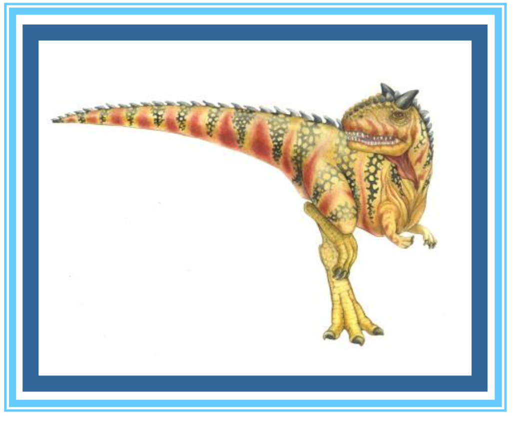
Module 1.2:
Operating-System Structures



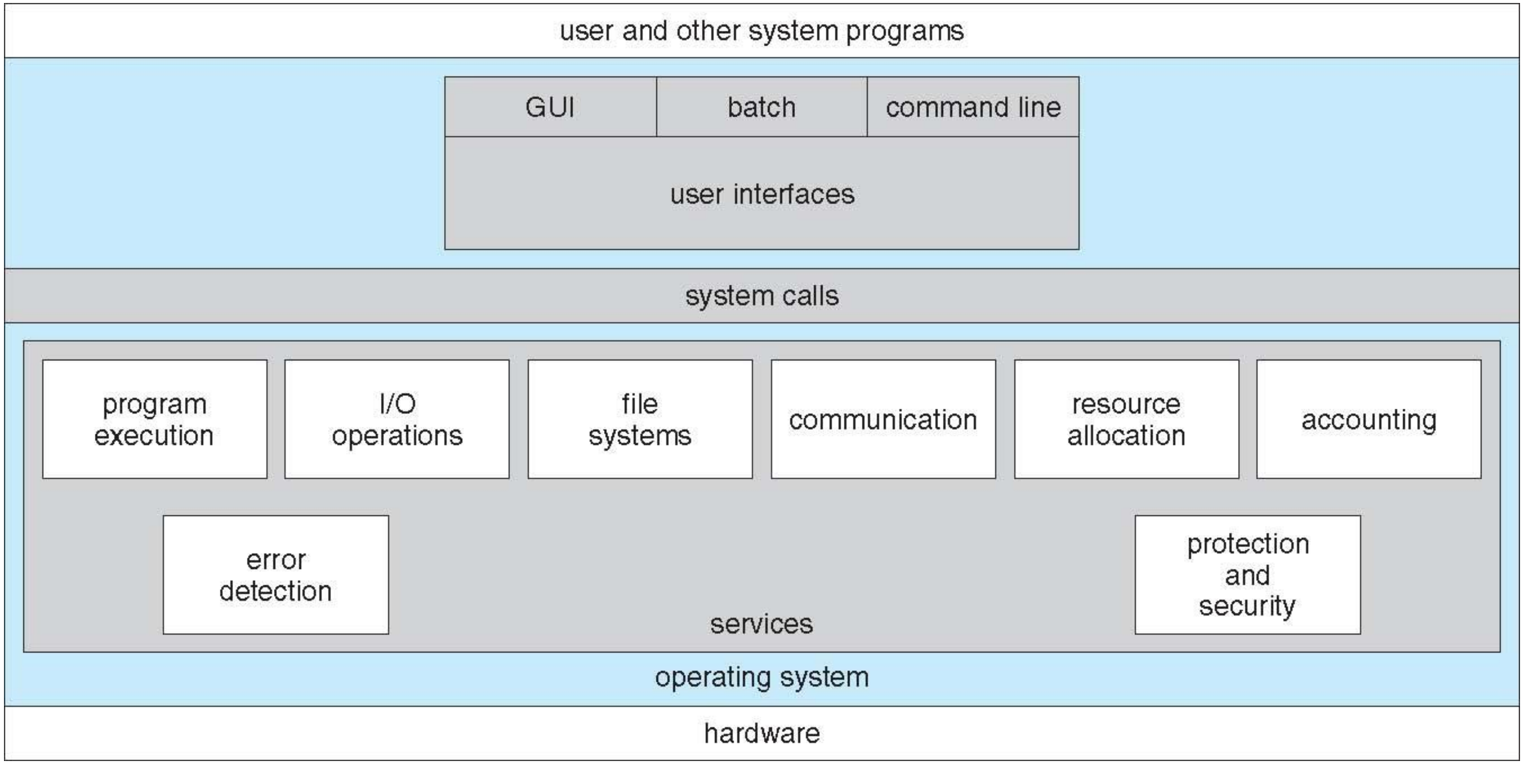
Chapter 2: Operating-System Structures

- Operating System Services
- User Operating System Interface
- System Calls
- Types of System Calls
- System Programs
- Operating System Design and Implementation
- Operating System Structure
- Operating System Debugging
- Operating System Generation
- System Boot

Objectives

- To describe the services an operating system provides to users, processes, and other systems
- To discuss the various ways of structuring an operating system
- To explain how operating systems are installed and customized and how they boot

A View of Operating System Services



Operating System Services

- Operating systems provide an environment for execution of programs and services to programs and users
- One set of operating-system services provides functions that are helpful to the user:
  - **User interface** - Almost all operating systems have a user interface (**UI**).
    - Varies between **Command-Line** **(CLI)**, **Graphics User Interface** **(GUI)**, **Batch**
  - **Program execution** - The system must be able to load a program into memory and to run that program, end execution, either normally or abnormally (indicating error)
  - **I/O operations** - A running program may require I/O, which may involve a file or an I/O device

Operating System Services (Cont.)

- One set of operating-system services provides functions that are helpful to the user (Cont.):
  - **File-system manipulation** - The file system is of particular interest. Programs need to read and write files and directories, create and delete them, search them, list file Information, permission management.
  - **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

Operating System Services (Cont.)

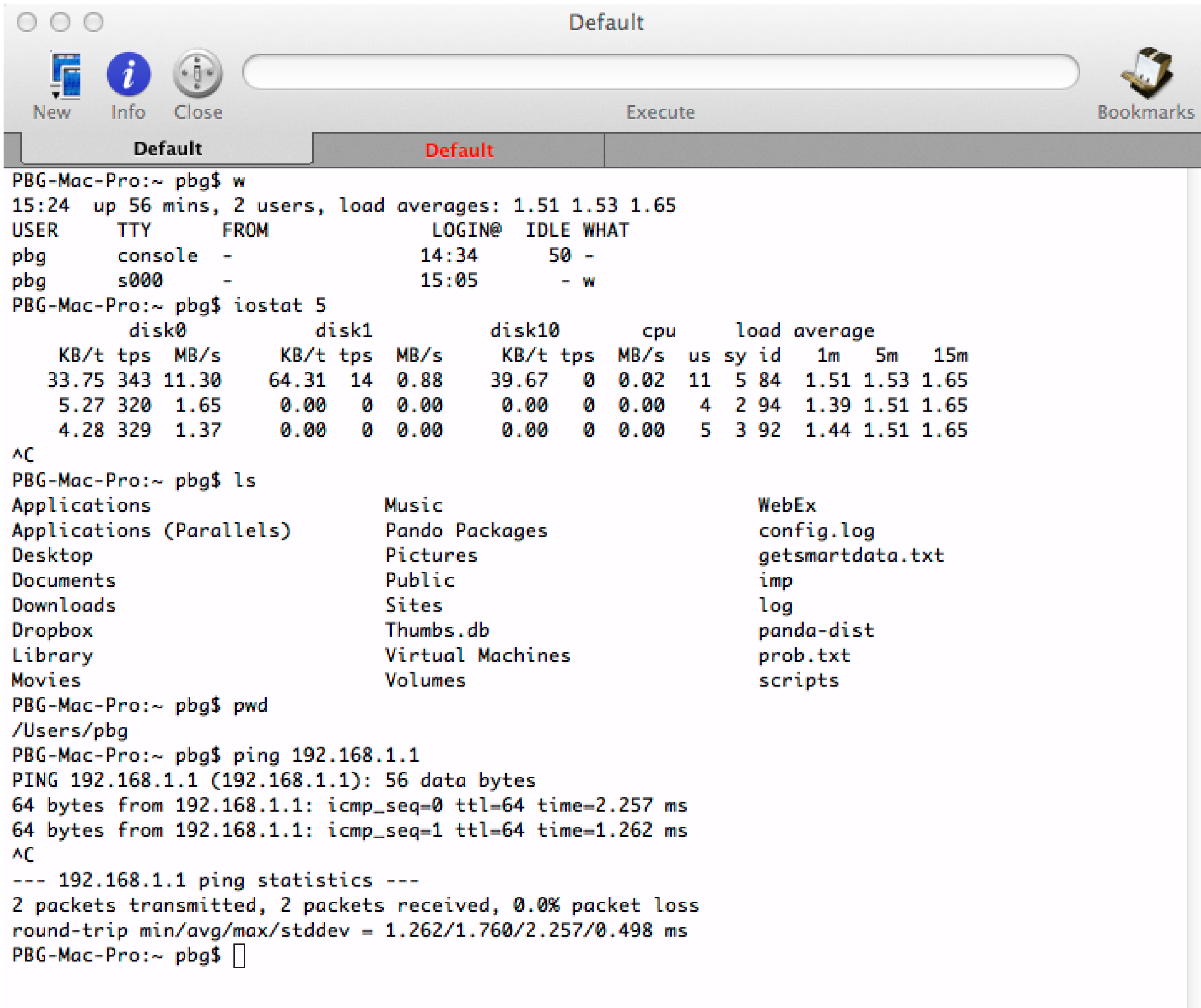
- Another set of OS functions exists for ensuring the efficient operation of the system itself via resource sharing
  - **Resource allocation -** When multiple users or multiple jobs running concurrently, resources must be allocated to each of them
    - Many types of resources -   CPU cycles, main memory, file storage, I/O devices.
  - **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

User Operating System Interface - CLI

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

Bourne Shell Command Interpreter




```
PBG-Mac-Pro:~ pbg$ w
15:24  up 56 mins, 2 users, load averages: 1.51 1.53 1.65
USER     TTY      FROM              LOGIN@  IDLE WHAT
pbg      console  -                14:34      50 -
pbg      s000     -                15:05       - w
PBG-Mac-Pro:~ pbg$ iostat 5
          disk0           disk1           disk10       cpu     load average
    KB/t tps  MB/s     KB/t tps  MB/s     KB/t tps  MB/s  us sy id   1m   5m   15m
   33.75 343 11.30    64.31  14  0.88    39.67   0  0.02  11  5 84  1.51 1.53 1.65
    5.27 320  1.65     0.00   0  0.00     0.00   0  0.00   4  2 94  1.39 1.51 1.65
    4.28 329  1.37     0.00   0  0.00     0.00   0  0.00   5  3 92  1.44 1.51 1.65
^C
PBG-Mac-Pro:~ pbg$ ls
Applications                Music                       WebEx
Applications (Parallels)    Pando Packages              config.log
Desktop                     Pictures                    getsmartdata.txt
Documents                   Public                      imp
Downloads                   Sites                       log
Dropbox                     Thumbs.db                   panda-dist
Library                     Virtual Machines            prob.txt
Movies                      Volumes                     scripts
PBG-Mac-Pro:~ pbg$ pwd
/Users/pbg
PBG-Mac-Pro:~ pbg$ ping 192.168.1.1
PING 192.168.1.1 (192.168.1.1): 56 data bytes
64 bytes from 192.168.1.1: icmp_seq=0 ttl=64 time=2.257 ms
64 bytes from 192.168.1.1: icmp_seq=1 ttl=64 time=1.262 ms
^C
--- 192.168.1.1 ping statistics ---
2 packets transmitted, 2 packets received, 0.0% packet loss
round-trip min/avg/max/stddev = 1.262/1.760/2.257/0.498 ms
PBG-Mac-Pro:~ pbg$
```

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 is "Aqua" GUI interface with UNIX kernel underneath and shells available
  - Unix and Linux have CLI with optional GUI interfaces (CDE, KDE, GNOME)

Touchscreen Interfaces

- Touchscreen devices require new interfaces
  - Mouse not possible or not desired
  - Actions and selection based on gestures
  - Virtual keyboard for text entry
- Voice commands.

The Mac OS X GUI

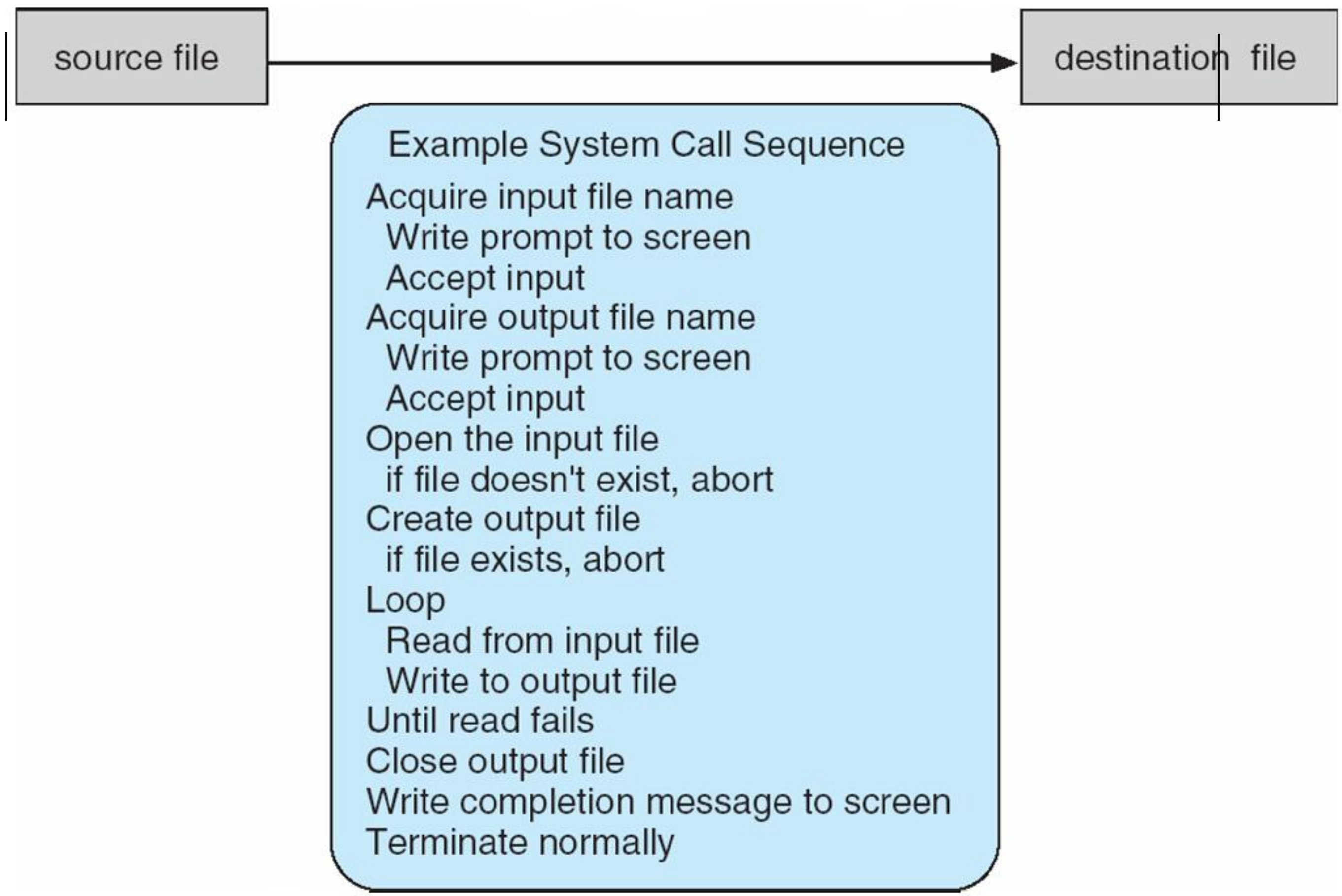
System Calls

- 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 Programming Interface** **(API)** rather than direct system call use
- A programmer accesses an API via a library of code provided by the operating system.
- Three 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)

Note that the system-call names used throughout this text are generic

Example of System Calls

- System call sequence to copy the contents of one file to another file



Example of Standard API

EXAMPLE OF STANDARD API

As an example of a standard API, consider the `read()` function that is available in UNIX and Linux systems. The API for this function is obtained from the `man` page by invoking the command

```
man read
```

on the command line. A description of this API appears below:

```
#include <unistd.h>

ssize_t     read(int fd, void *buf, size_t count)
```

return value	function name	parameters
`ssize_t`	`read`	`(int fd, void *buf, size_t count)`

A program that uses the `read()` function must include the `unistd.h` header file, as this file defines the `ssize_t` and `size_t` data types (among other things). The parameters passed to `read()` are as follows:

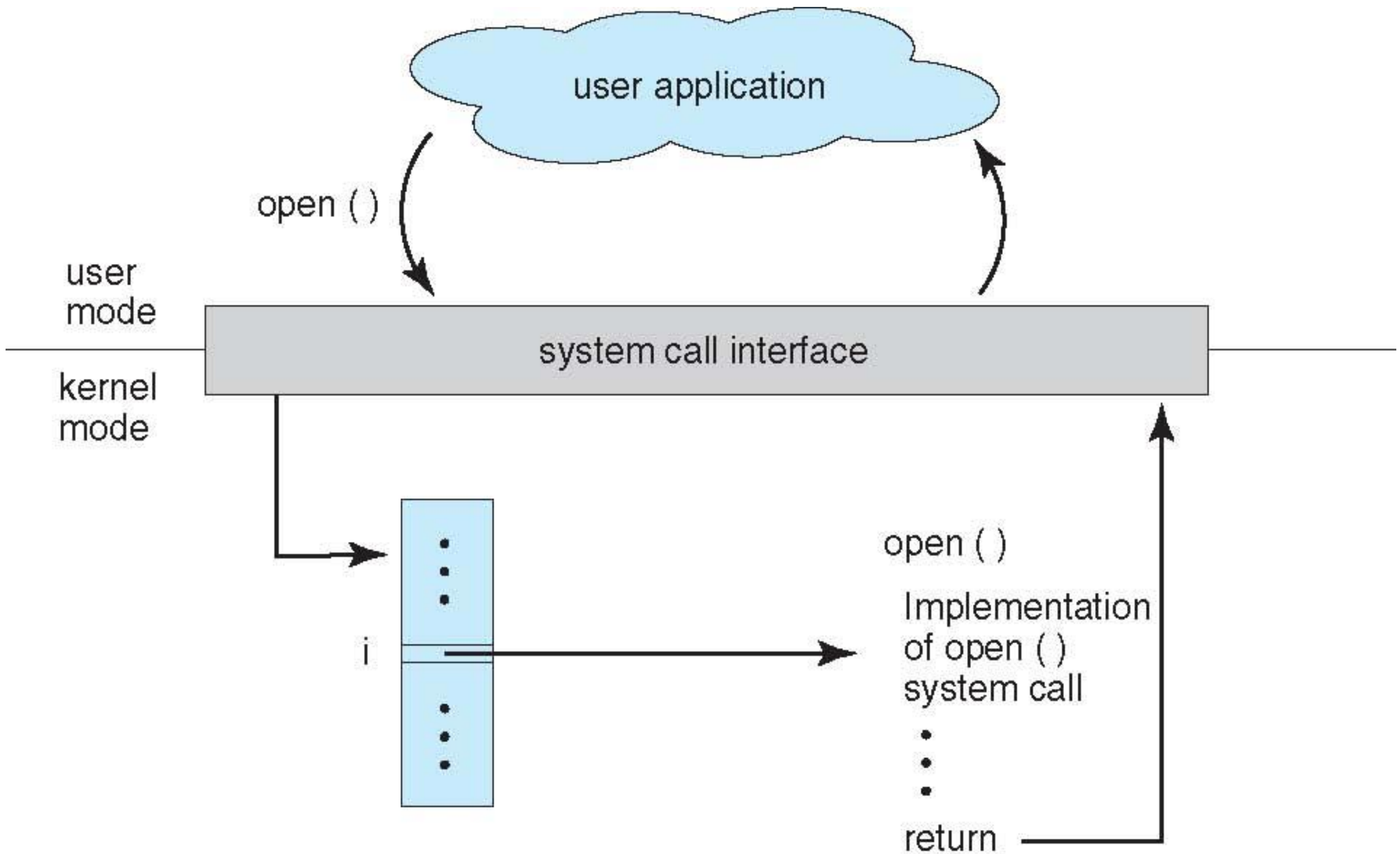
- `int fd`—the file descriptor to be read
- `void *buf`—a buffer where the data will be read into
- `size_t count`—the maximum number of bytes to be read into the buffer

On a successful read, the number of bytes read is returned. A return value of 0 indicates end of file. If an error occurs, `read()` returns −1.

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 the 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



Types of System Calls

- Process control
  - create process, terminate process
  - end, abort
  - load, execute
  - get process attributes, set process attributes
  - wait for time
  - wait event, signal event
  - allocate and free memory
  - Dump memory if error
  - **Debugger** for determining **bugs, single step** execution
  - **Locks** for managing access to shared data between processes

Types of System Calls

- File management
  - create file, delete file
  - open, close file
  - read, write, reposition
  - get and set file attributes
- Device management
  - request device, release device
  - read, write, reposition
  - get device attributes, set device attributes
  - logically attach or detach devices

Types of System Calls (Cont.)

- Information maintenance
  - get time or date, set time or date
  - get system data, set system data
  - get and set process, file, or device attributes
- Communications
  - create, delete communication connection
  - send, receive messages if **message passing model** to **host name** or **process name**
    - From **client** to **server**
  - **Shared-memory model** create and gain access to memory regions
  - transfer status information
  - attach and detach remote devices

Types of System Calls (Cont.)

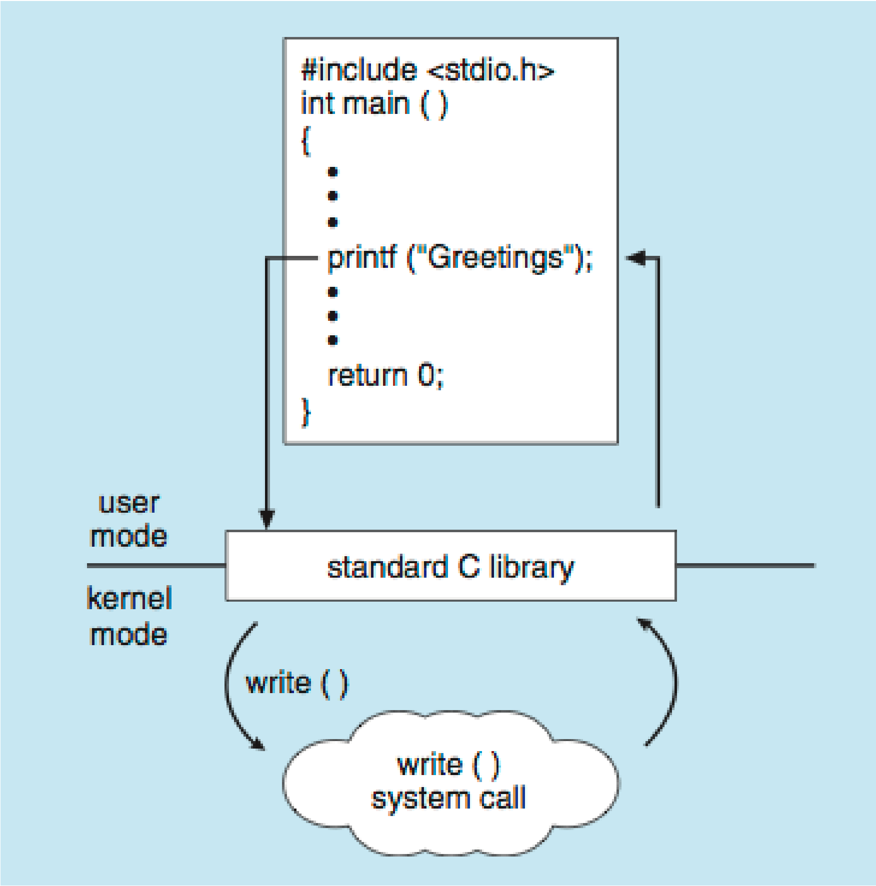
- Protection
  - Control access to resources
  - Get and set permissions
  - Allow and deny user access

Examples of Windows and Unix System Calls

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

Standard C Library Example

- C program invoking printf() library call, which calls write() system call



The fork() System Call

- System call **fork()** is used to create processes.
- It takes no arguments and returns a process ID.
- After a new child process is created, ***both*** processes will execute the next instruction following the ***fork()*** system call. Therefore, we have to distinguish the parent from the child. This can be done by testing the returned value of **fork()**:
- ***Negative Value***: creation of a child process was unsuccessful.
  Zero: Returned to the newly created child process.
  Positive value: Returned to parent or caller. The value contains process ID of newly created child process.
- A child process uses the same pc(program counter), same CPU registers, same open files which use in the parent process.

Example (1)

```
#include <stdio.h>
int main()
{

        fork();
        printf("Hello world!\n");
        return 0;
}
```

- o/p: Hello World!

  Hello World!

Example (2)

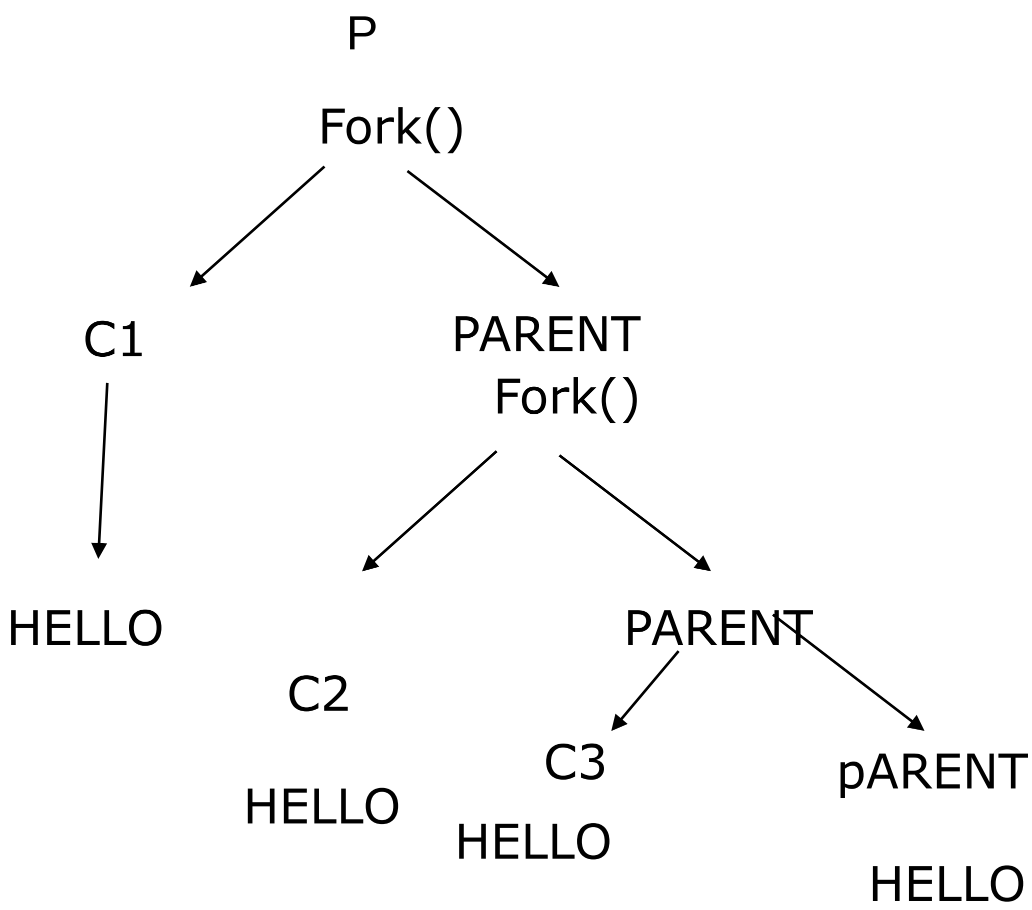
```
#include <stdio.h>
int main()
{
        fork();
        fork();
        printf("hello\n");
        return 0;
}
```

- The number of times ‘hello’ is printed is equal to number of process created. Total Number of Processes = 2^n, where n is number of fork system calls. So here n = 2, $2^2 = 4$
- Parent & child process? Child= = $2^n - 1$

GATE Questions (1)

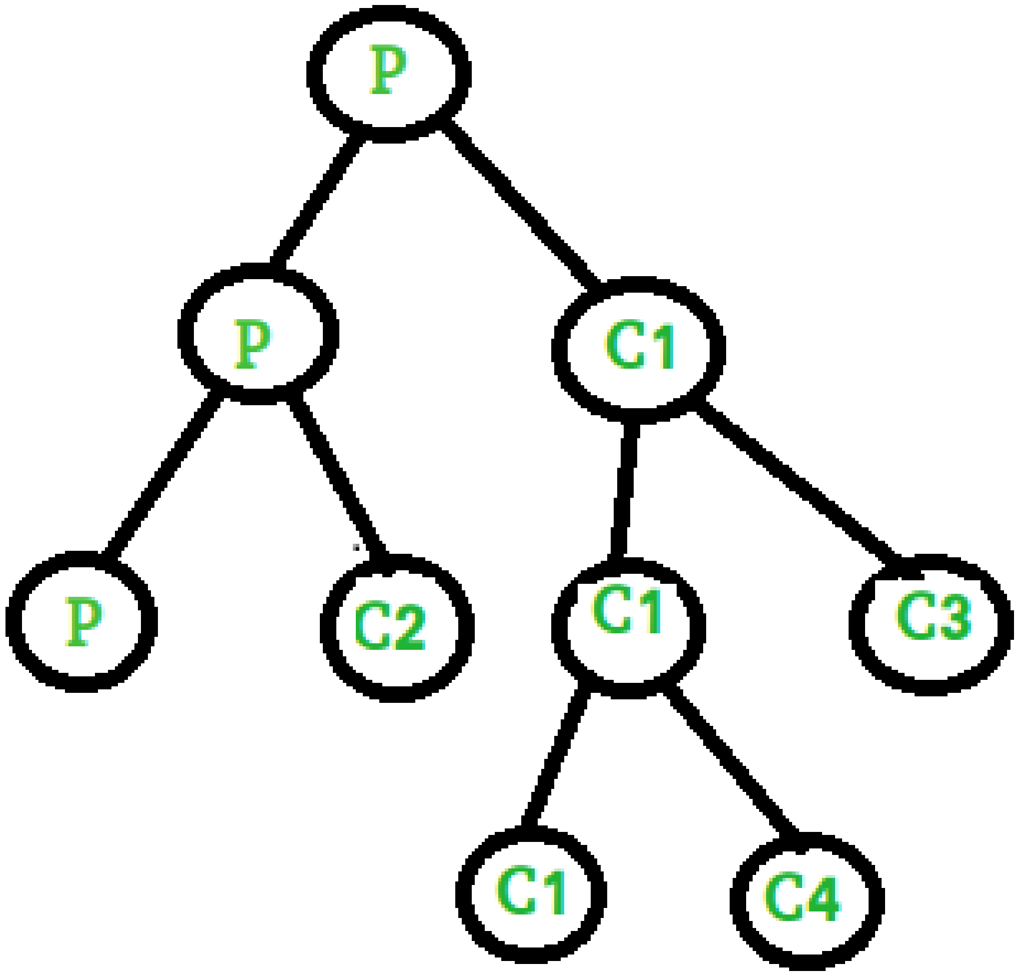
What is the output of the following code?

```
#include <stdio.h>
#include <unistd.h>
int main()
{
        if (fork() && fork())
                fork();
        printf(“Hello ");
        return 0;
}
```


P
Fork()
C1
PARENT
Fork()
HELLO
C2
PARENT
C3
pARENT
HELLO
HELLO
HELLO

GATE (2)

```
#include <stdio.h>
#include <unistd.h>
int main()
{
        if (fork() || fork())
                fork();
        printf("1 ");
        return 0;
}
```


P
P
C1
P
C2
C1
C3
C1
C4

UGC/NET

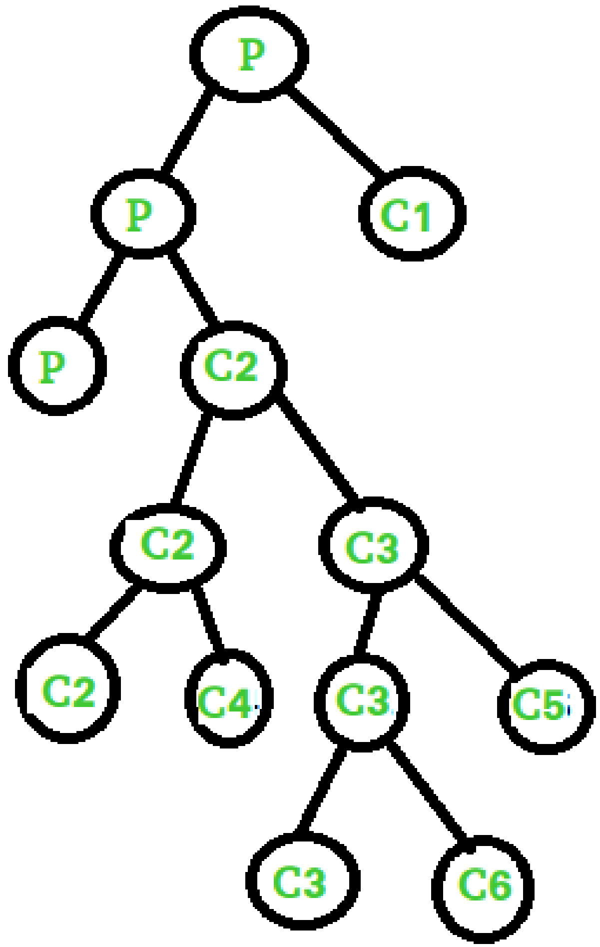
- Statement I: P1 displays “Happy” 8 times
- Statement II: P1 displays “Happy” 12 times

```
/* P1 */
int main () {
      fork ();
      fork ();
      fork ();
      printf(“Happy\n”);
}
```

```
/* P2 */
int main () {
      fork ();
      printf(“Happy\n”);
      fork();
      printf(“Happy\n”);
      fork();
      printf(“Happy\n”);
}
```

GATE Questions (3)

```
#include <stdio.h>
int main()
{
        if (fork() && (!fork())) {
                if (fork() || fork()) {
                        fork();
                }
        }
        printf("2 ");
        return 0;
}
```


P
P
C1
P
C2
C2
C3
C2
C4
C3
C5
C3
C6

Exec()

- The **exec()** system call is used to make the processes.
- When the exec() function is used, the currently running process is terminated and replaced with the newly formed process.
- In other words, only the new process persists after calling exec(). The parent process is shut down. This system call also substitutes the parent process's text segment, address space, and data segment with the child process.

fork VERSUS exec

fork	exec
Operation in UNIX operating system that allows a process to create a copy of itself	Operation in UNIX operating system that creates a process by replacing the previous process
After calling fork(), there is parent process and child process	After calling exec(), there is only child process and there is no parent process
Creates a child process which is similar to the parent process	Creates a child process and replace it with the parent process
Parent and the child processes are in different address spaces	Parent address space is replaced by the child address space

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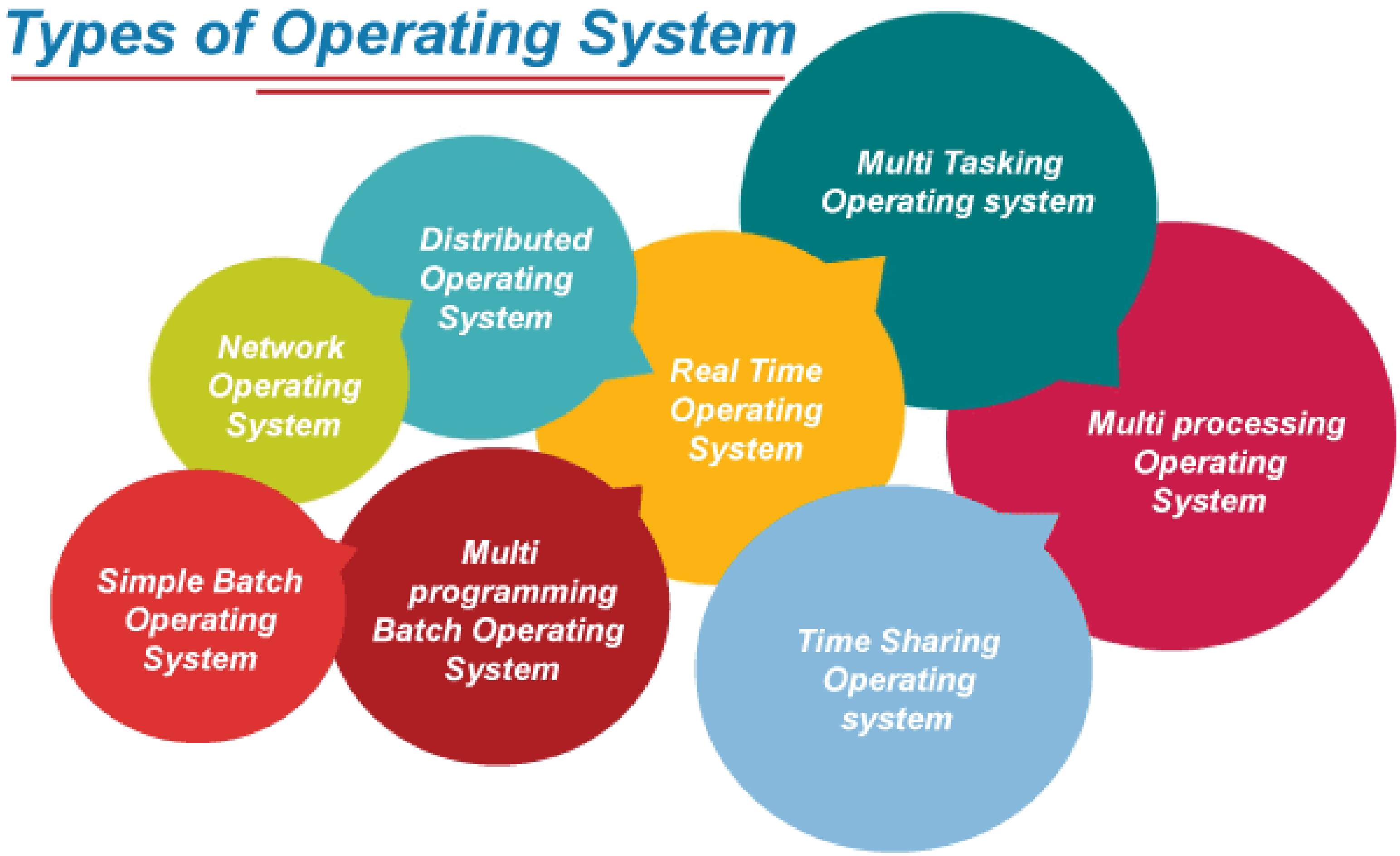
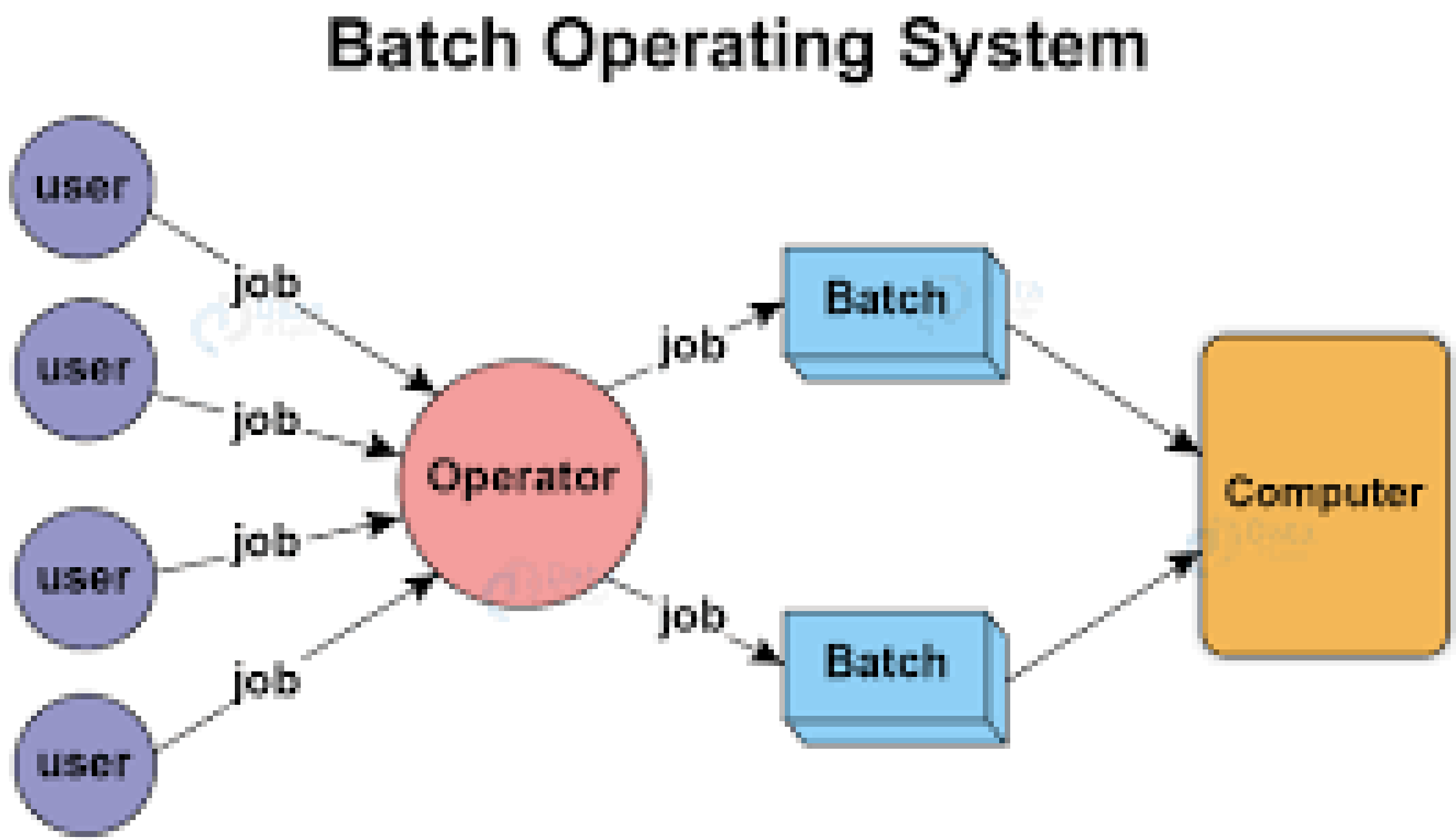
Types of OS

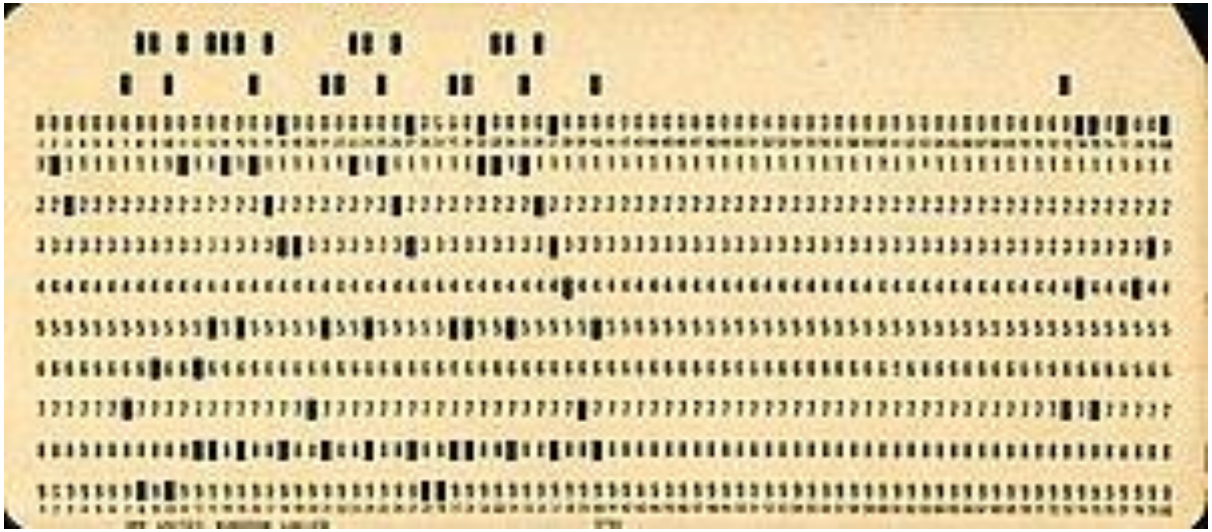

Types of Operating System
Distributed Operating System
Multi Tasking Operating system
Network Operating System
Real Time Operating System
Multi processing Operating System
Simple Batch Operating System
Multi programming Batch Operating System
Time Sharing Operating system



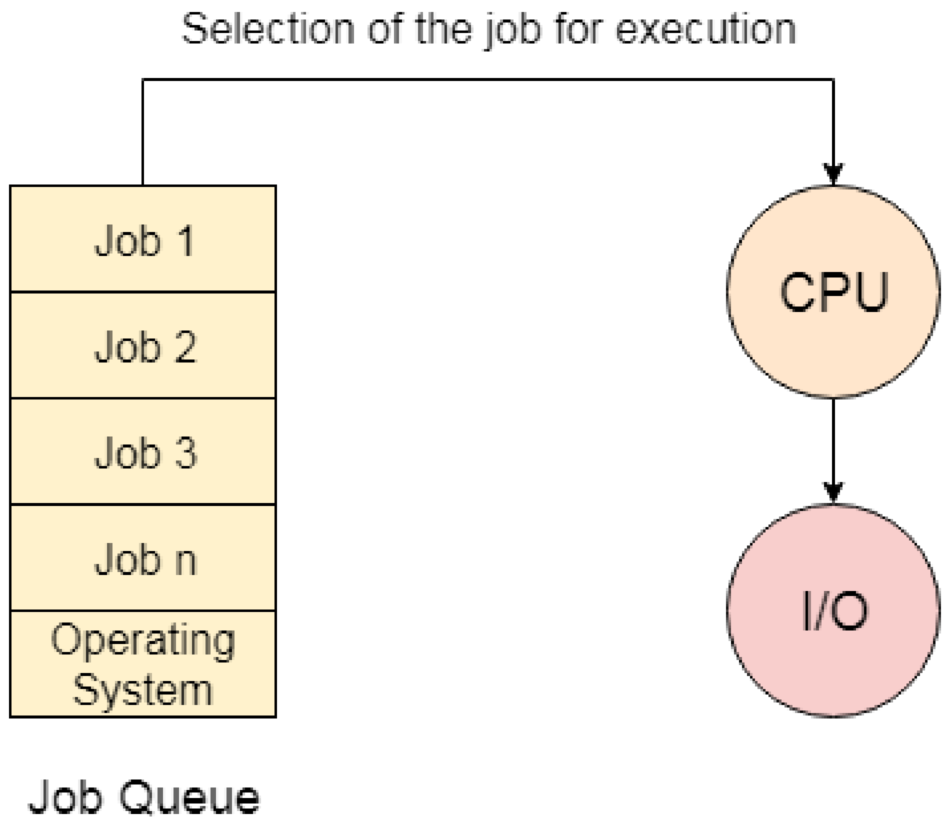
Batch Operating System
user
user
user
user
job
job
job
job
Operator
job
job
Batch
Batch
Computer

Batch OS

- 1960's : Batches – Similar jobs
- Input : Punch cards/Magnetic tapes
- Non-interactive
- There is an operator which takes similar jobs having the same requirement and group them into batches
- BankSystem, Payroll System, etc

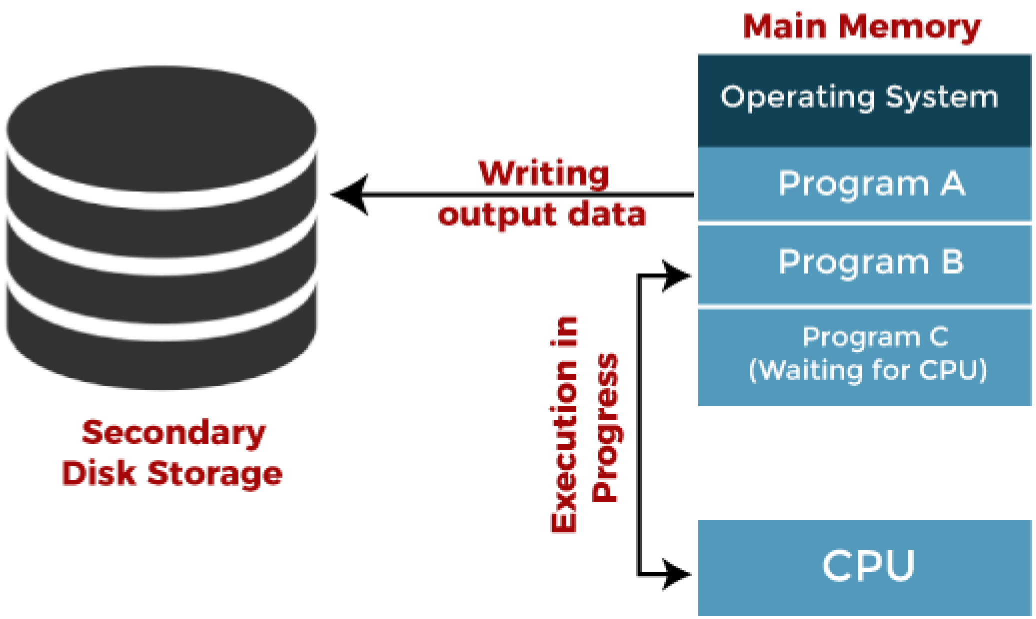


- Disadvantage- Non premption
- CPU utilization low,Starvation



Multiprogramming Operating System

- Multi-programming is defined as the capability of an Operating system to run more than one program on a single processor.
- Each process needs two types of system time: CPU time and IO time.
- Non premtive
- Advantages & Disadvantage?



Jobs in multiprogramming system

Multiprogramming Operating System

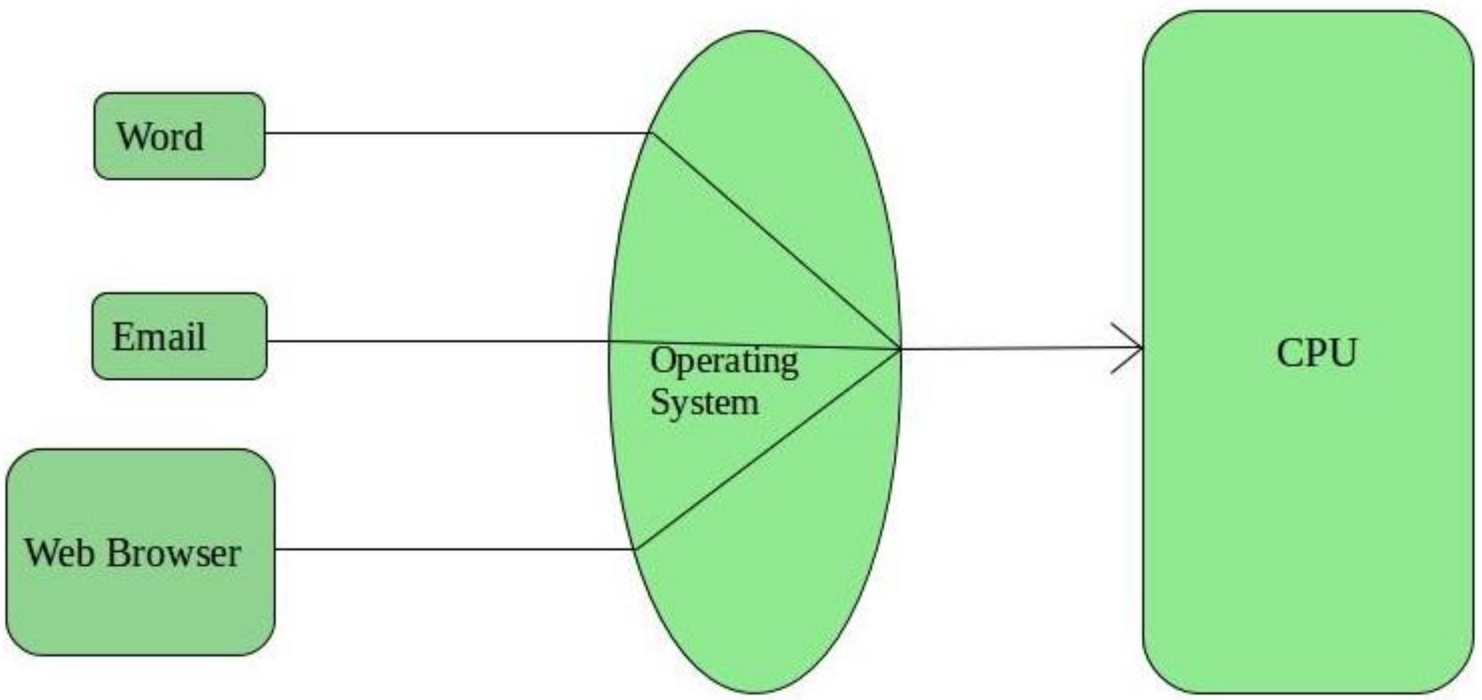
Advantages of Multi-programming

- Efficient CPU utilization.
- The users assume that CPU is simultaneously working on multiple programs.

Disadvantages of Multi-programming

- It needs CPU scheduling.
- Memory management is needed to accommodate different jobs in memory.

Multi-Tasking OS/Time-sharing



Multi-Tasking OS/Time-sharing

- Multitasking is a technique in which the CPU executes a number of jobs within the same time by switching among the jobs.
- The task of switching the job is so frequent that the user will be able to communicate with each program when the program is running.
- The time that each task gets to execute is called quantum. After this time interval is over OS switches over to the next task.

Multi-Tasking OS/Time-sharing

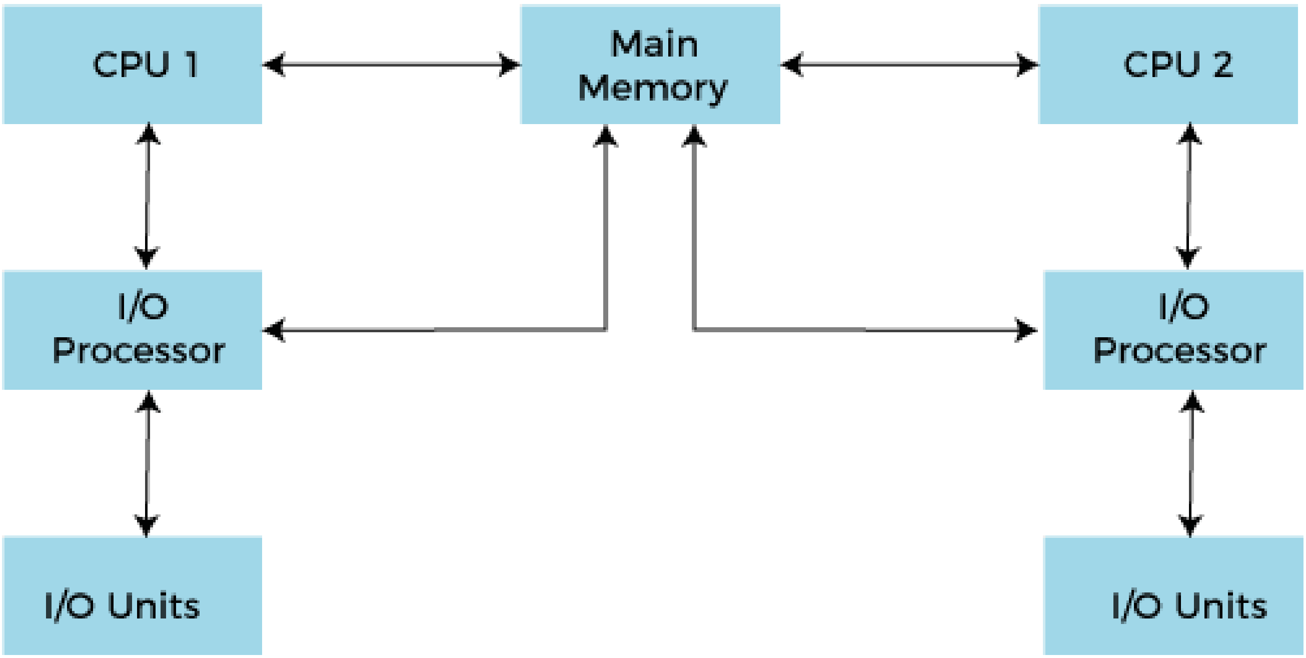
Advantages of Time-Sharing OS:

- Each task gets an equal opportunity
- Fewer chances of duplication of software
- CPU idle time can be reduced

Disadvantages of Time-Sharing OS:

- One must have to take care of the security and integrity of user programs and data
- Data communication problem
- Reliability problem

Multiprocessing Operating System

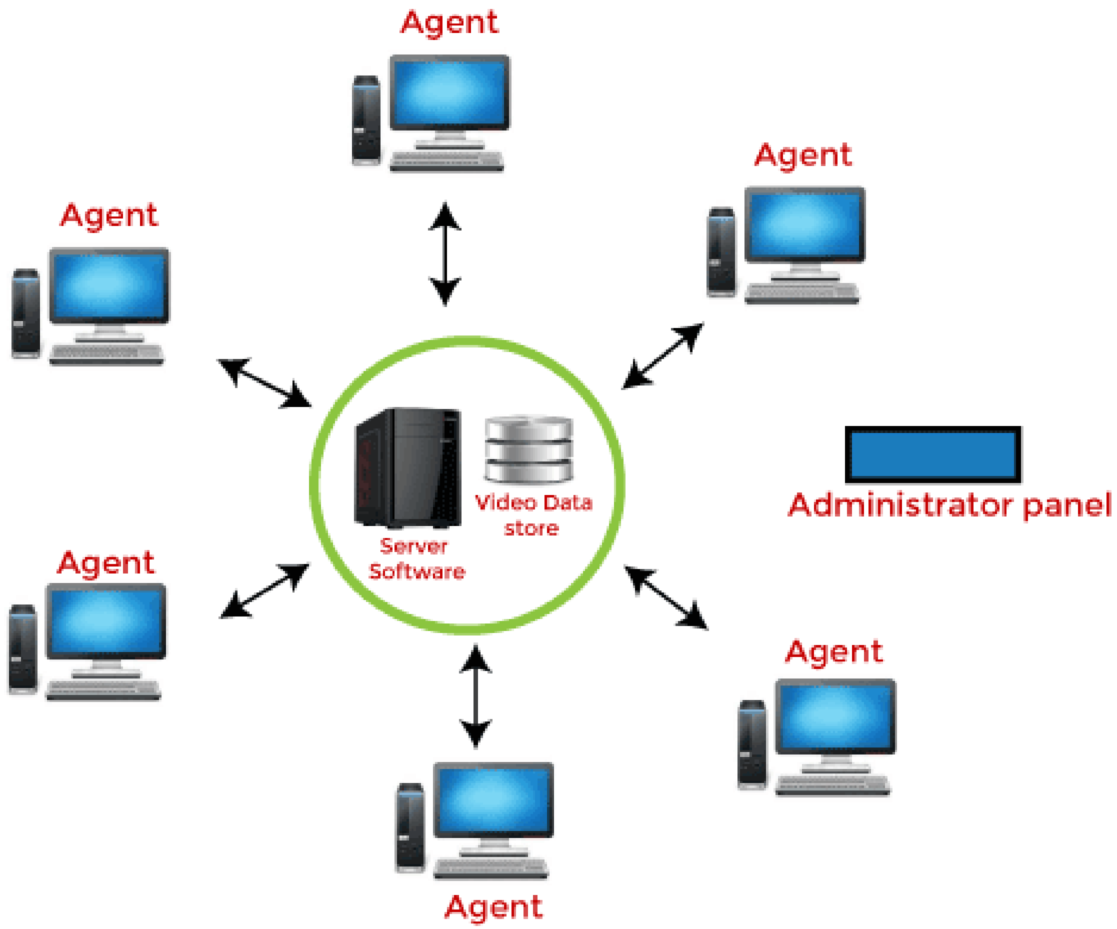


Working of Multiprocessor System

Multiprocessing Operating System

- Parallel computing is achieved. There are more than one processors present in the system which can execute more than one process at the same time. This will increase the throughput of the system.
- Same as Multicomputer?
- Dual Processor, Quad etc

Network Operating System



Network Operating Systems

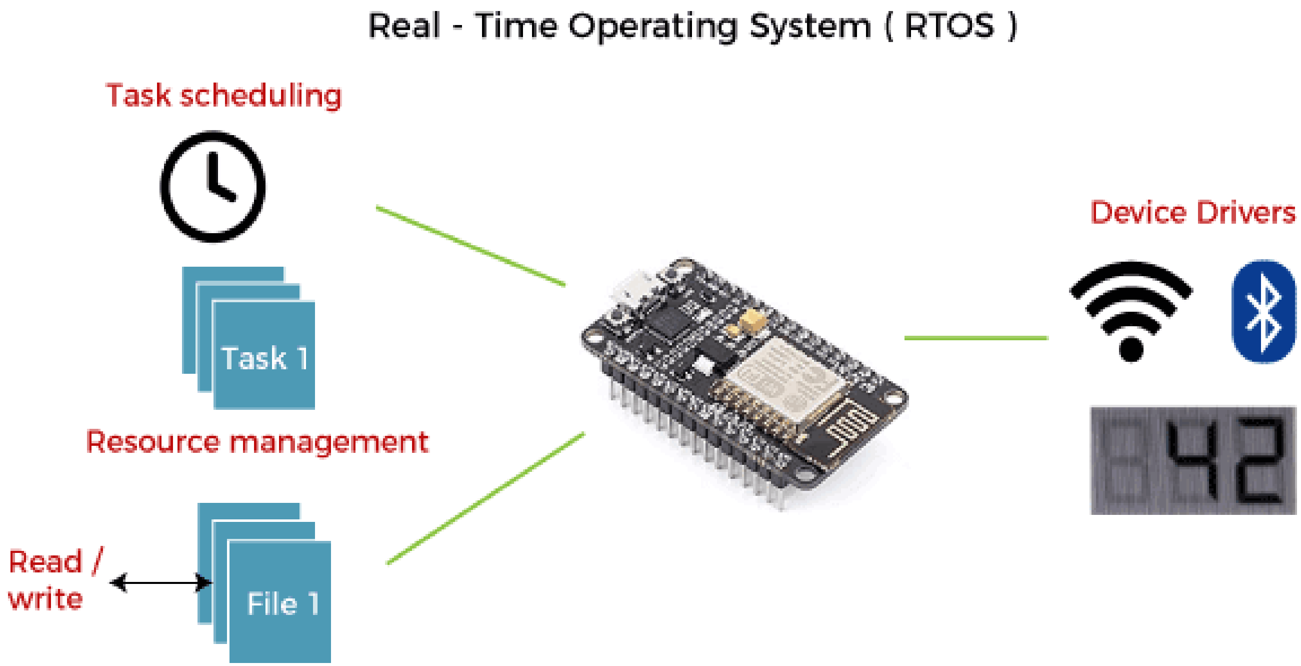
tightly coupled systems.

Network Operating System

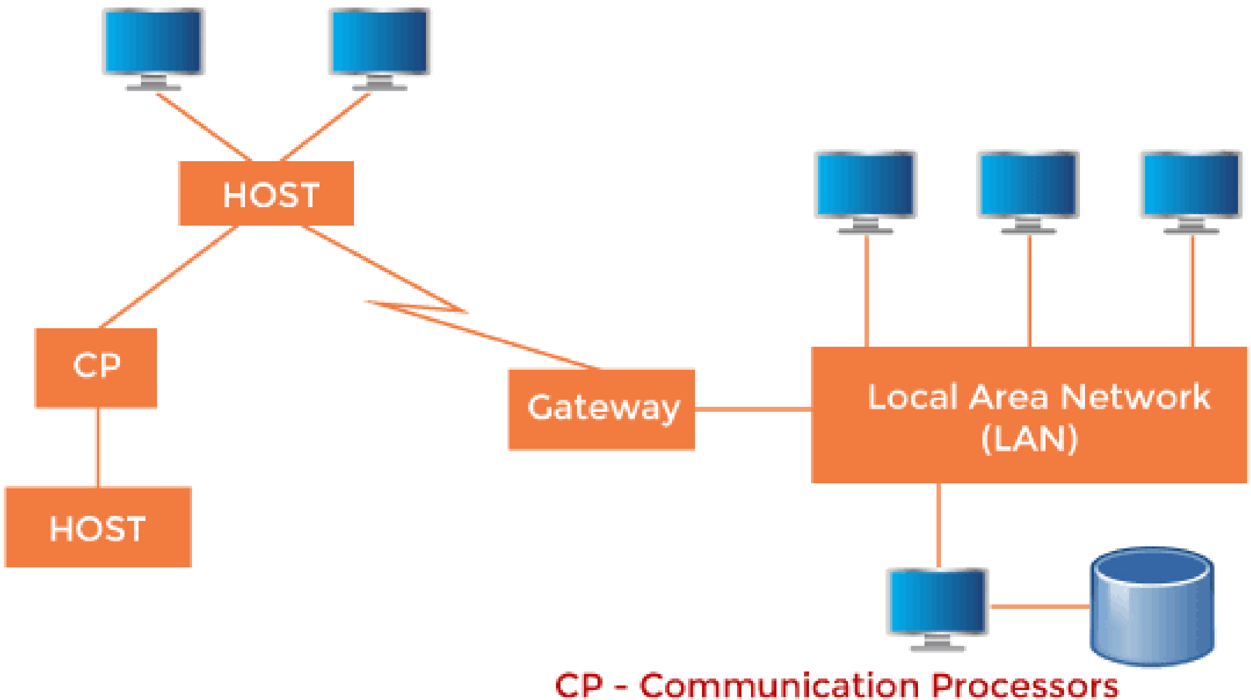
- These systems run on a server and provide the capability to manage data, users, groups, security, applications, and other networking functions.
- These types of operating systems allow shared access of files, printers, security, applications, and other networking functions over a small private network.
- All the users are well aware of the underlying configuration, of all other users within the network, their individual connections, etc. and that’s why these computers are popularly known as **tightly coupled systems**.
- Microsoft Windows Server 2003, Microsoft Windows Server 2008

Real Time Operating System

- Each job carries a certain deadline within which the job is supposed to be completed, otherwise, the huge loss will be there, or even if the result is produced, it will be completely useless. E.g. Military App
- Soft RTOS & Hard RTOS



Distributed Operating System



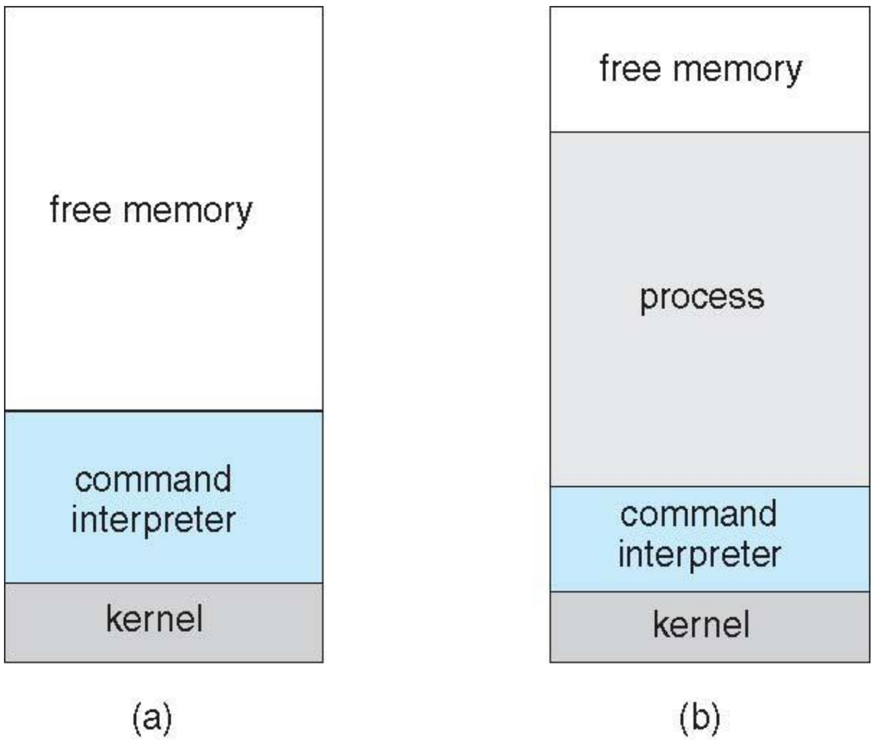
A Typical View of a Distributed System

Distributed

- Various autonomous interconnected computers communicate with each other using a shared communication network. Independent systems possess their own memory unit and CPU.
- These are referred to as **loosely coupled systems** or distributed systems. These system's processors differ in size and function.
- The major benefit of working with these types of the operating system is that it is always possible that one user can access the files or software which are not actually present on his system but some other system connected within this network i.e., remote access is enabled within the devices connected in that network.

Case Study: MS-DOS

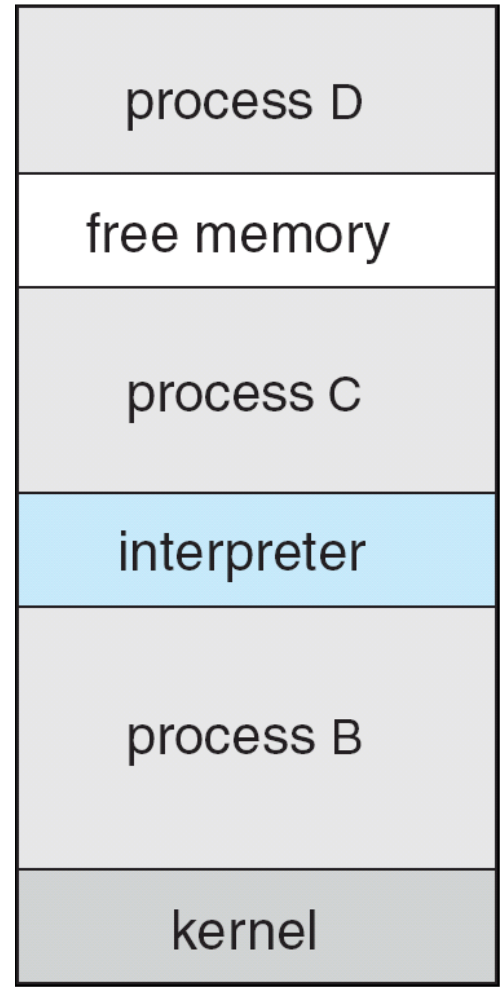
- Single-tasking
- Shell invoked when system booted
- Simple method to run program
  - No process created
- Single memory space
- Loads program into memory, overwriting all but the kernel
- Program exit -> shell reloaded



At system startup   running a program

Case Study : FreeBSD

- Unix variant
- Multitasking
- User login -> invoke user's choice of shell
- Shell executes fork() system call to create process
  - Executes exec() to load program into process
  - Shell waits for process to terminate or continues with user commands
- Process exits with:
  - code = 0 – no error
  - code > 0 – error code



System Programs

- System programs provide a convenient environment for program development and execution. They can be divided into:
  - File manipulation
  - Status information sometimes stored in a File modification
  - Programming language support
  - Program loading and execution
  - Communications
  - Background services
  - Application programs
- Most users' view of the operation system is defined by system programs, not the actual system calls

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
- **File management** - Create, delete, copy, rename, print, dump, list, and generally manipulate files and directories
- **Status information**
  - Some ask the system for info - date, time, amount of available memory, disk space, number of users
  - Others provide detailed performance, logging, and debugging information
  - Typically, these programs format and print the output to the terminal or other output devices
  - Some systems implement a **registry** - used to store and retrieve configuration information

System Programs (Cont.)

- **File modification**
  - Text editors to create and modify files
  - Special commands to search contents of files or perform transformations of the text
- **Programming-language support** - Compilers, assemblers, debuggers and interpreters sometimes provided
- **Program loading and execution**- Absolute loaders, relocatable loaders, linkage editors, and overlay-loaders, debugging systems for higher-level and machine language
- **Communications** - Provide the mechanism for creating virtual connections among processes, users, and computer systems
  - Allow users to send messages to one another's screens, browse web pages, send electronic-mail messages, log in remotely, transfer files from one machine to another

System Programs (Cont.)

- **Background Services**
  - Launch at boot time
    - Some for system startup, then terminate
    - Some from system boot to shutdown
  - Provide facilities like disk checking, process scheduling, error logging, printing
  - Run in user context not kernel context
  - Known as **services**, **subsystems**, **daemons**
- **Application programs**
  - Don’t pertain to system
  - Run by users
  - Not typically considered part of OS
  - Launched by command line, mouse click, finger poke

Operating System Design and Implementation

- Design and Implementation of OS not “solvable”, but some approaches have proven successful
- Internal structure of different Operating Systems can vary widely
- Start the design by defining goals and specifications
- Affected by choice of hardware, type of system
- **User** goals and **System** goals
  - User goals – operating system should be convenient to use, easy to learn, reliable, safe, and fast
  - System goals – operating system should be easy to design, implement, and maintain, as well as flexible, reliable, error-free, and efficient

Operating System Design and Implementation (Cont.)

- Important principle to separate

  Policy: ***What*** will be done?
  Mechanism: ***How*** to do it?

- Mechanisms determine how to do something, policies decide what will be done
- The separation of policy from mechanism is a very important principle, it allows maximum flexibility if policy decisions are to be changed later (example – timer)
- Specifying and designing an OS is highly creative task of **software engineering**

Implementation

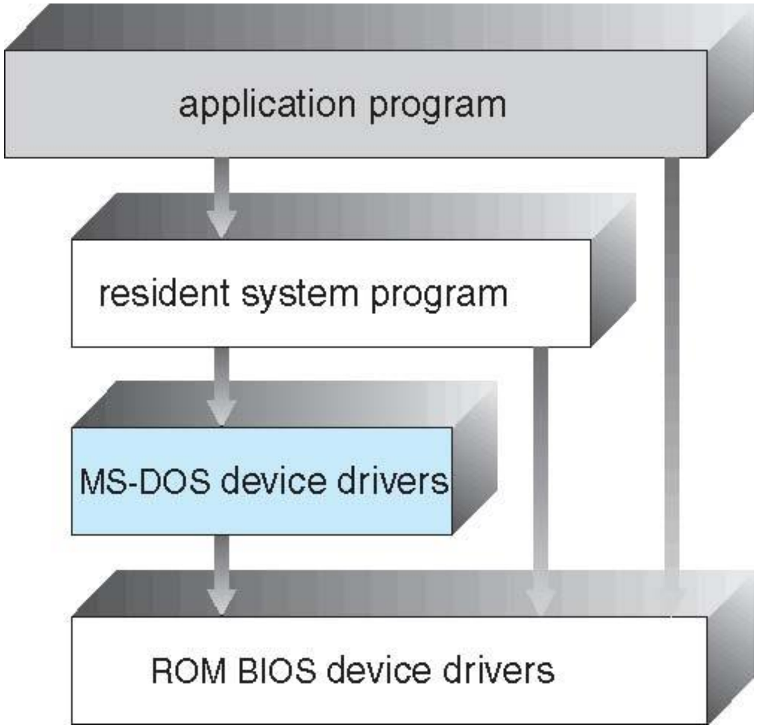
- Much variation
  - Early OSes in assembly language
  - Then system programming languages like Algol, PL/1
  - Now C, C++
- Actually usually a mix of languages
  - Lowest levels in assembly
  - Main body in C
  - Systems programs in C, C++, scripting languages like PERL, Python, shell scripts
- More high-level language easier to **port** to other hardware
  - But slower
- **Emulation** can allow an OS to run on non-native hardware

Operating System Structure

- General-purpose OS is very large program
- Various ways to structure ones
  - Simple structure – MS-DOS, More complex -- UNIX
  - Layered – an abstraction
  - Microkernel -Mach
  - Modular

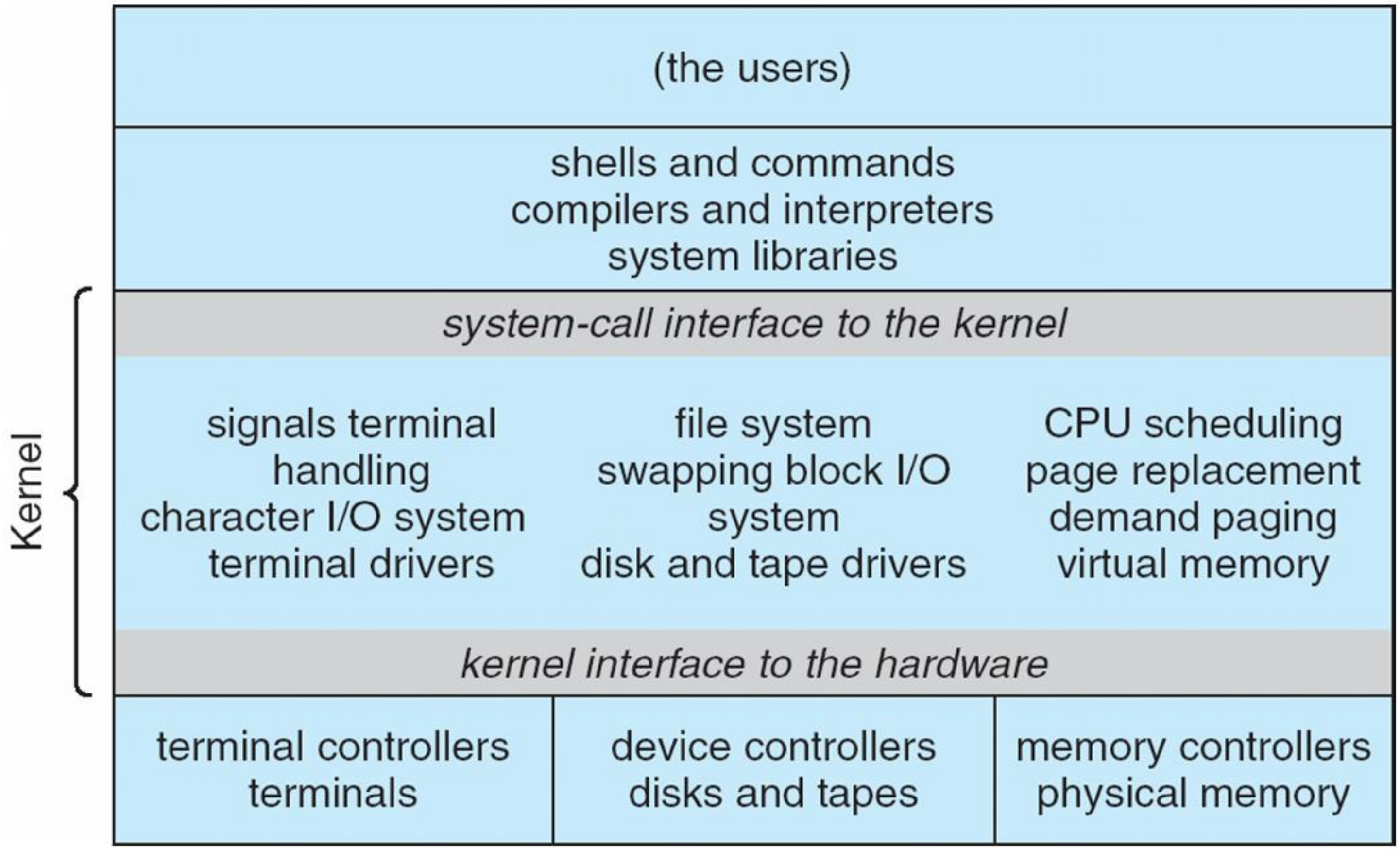
Simple Structure -- MS-DOS

- MS-DOS – written to provide the most functionality in the least space
  - Not divided into modules
  - Although MS-DOS has some structure, its interfaces and levels of functionality are not well separated
  - Written on Intel 8088-
    - No dual mode & no H/W protection.



Traditional UNIX System Structure

Beyond simple but not fully layered



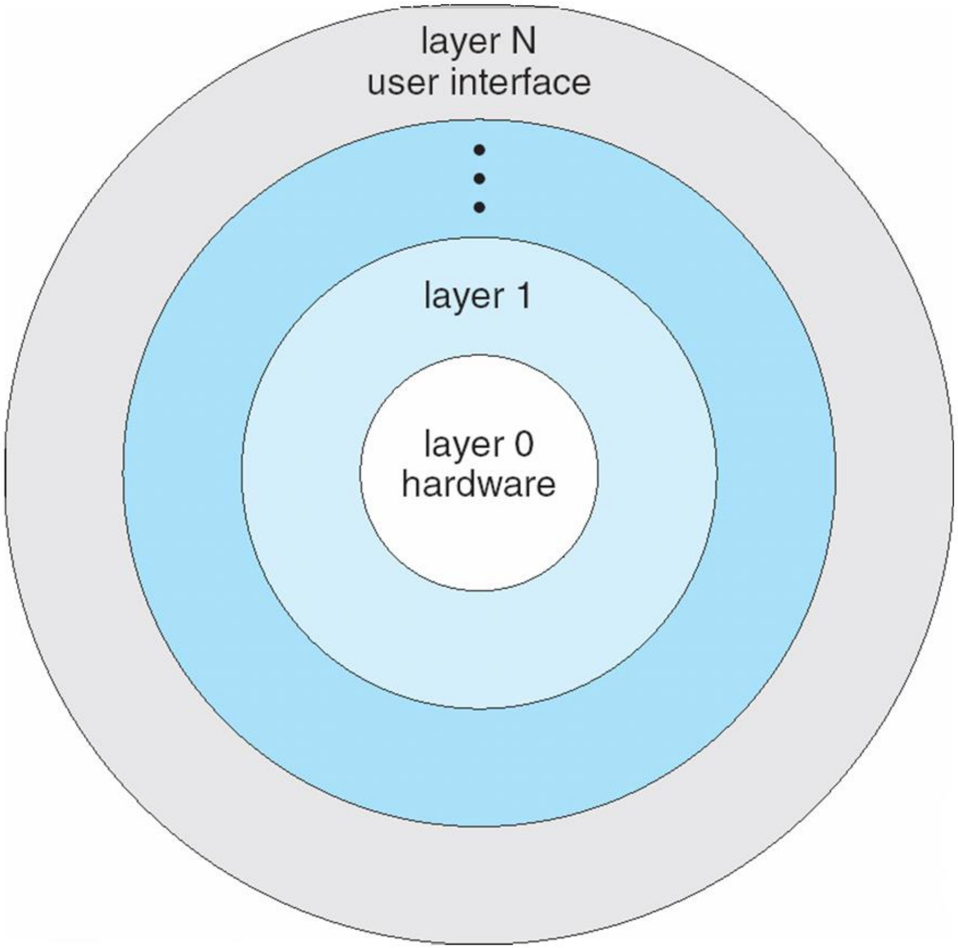
Non Simple Structure -- UNIX

UNIX – limited by hardware functionality, the original UNIX operating system had limited structuring. The UNIX OS consists of two separable parts

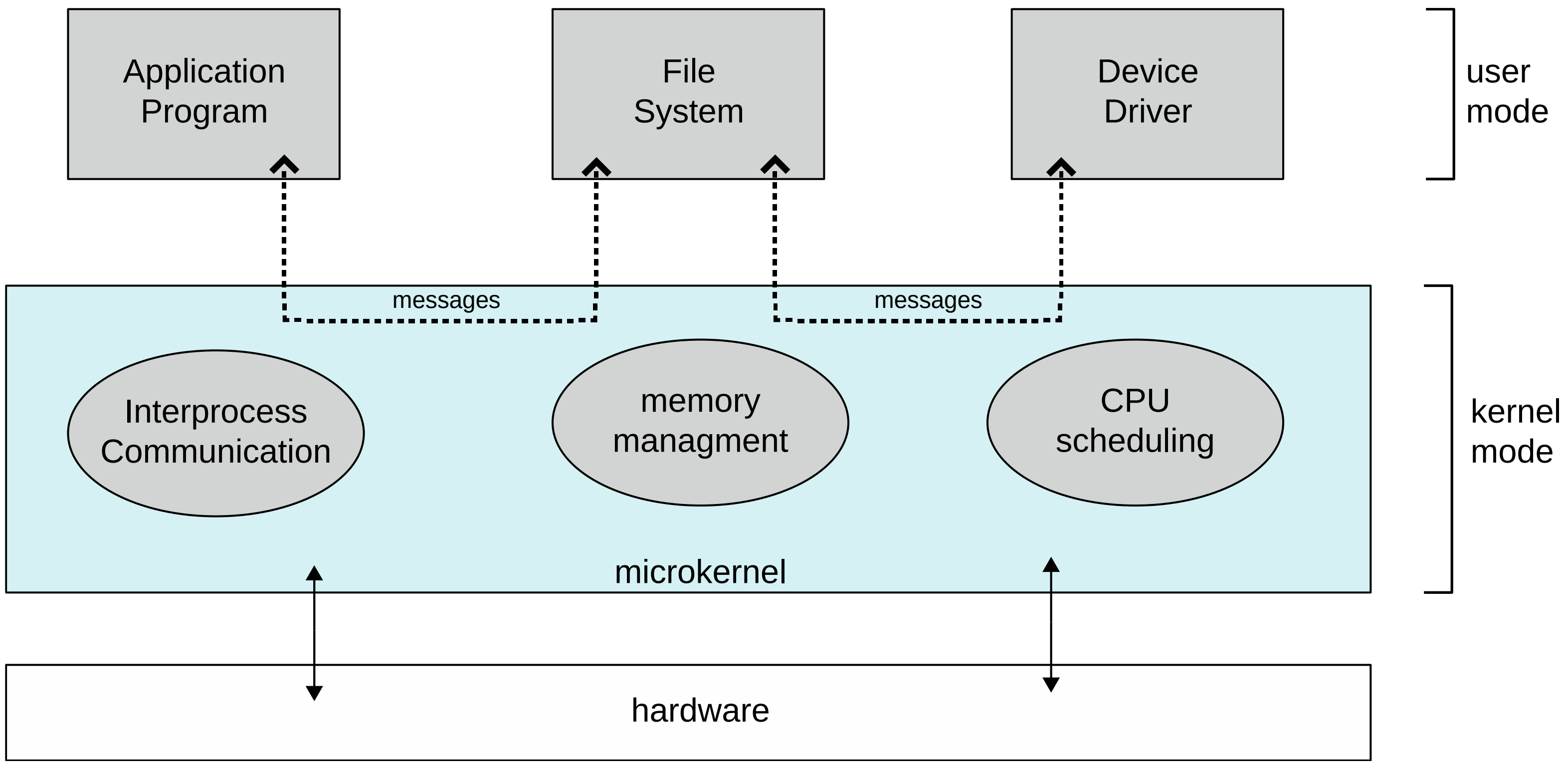
- Systems programs
- The kernel
  - Consists of everything below the system-call interface and above the physical hardware
  - Provides the file system, CPU scheduling, memory management, and other operating-system functions; a large number of functions for one level—through system calls.
  - Distadvantage: Difficult to maintain
  - Advantage:

Layered Approach

- The operating system is divided into a number of layers (levels), each built on top of lower layers. The bottom layer (layer 0), is the hardware; the highest (layer N) is the user interface.
- With modularity, layers are selected such that each uses functions (operations) and services of only lower-level layers.
- Advantages?
- Disadv: Not so EFFICIENT
- Designing & defining?



Microkernel System Structure

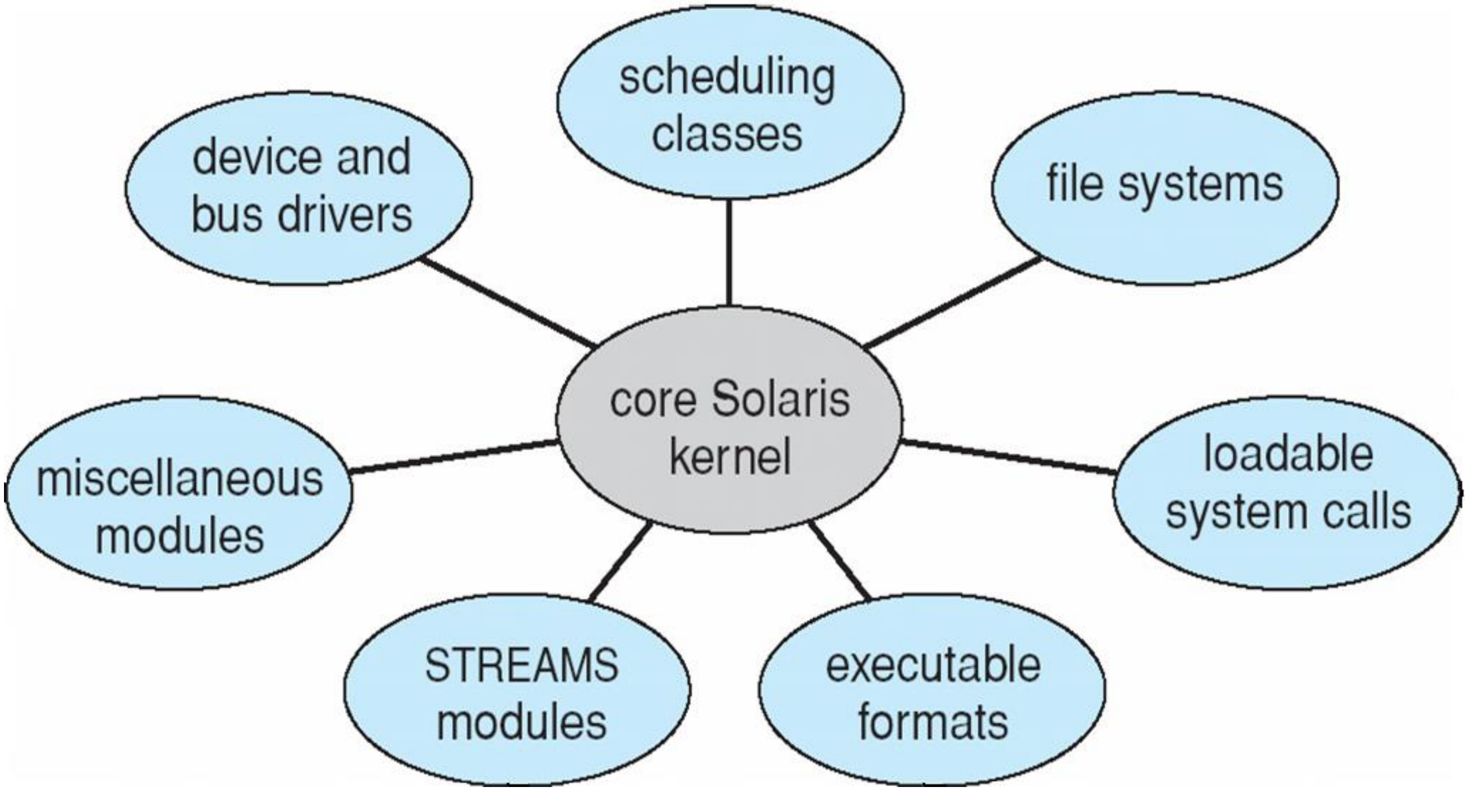


Main function: To provide communication between the client program and various service in user space

Microkernel System Structure

- Moves as much from the kernel into user space
- **Mach** example of **microkernel**
  - Mac OS X kernel (**Darwin**) partly based on Mach
- Communication takes place between user modules using **message passing**
- Benefits:
  - Easier to extend a microkernel
  - Easier to port the operating system to new architectures
  - More reliable (less code is running in kernel mode)
  - More secure
- Detriments:
  - Performance overhead of user space to kernel space communication

Solaris Modular Approach



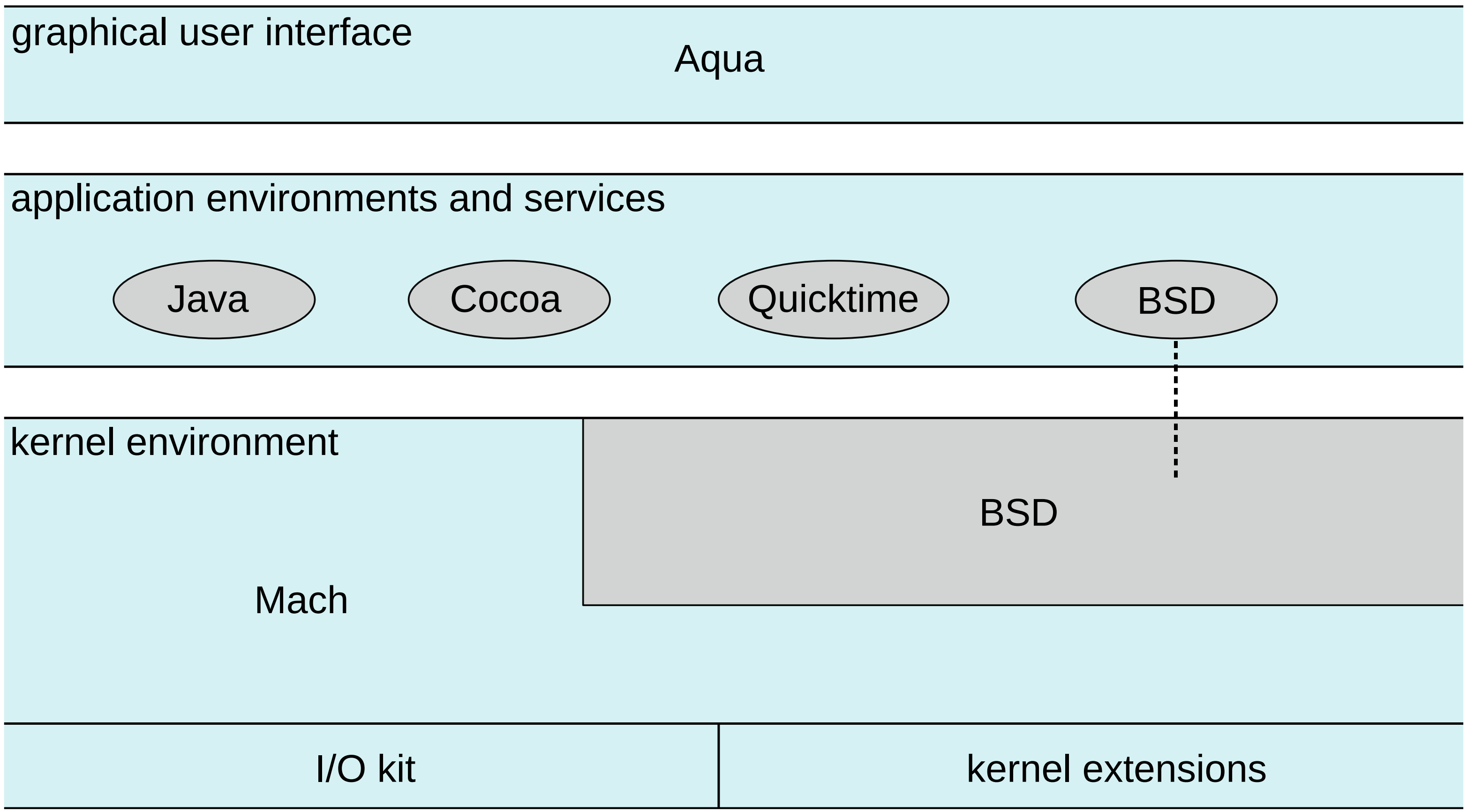
Modules

- Many modern operating systems implement **loadable kernel modules**
  - Uses object-oriented approach
  - Each core component is separate
  - Each talks to the others over known interfaces
  - Each is loadable as needed within the kernel
- Overall, similar to layers but with more flexible
  - Linux, Solaris, etc

Hybrid Systems

- Most modern operating systems are actually not one pure model
  - Hybrid combines multiple approaches to address performance, security, usability needs
  - Linux and Solaris kernels in kernel address space, so monolithic, plus modular for dynamic loading of functionality
  - Windows mostly monolithic, plus microkernel for different subsystem ***personalities***
- Apple Mac OS X hybrid, layered, **Aqua** UI plus **Cocoa** programming environment
  - Below is kernel consisting of Mach microkernel and BSD Unix parts, plus I/O kit and dynamically loadable modules (called **kernel extensions**)

Mac OS X Structure



iOS

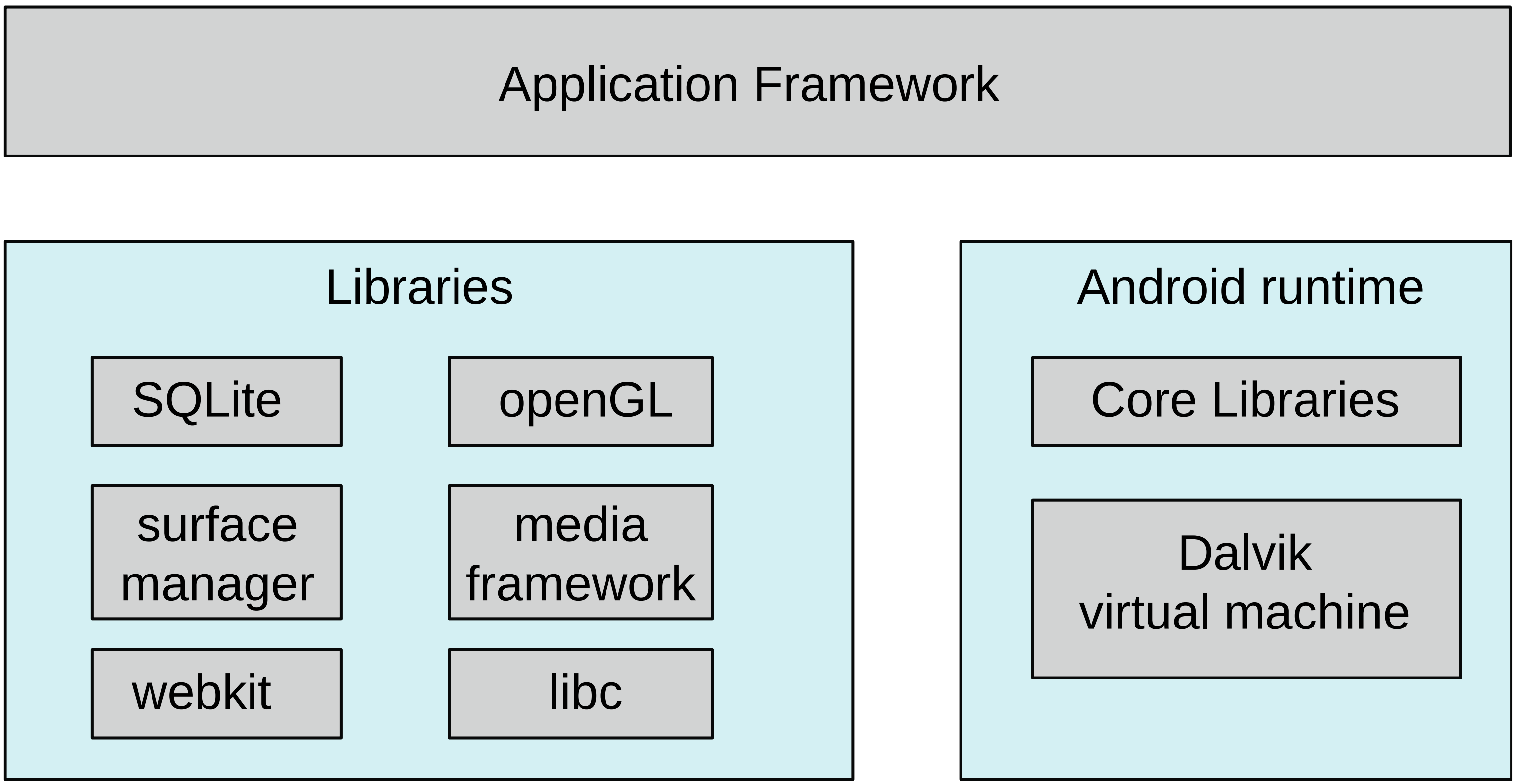
- Apple mobile OS for ***iPhone***, ***iPad***
  - Structured on Mac OS X, added functionality
  - Does not run OS X applications natively
    - Also runs on different CPU architecture (ARM vs. Intel)
  - **Cocoa Touch** Objective-C API for developing apps
  - **Media services** layer for graphics, audio, video
  - **Core services** provides cloud computing, databases
  - Core operating system, based on Mac OS X kernel

Cocoa Touch
Media Services
Core Services
Core OS

Android

- Developed by Open Handset Alliance (mostly Google)
  - Open Source
- Similar stack to IOS
- Based on Linux kernel but modified
  - Provides process, memory, device-driver management
  - Adds power management
- Runtime environment includes core set of libraries and Dalvik virtual machine
  - Apps developed in Java plus Android API
    - Java class files compiled to Java bytecode then translated to executable than runs in Dalvik VM
- Libraries include frameworks for web browser (webkit), database (SQLite), multimedia, smaller libc

Android Architecture



System Boot

- When power initialized on system, execution starts at a fixed memory location
  - Firmware ROM used to hold initial boot code
- Operating system must be made available to hardware so hardware can start it
  - Small piece of code – **bootstrap loader**, stored in **ROM** or **EEPROM** locates the kernel, loads it into memory, and starts it
  - Sometimes two-step process where **boot block** at fixed location loaded by ROM code, which loads bootstrap loader from disk
- Common bootstrap loader, **GRUB**, allows selection of kernel from multiple disks, versions, kernel options
- Kernel loads and system is then **running**

End of Chapter 2