Local Area Network (LAN).
- Now, any attempt to log in by a CS department employee at any wrong time or from any wrong place would be treated or handled as an attempted break in and log in failure.