

21CSC202J Operating Systems

UNIT I

Course Learning Rationale

- Outline the structure of OS and basic architectural Component is involved in OS design

Course Learning Outcomes

- Use the appropriate Concepts of Operating System for Resource Utilization

Learning Resources

- Abraham Silberschatz, Peter Baer Galvin, Greg Gagne, Operating systems, 9th ed., John Wiley & Sons, 2013

Introduction

- What Operating Systems Do
- Computer-System Organization
- Computer-System Architecture
- Operating-System Structure
- Operating-System Operations
- Process Management
- Memory Management
- Storage Management
- Protection and Security
- Kernel Data Structures
- Computing Environments
- Open-Source Operating Systems

Objectives

- To describe the basic organization of computer systems
- To provide a grand tour of the major components of operating systems
- To give an overview of the many types of computing environments
- To explore several open-source operating systems

What is an Operating System?

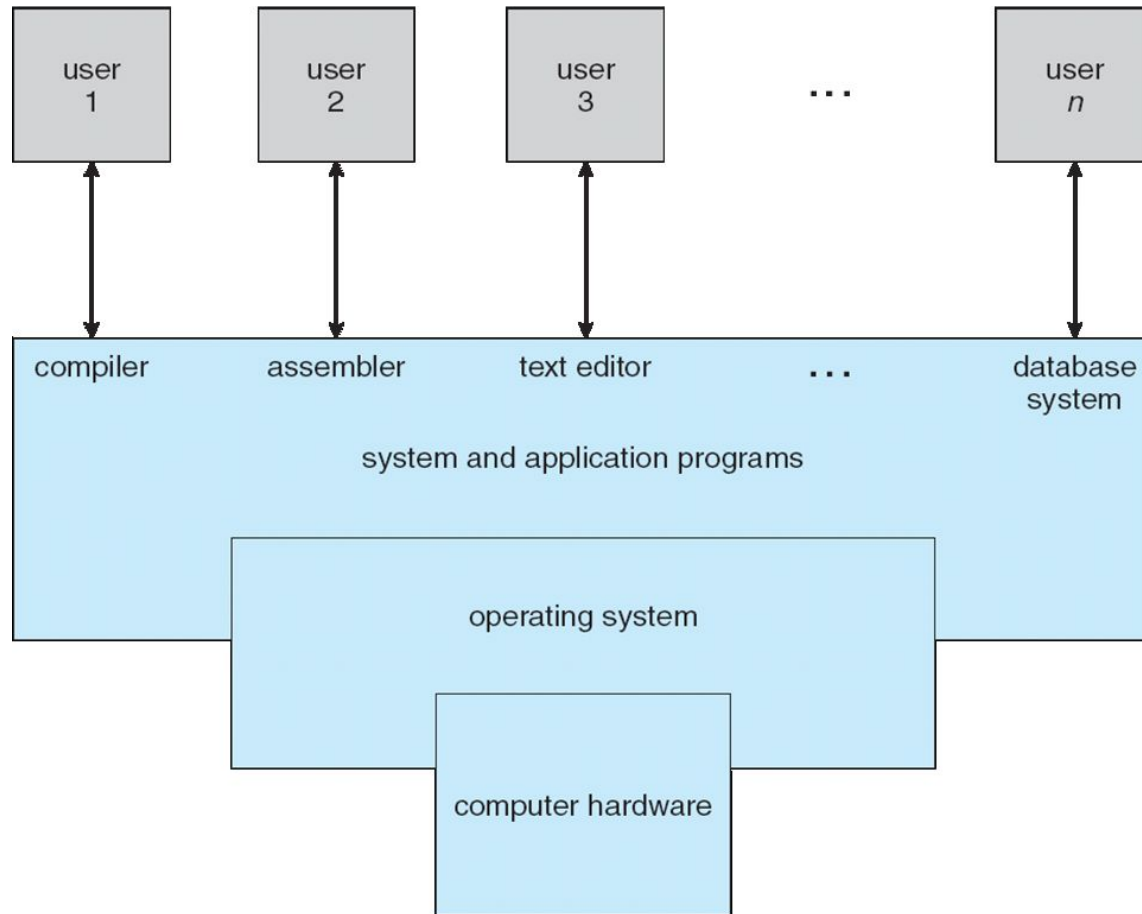
What is an Operating System?

- 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



What Operating Systems Do

- Depends on the point of view
- Users want convenience, **ease of use** and **good performance**
 - Don't care about **resource utilization**
- But shared computer such as **mainframe** or **minicomputer** must keep all users happy
- Users of dedicate systems such as **workstations** have dedicated resources but frequently use shared resources from **servers**
- Handheld computers are resource poor, optimized for usability and battery life
- Some computers have little or no user interface, such as embedded computers in devices and automobiles

Operating System Definition

- OS is a **resource allocator**
 - Manages all resources
 - Decides between conflicting requests for efficient and fair resource use
- OS is a **control program**
 - Controls execution of programs to prevent errors and improper use of the computer

Operating System Definition (Cont.)

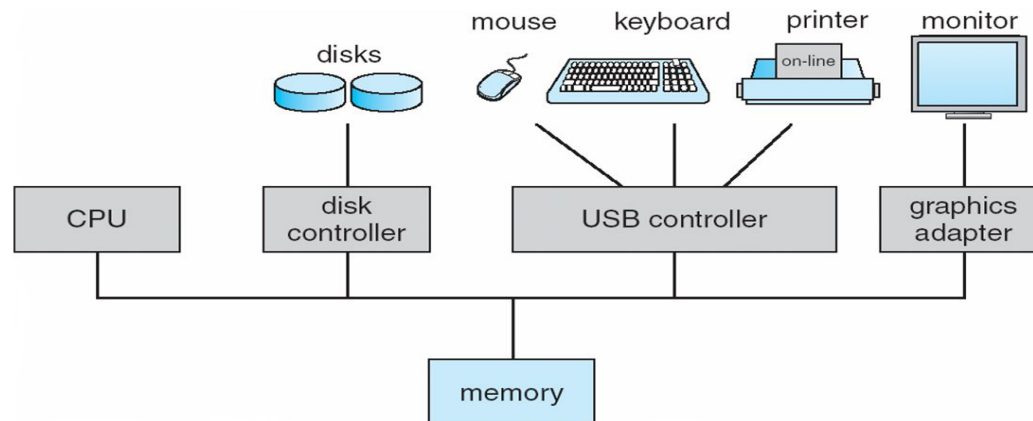
- No universally accepted definition
- “Everything a vendor ships when you order an operating system” is a good approximation
 - But varies wildly
- “The one program running at all times on the computer” is the **kernel**.
- Everything else is either
 - a system program (ships with the operating system) , or
 - an application program.

Computer Startup

- **bootstrap program** is loaded at power-up or reboot
 - Typically stored in ROM or EPROM, generally known as **firmware**
 - Initializes all aspects of system
 - Loads operating system kernel and starts execution

Computer System Organization

- Computer-system operation
 - One or more CPUs, device controllers connect through common bus providing access to shared memory
 - Concurrent execution of CPUs and devices competing for memory cycles



Computer-System Operation

- I/O devices and the CPU can execute concurrently
- Each device controller is in charge of a particular device type
- Each device controller has a local buffer
- CPU moves data from/to main memory to/from local buffers
- I/O is from the device to local buffer of controller
- Device controller informs CPU that it has finished its operation by causing an **interrupt**

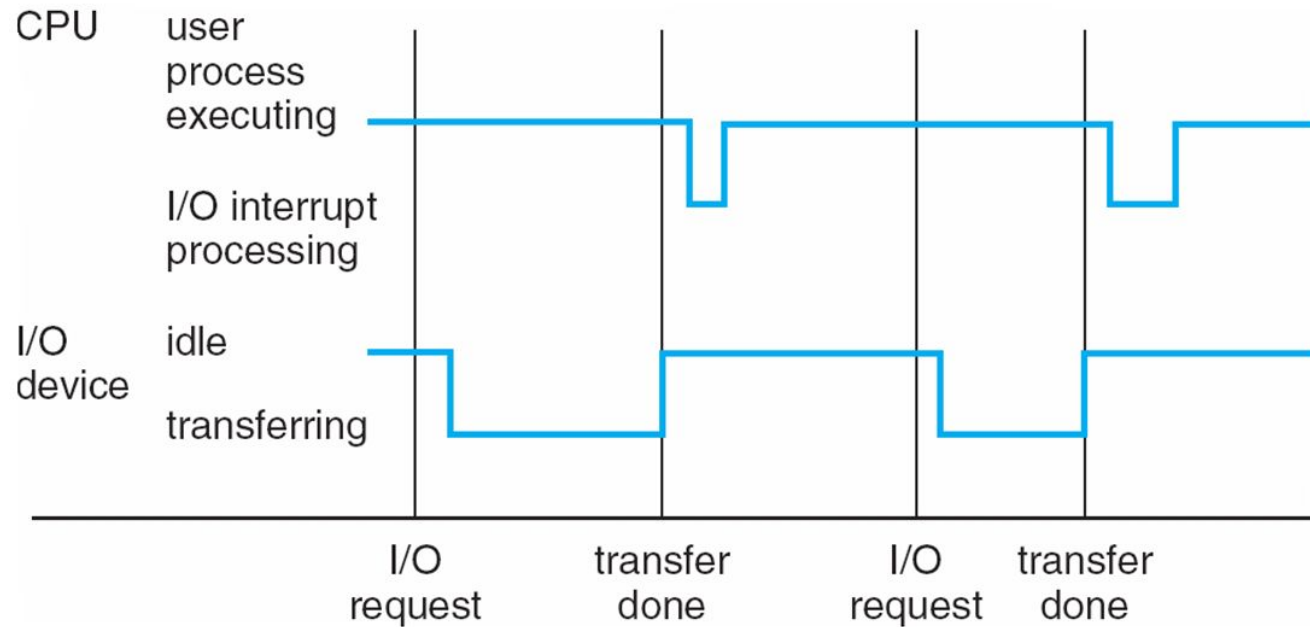
Common Functions of Interrupts

- Interrupt transfers control to the interrupt service routine generally, through the **interrupt vector**, which contains the addresses of all the service routines
- Interrupt architecture must save the address of the interrupted instruction
- A **trap** or **exception** is a software-generated interrupt caused either by an error or a user request
- An operating system is **interrupt driven**

Interrupt Handling

- The operating system preserves the state of the CPU by storing registers and the program counter
- Determines which type of interrupt has occurred:
 - **polling**
 - **vectored** interrupt system
- Separate segments of code determine what action should be taken for each type of interrupt

Interrupt Timeline



I/O Structure

- After I/O starts, control returns to user program only upon I/O completion
 - Wait instruction idles the CPU until the next interrupt
 - Wait loop (contention for memory access)
 - At most one I/O request is outstanding at a time, no simultaneous I/O processing
- After I/O starts, control returns to user program without waiting for I/O completion
 - **System call** – request to the OS to allow user to wait for I/O completion
 - **Device-status table** contains entry for each I/O device indicating its type, address, and state
 - OS indexes into I/O device table to determine device status and to modify table entry to include interrupt

Storage Definitions and Notation Review

The basic unit of computer storage is the **bit**. A bit can contain one of two values, 0 and 1. All other storage in a computer is based on collections of bits. Given enough bits, it is amazing how many things a computer can represent: numbers, letters, images, movies, sounds, documents, and programs, to name a few. A **byte** is 8 bits, and on most computers it is the smallest convenient chunk of storage. For example, most computers don't have an instruction to move a bit but do have one to move a byte. A less common term is **word**, which is a given computer architecture's native unit of data. A word is made up of one or more bytes. For example, a computer that has 64-bit registers and 64-bit memory addressing typically has 64-bit (8-byte) words. A computer executes many operations in its native word size rather than a byte at a time.

Computer storage, along with most computer throughput, is generally measured and manipulated in bytes and collections of bytes.

A **kilobyte**, or **KB**, is 1,024 bytes

a **megabyte**, or **MB**, is $1,024^2$ bytes

a **gigabyte**, or **GB**, is $1,024^3$ bytes

a **terabyte**, or **TB**, is $1,024^4$ bytes

a **petabyte**, or **PB**, is $1,024^5$ bytes

Computer manufacturers often round off these numbers and say that a megabyte is 1 million bytes and a gigabyte is 1 billion bytes. Networking measurements are an exception to this general rule; they are given in bits (because networks move data a bit at a time).

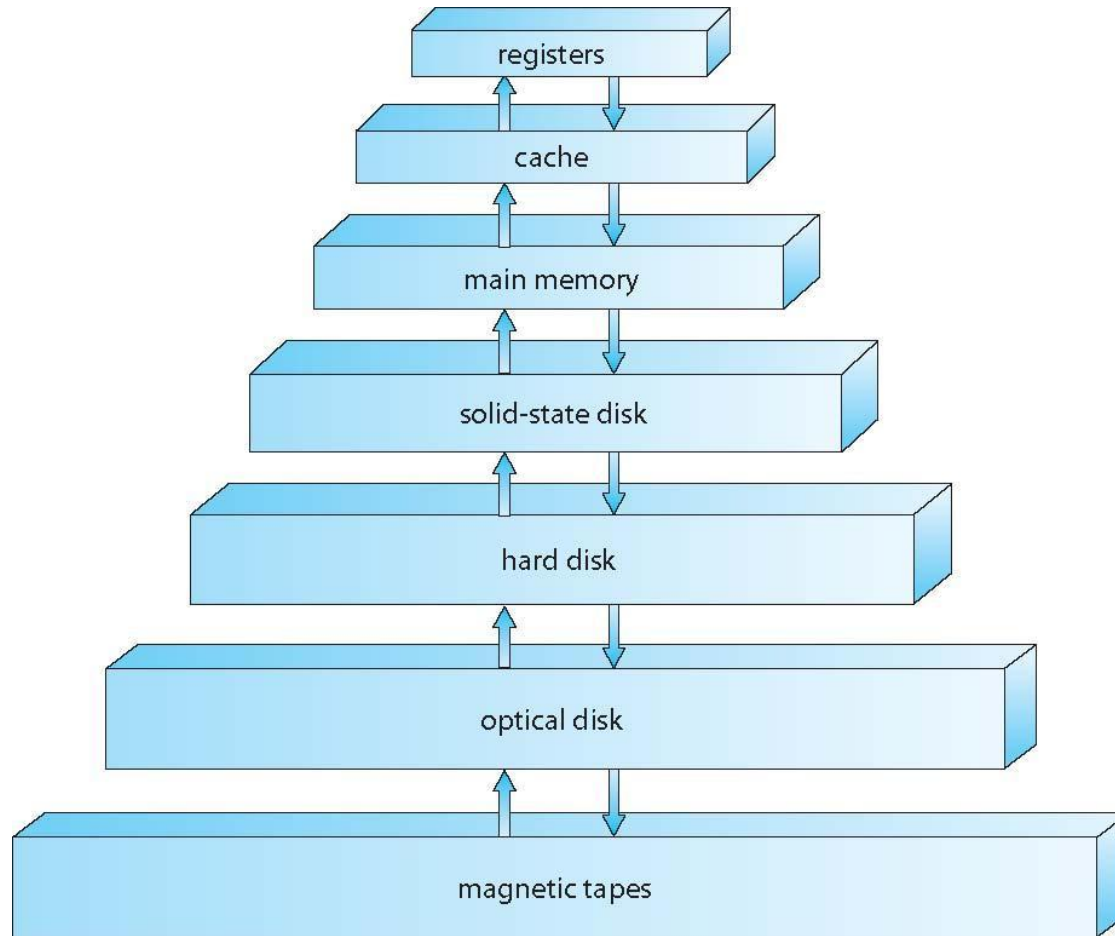
Storage Structure

- Main memory – only large storage media that the CPU can access directly
 - **Random access**
 - Typically **volatile**
- Secondary storage – extension of main memory that provides large **nonvolatile** storage capacity
- Hard disks – rigid metal or glass platters covered with magnetic recording material
 - Disk surface is logically divided into **tracks**, which are subdivided into **sectors**
 - The **disk controller** determines the logical interaction between the device and the computer
- **Solid-state disks** – faster than hard disks, nonvolatile
 - Various technologies
 - Becoming more popular

Storage Hierarchy

- Storage systems organized in hierarchy
 - Speed
 - Cost
 - Volatility
- **Caching** – copying information into faster storage system; main memory can be viewed as a cache for secondary storage
- **Device Driver** for each device controller to manage I/O
 - Provides uniform interface between controller and kernel

Storage-Device Hierarchy



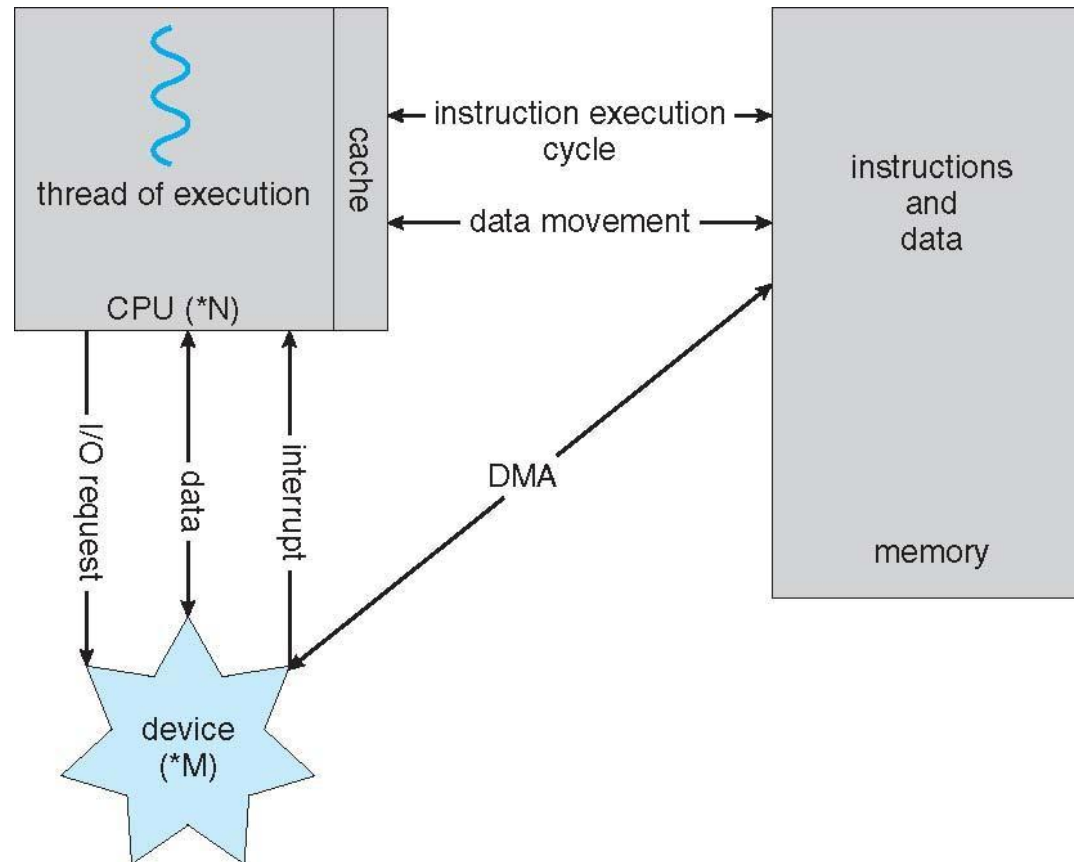
Caching

- Important principle, performed at many levels in a computer (in hardware, operating system, software)
- Information in use copied from slower to faster storage temporarily
- Faster storage (cache) checked first to determine if information is there
 - If it is, information used directly from the cache (fast)
 - If not, data copied to cache and used there
- Cache smaller than storage being cached
 - Cache management important design problem
 - Cache size and replacement policy

Direct Memory Access Structure

- Used for high-speed I/O devices able to transmit information at close to memory speeds
- Device controller transfers blocks of data from buffer storage directly to main memory without CPU intervention
- Only one interrupt is generated per block, rather than the one interrupt per byte

How a Modern Computer Works

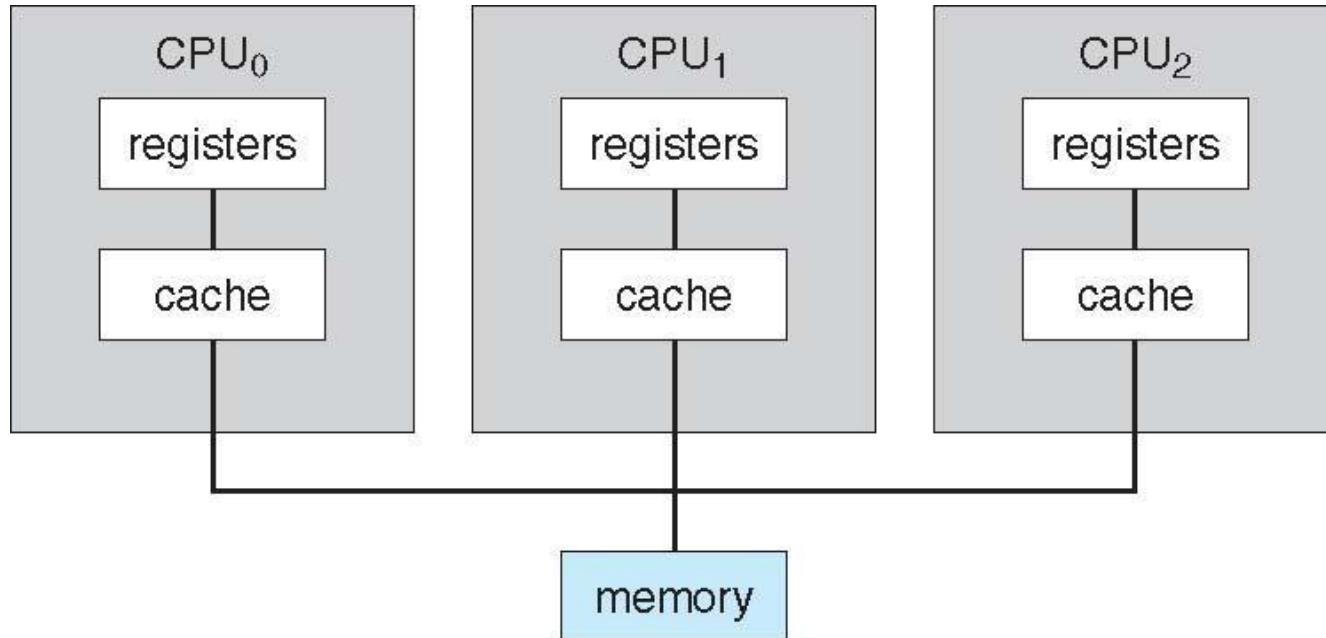


A von Neumann architecture

Computer-System Architecture

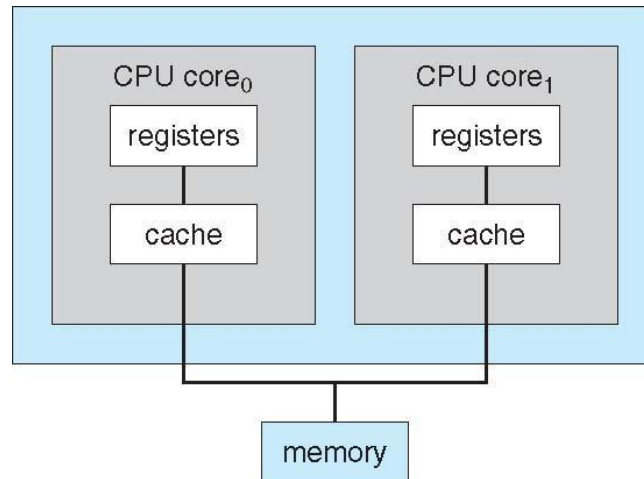
- Most systems use a single general-purpose processor
 - Most systems have special-purpose processors as well
- **Multiprocessors** systems growing in use and importance
 - Also known as **parallel systems**, **tightly-coupled systems**
 - Advantages include:
 1. **Increased throughput**
 2. **Economy of scale**
 3. **Increased reliability** – graceful degradation or fault tolerance
 - Two types:
 1. **Asymmetric Multiprocessing** – each processor is assigned a specific task.
 2. **Symmetric Multiprocessing** – each processor performs all tasks

Symmetric Multiprocessing Architecture



A Dual-Core Design

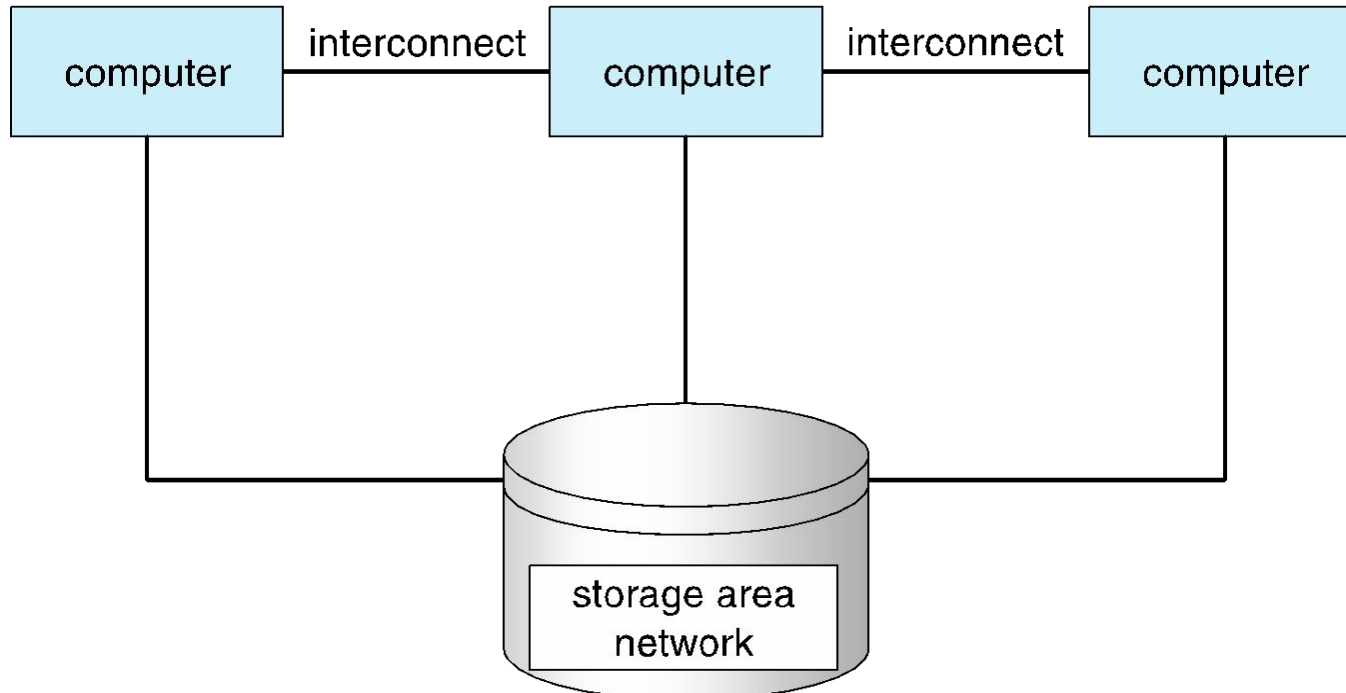
- Multi-chip and **multicore**
- Systems containing all chips
 - Chassis containing multiple separate systems



Clustered Systems

- Like multiprocessor systems, but multiple systems working together
 - Usually sharing storage via a **storage-area network (SAN)**
 - Provides a **high-availability** service which survives failures
 - **Asymmetric clustering** has one machine in hot-standby mode
 - **Symmetric clustering** has multiple nodes running applications, monitoring each other
 - Some clusters are for **high-performance computing (HPC)**
 - Applications must be written to use **parallelization**
 - Some have **distributed lock manager (DLM)** to avoid conflicting operations

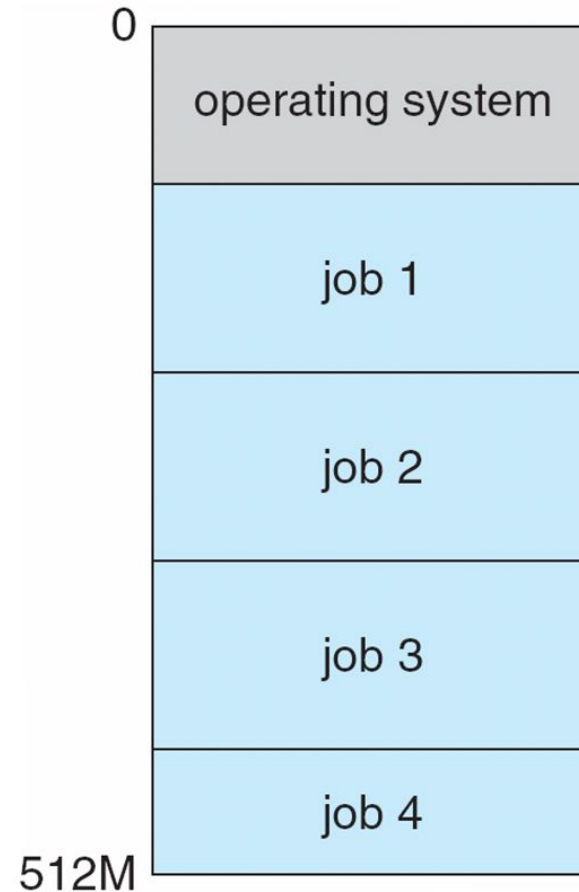
Clustered Systems



Operating System Structure

- **Multiprogramming (Batch system)** needed for efficiency
 - Single user cannot keep CPU and I/O devices busy at all times
 - Multiprogramming organizes jobs (code and data) so CPU always has one to execute
 - A subset of total jobs in system is kept in memory
 - One job selected and run via **job scheduling**
 - When it has to wait (for I/O for example), OS switches to another job
- **Timesharing (multitasking)** is logical extension in which CPU switches jobs so frequently that users can interact with each job while it is running, creating **interactive** computing
 - **Response time** should be < 1 second
 - Each user has at least one program executing in memory □ **process**
 - If several jobs ready to run at the same time □ **CPU scheduling**
 - If processes don't fit in memory, **swapping** moves them in and out to run
 - **Virtual memory** allows execution of processes not completely in memory

Memory Layout for Multiprogrammed System



Operating-System Operations

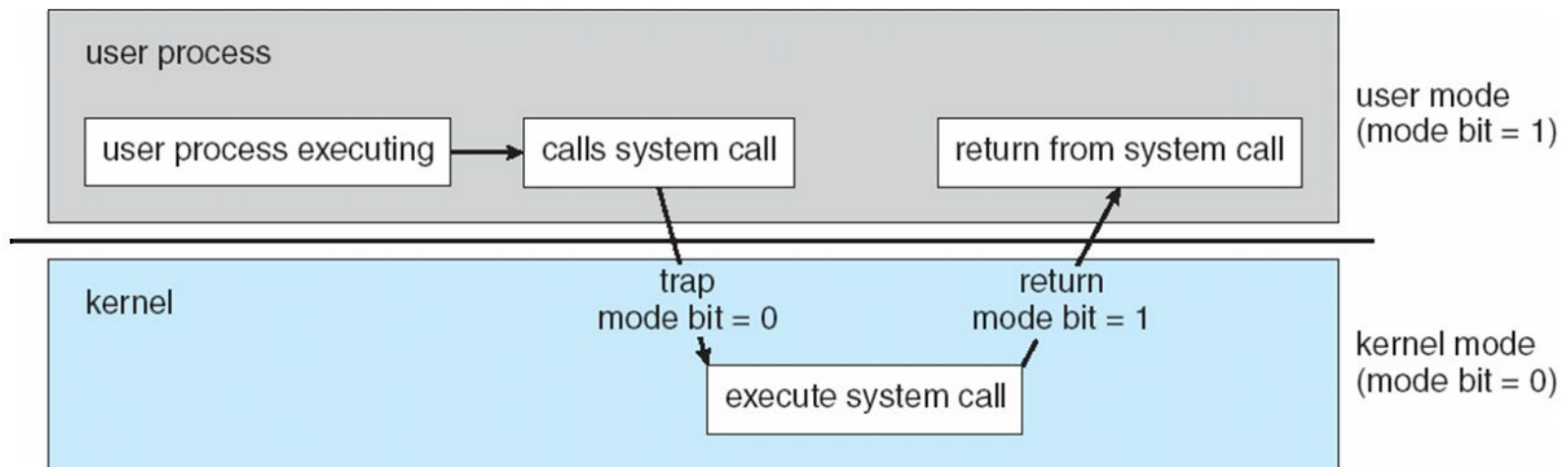
- **Interrupt driven** (hardware and software)
 - Hardware interrupt by one of the devices
 - Software interrupt (**exception** or **trap**):
 - Software error (e.g., division by zero)
 - Request for operating system service
 - Other process problems include infinite loop, processes modifying each other or the operating system

Operating-System Operations (cont.)

- **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
- Increasingly CPUs support multi-mode operations
 - i.e. **virtual machine manager (VMM)** mode for guest **VMs**

Transition from User to Kernel Mode

- Timer to prevent infinite loop / process hogging resources
 - Timer is set to interrupt the computer after some time period
 - Keep a counter that is decremented by the physical clock.
 - Operating system set the counter (privileged instruction)
 - When counter zero generate an interrupt
 - Set up before scheduling process to regain control or terminate program that exceeds allotted time



Process Management

- 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

- To execute a program all (or part) of the instructions must be in memory
- All (or part) of the data that is needed by the program must be in memory.
- Memory management determines what is in memory and 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 deallocating 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 directories
 - 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
- OS 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 – by OS or applications
 - Varies between WORM (write-once, read-many-times) and RW (read-write)

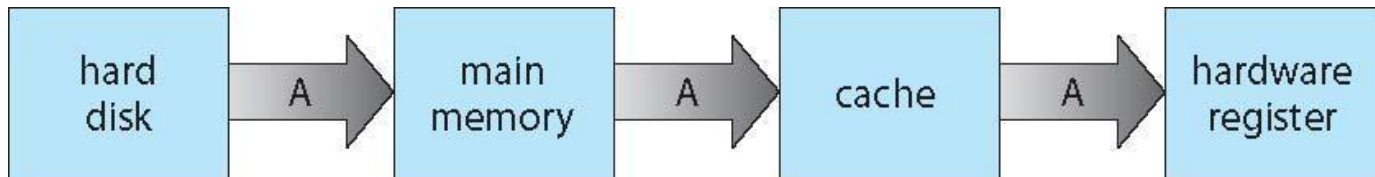
Performance of Various Levels of Storage

Level	1	2	3	4	5
Name	registers	cache	main memory	solid state disk	magnetic disk
Typical size	< 1 KB	< 16MB	< 64GB	< 1 TB	< 10 TB
Implementation technology	custom memory with multiple ports CMOS	on-chip or off-chip CMOS SRAM	CMOS SRAM	flash memory	magnetic disk
Access time (ns)	0.25 - 0.5	0.5 - 25	80 - 250	25,000 - 50,000	5,000,000
Bandwidth (MB/sec)	20,000 - 100,000	5,000 - 10,000	1,000 - 5,000	500	20 - 150
Managed by	compiler	hardware	operating system	operating system	operating system
Backed by	cache	main memory	disk	disk	disk or tape

Movement between levels of storage hierarchy can be explicit or implicit

Migration of data “A” from Disk to Register

- Multitasking environments must be careful to use most recent value, no matter where it is stored in the storage hierarchy



- Multiprocessor environment must provide **cache coherency** in hardware such that all CPUs have the most recent value in their cache
- Distributed environment situation even more complex
 - Several copies of a datum can exist

I/O Subsystem

- One purpose of OS is to hide peculiarities of hardware devices from the user
- I/O subsystem responsible for
 - Memory management of I/O including buffering (storing data temporarily while it is being transferred), caching (storing parts of data in faster storage for performance), spooling (the overlapping of output of one job with input of other jobs)
 - General device-driver interface
 - Drivers for specific hardware devices

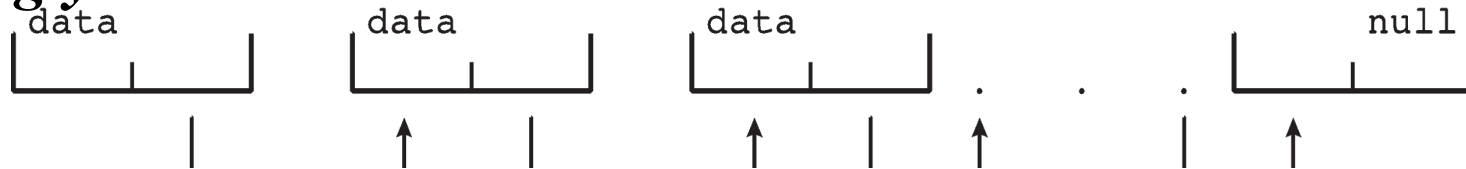
Protection and Security

- **Protection** – any mechanism for controlling access of processes or users to resources defined by the OS
- **Security** – defense of the system against internal and external attacks
 - Huge range, including denial-of-service, worms, viruses, identity theft, theft of service
- Systems generally first distinguish among users, to determine who can do what
 - User identities (**user IDs**, security IDs) include name and associated number, one per user
 - 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

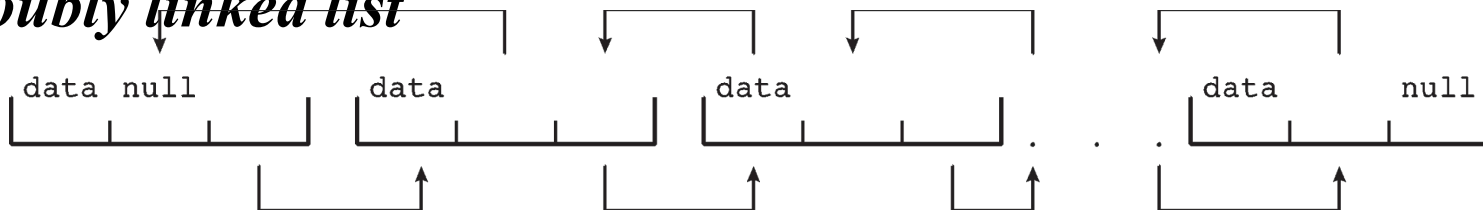
Kernel Data Structures

- Many similar to standard programming data structures

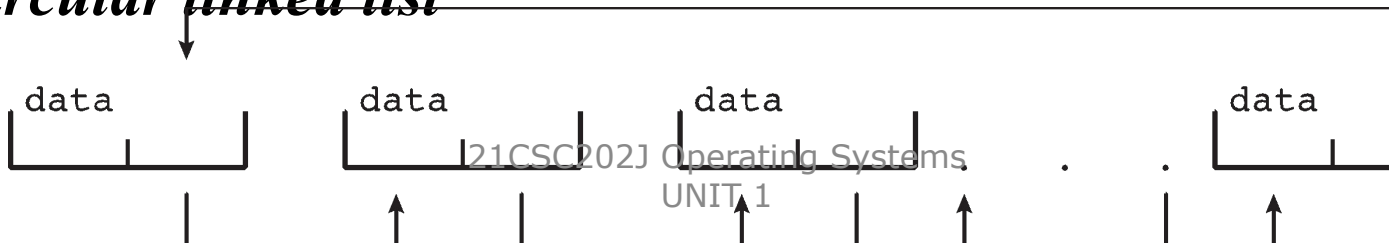
- Singly linked list***



- Doubly linked list***



- Circular linked list***

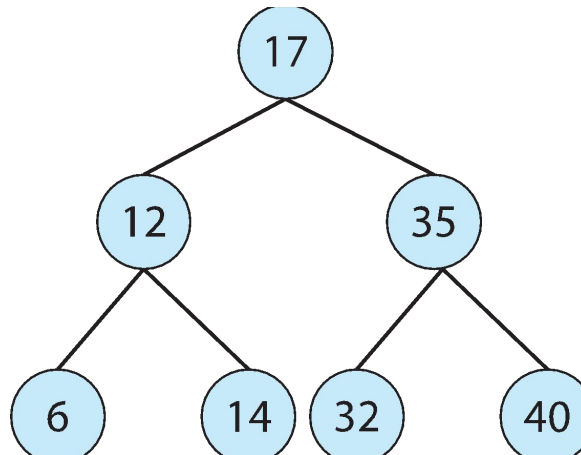


Kernel Data Structures

- **Binary search tree**

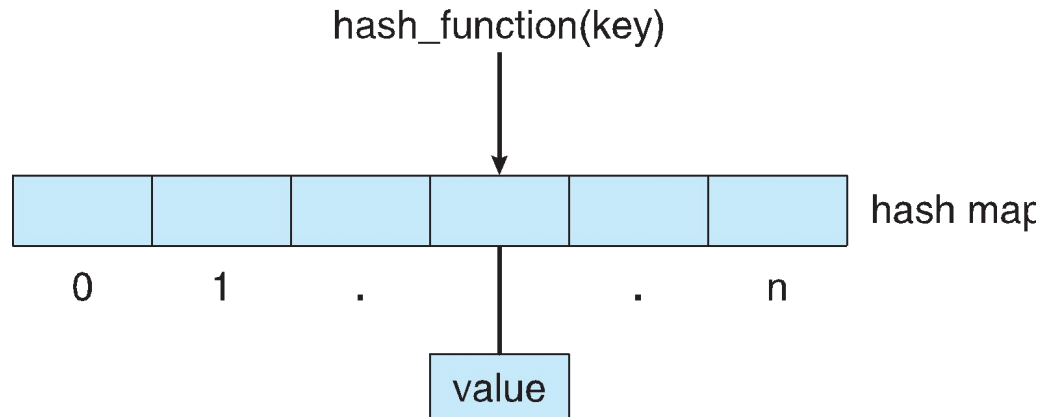
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- Search performance is $O(n)$
- **Balanced binary search tree** is $O(\lg n)$



Kernel Data Structures

- **Hash function** can create a **hash map**



- **Bitmap** – string of n binary digits representing the status of n items
- Linux data structures defined in
include files `<linux/list.h>`, `<linux/kfifo.h>`,
`<linux/rbtree.h>`

Computing Environments - Traditional

- Stand-alone general purpose machines
- But blurred as most systems interconnect with others (i.e., the Internet)
- **Portals** provide web access to internal systems
- **Network computers (thin clients)** are like Web terminals
- Mobile computers interconnect via **wireless networks**
- Networking becoming ubiquitous – even home systems use **firewalls** to protect home computers from Internet attacks

Computing Environments - Mobile

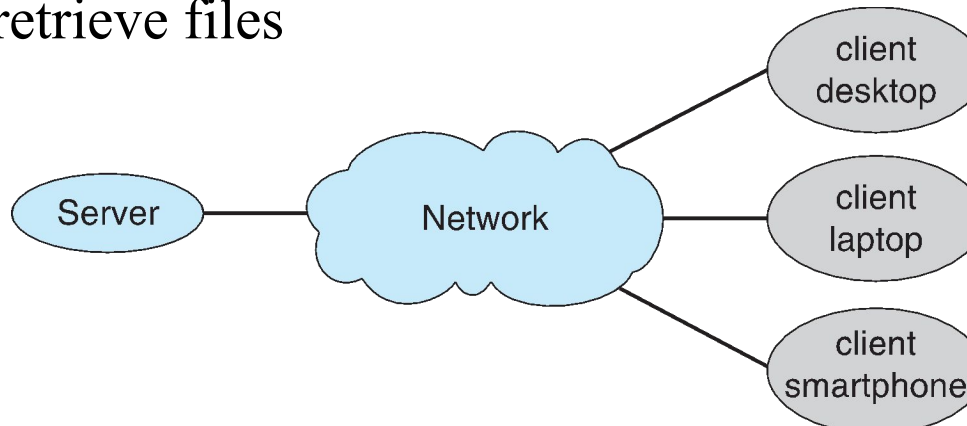
- Handheld smartphones, tablets, etc
- What is the functional difference between them and a “traditional” laptop?
- Extra feature – more OS features (GPS, gyroscope)
- Allows new types of apps like *augmented reality*
- Use IEEE 802.11 wireless, or cellular data networks for connectivity
- Leaders are **Apple iOS** and **Google Android**

Computing Environments – Distributed

- Distributed computing
 - Collection of separate, possibly heterogeneous, systems networked together
 - **Network** is a communications path, **TCP/IP** most common
 - **Local Area Network (LAN)**
 - **Wide Area Network (WAN)**
 - **Metropolitan Area Network (MAN)**
 - **Personal Area Network (PAN)**
 - **Network Operating System** provides features between systems across network
 - Communication scheme allows systems to exchange messages
 - Illusion of a single system

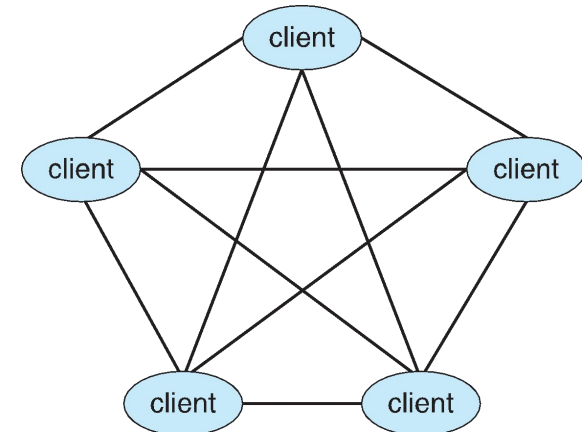
Computing Environments – Client-Server

- Client-Server Computing
 - Dumb terminals supplanted by smart PCs
 - Many systems now **servers**, responding to requests generated by **clients**
 - 4 **Compute-server system** provides an interface to client to request services (i.e., database)
 - 4 **File-server system** provides interface for clients to store and retrieve files



Computing Environments - Peer-to-Peer

- Another model of distributed system
- P2P does not distinguish clients and servers
 - Instead all nodes are considered peers
 - May each act as client, server or both
 - Node must join P2P network
 - Registers its service with central lookup service on network, or
 - Broadcast request for service and respond to requests for service via *discovery protocol*
 - Examples include Napster and Gnutella, **Voice over IP (VoIP)** such as Skype



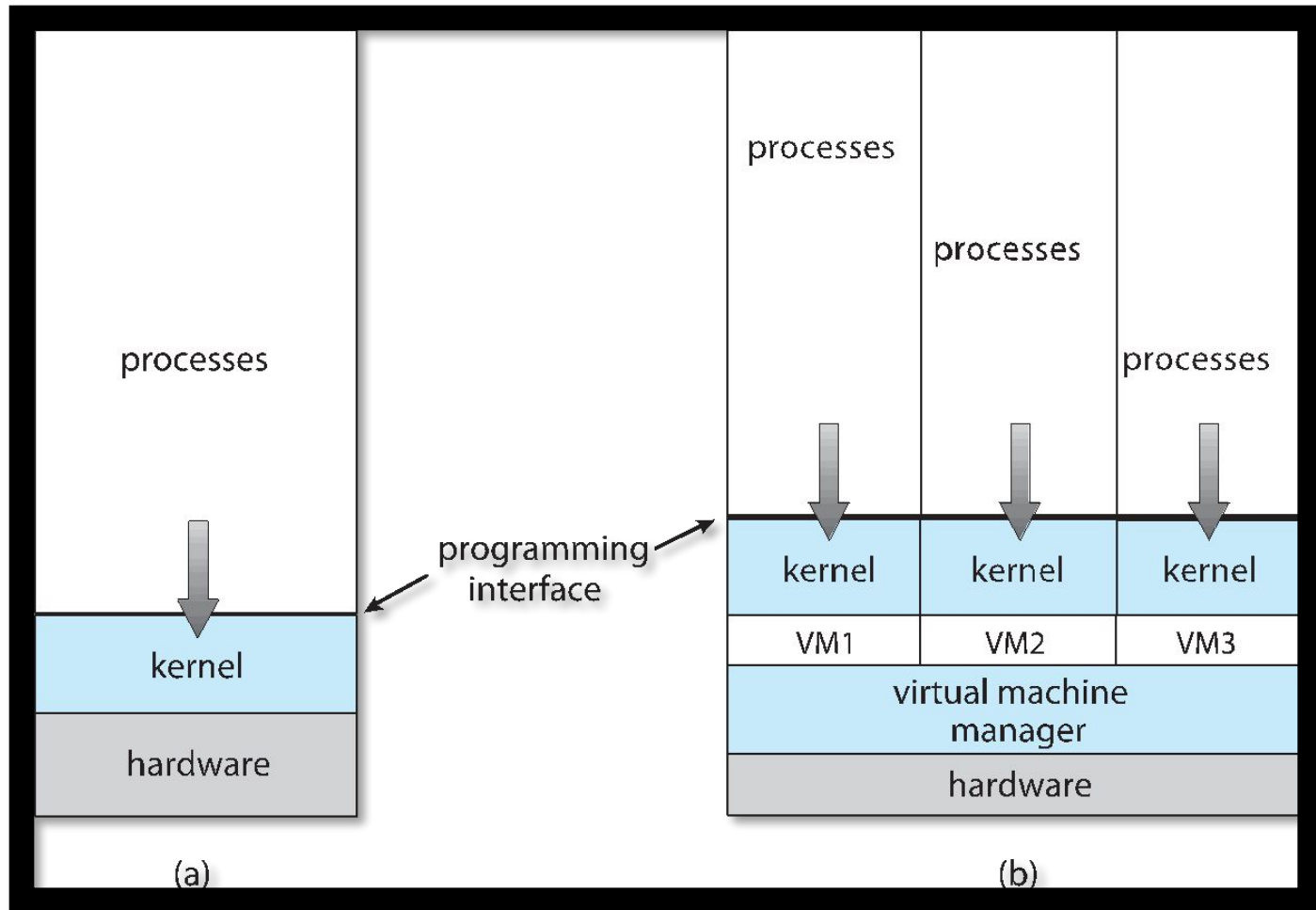
Computing Environments - Virtualization

- Allows operating systems to run applications within other OSES
 - Vast and growing industry
- **Emulation** used when source CPU type different from target type (i.e. PowerPC to Intel x86)
 - Generally slowest method
 - When computer language not compiled to native code –
Interpretation
- **Virtualization** – OS natively compiled for CPU, running **guest** OSES also natively compiled
 - Consider VMware running WinXP guests, each running applications, all on native WinXP **host** OS
 - **VMM** (virtual machine Manager) provides virtualization services

Computing Environments - Virtualization

- Use cases involve laptops and desktops running multiple OSES for exploration or compatibility
 - Apple laptop running Mac OS X host, Windows as a guest
 - Developing apps for multiple OSES without having multiple systems
 - QA testing applications without having multiple systems
 - Executing and managing compute environments within data centers
- VMM can run natively, in which case they are also the host
 - There is no general purpose host then (VMware ESX and Citrix XenServer)

Computing Environments - Virtualization

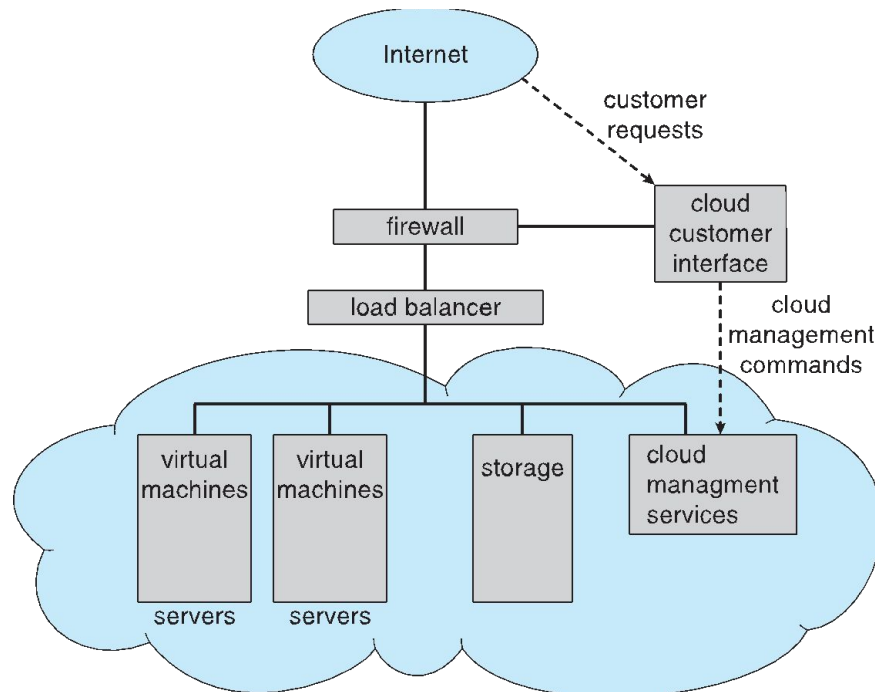


Computing Environments – Cloud Computing

- Delivers computing, storage, even apps as a service across a network
- Logical extension of virtualization because it uses virtualization as the base for its functionality.
 - Amazon **EC2** has thousands of servers, millions of virtual machines, petabytes of storage available across the Internet, pay based on usage
- Many types
 - **Public cloud** – available via Internet to anyone willing to pay
 - **Private cloud** – run by a company for the company's own use
 - **Hybrid cloud** – includes both public and private cloud components
 - Software as a Service (**SaaS**) – one or more applications available via the Internet (i.e., word processor)
 - Platform as a Service (**PaaS**) – software stack ready for application use via the Internet (i.e., a database server)
 - Infrastructure as a Service (**IaaS**) – servers or storage available over Internet (i.e., storage available for backup use)

Computing Environments – Cloud Computing

- Cloud computing environments composed of traditional OSe, plus VMMs, plus cloud management tools
 - Internet connectivity requires security like firewalls
 - Load balancers spread traffic across multiple applications



Computing Environments – Real-Time Embedded Systems

- Real-time embedded systems most prevalent form of computers
 - Vary considerable, special purpose, limited purpose OS, **real-time OS**
 - Use expanding
- Many other special computing environments as well
 - Some have OSeS, some perform tasks without an OS
- Real-time OS has well-defined fixed time constraints
 - Processing ***must*** be done within constraint
 - Correct operation only if constraints met

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
- Started by **Free Software Foundation (FSF)**, which has “copyleft” **GNU Public License (GPL)**
- Examples include **GNU/Linux** and **BSD UNIX** (including core of **Mac OS X**), and many more
- Can use VMM like VMware Player (Free on Windows), Virtualbox (open source and free on many platforms - <http://www.virtualbox.com>)
 - Use to run guest operating systems for exploration

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

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

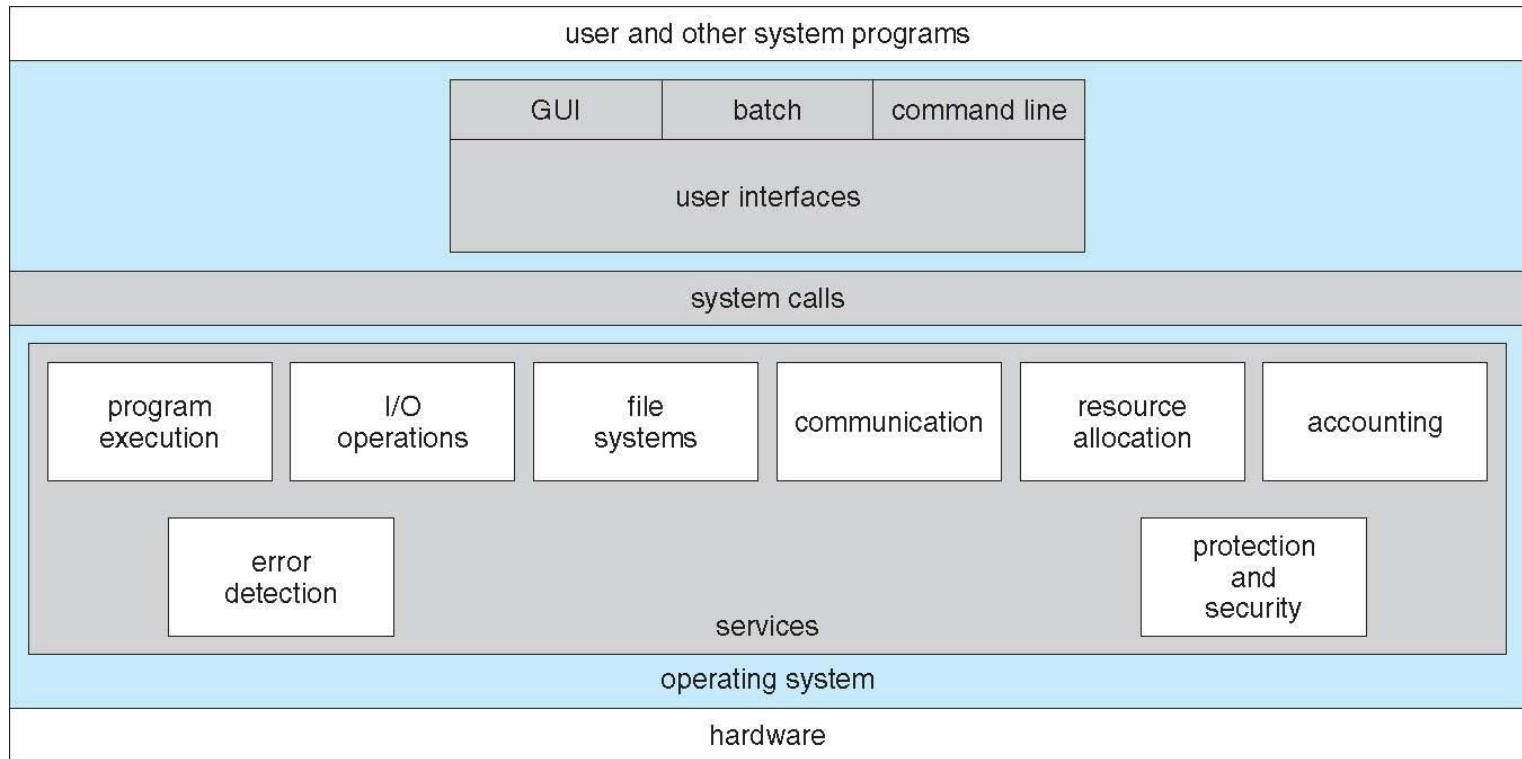
Operating System Services (Cont.)

- 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

A View of Operating System Services

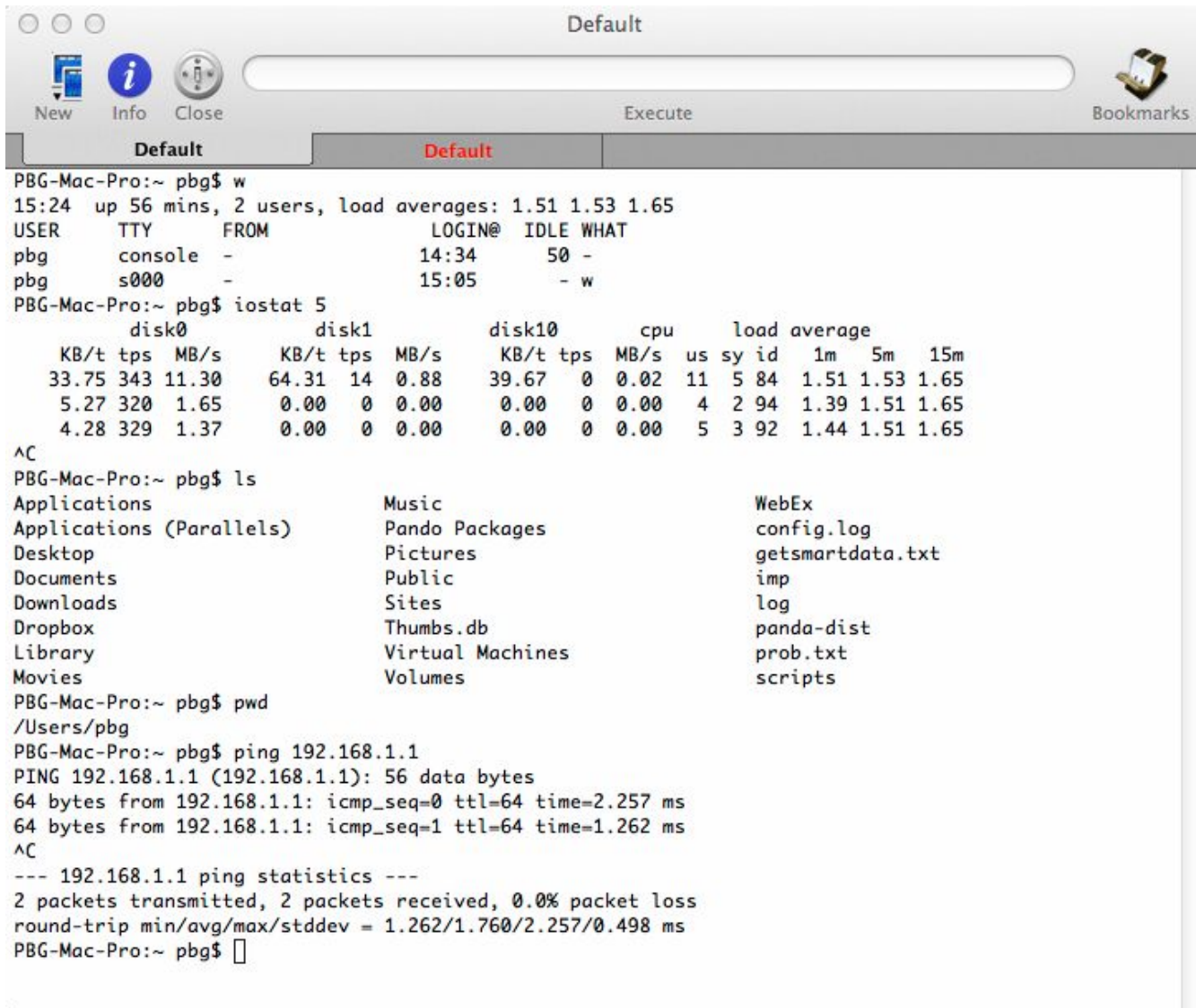


User Operating System Interface - CLI

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)

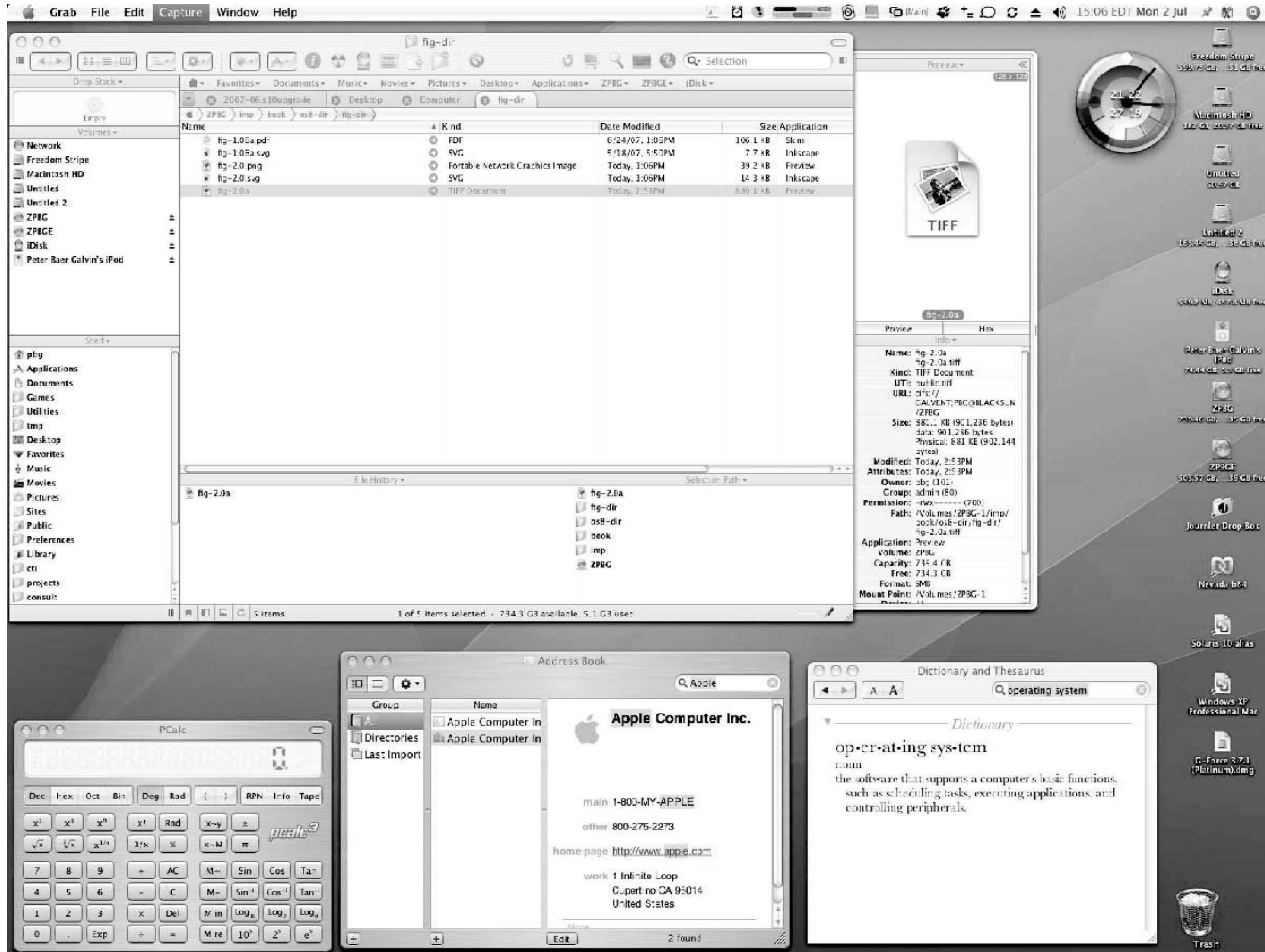
Touchscreen Interfaces

- 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



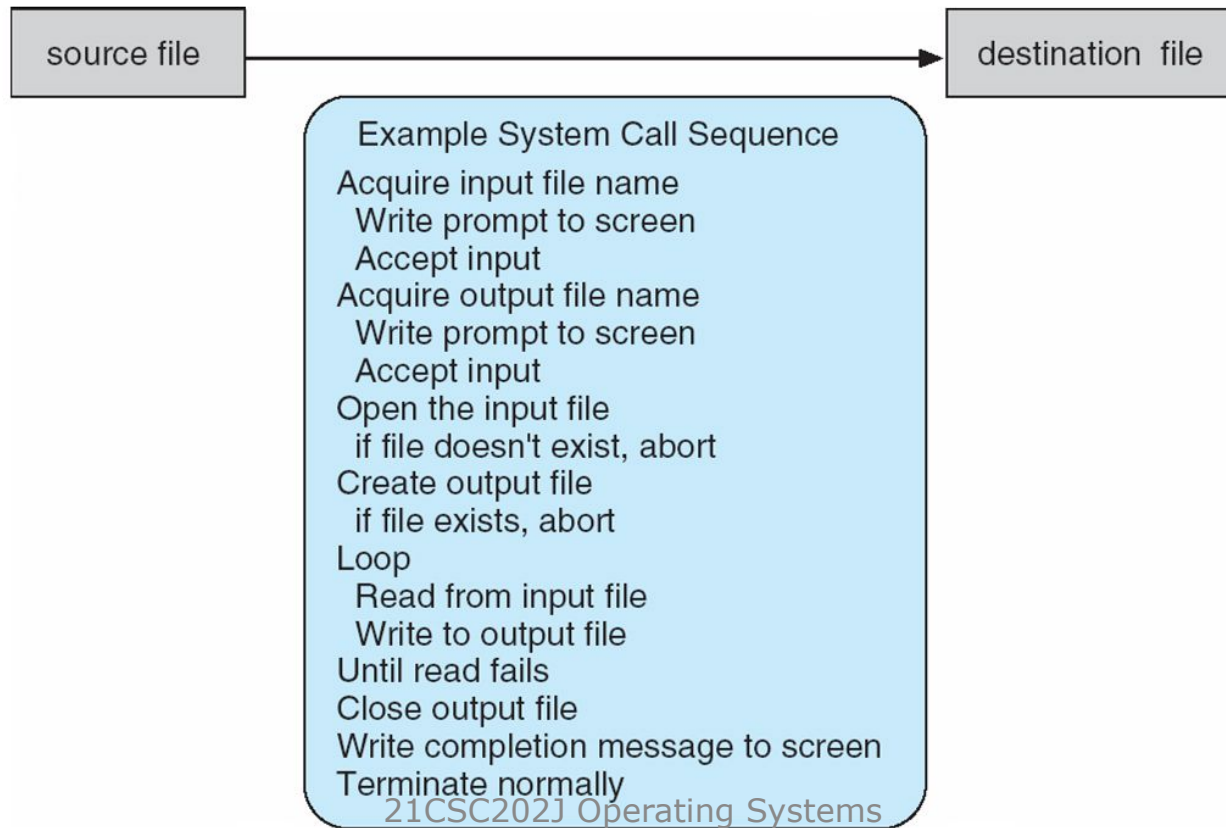
System Calls

- 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
- 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)
```

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

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:

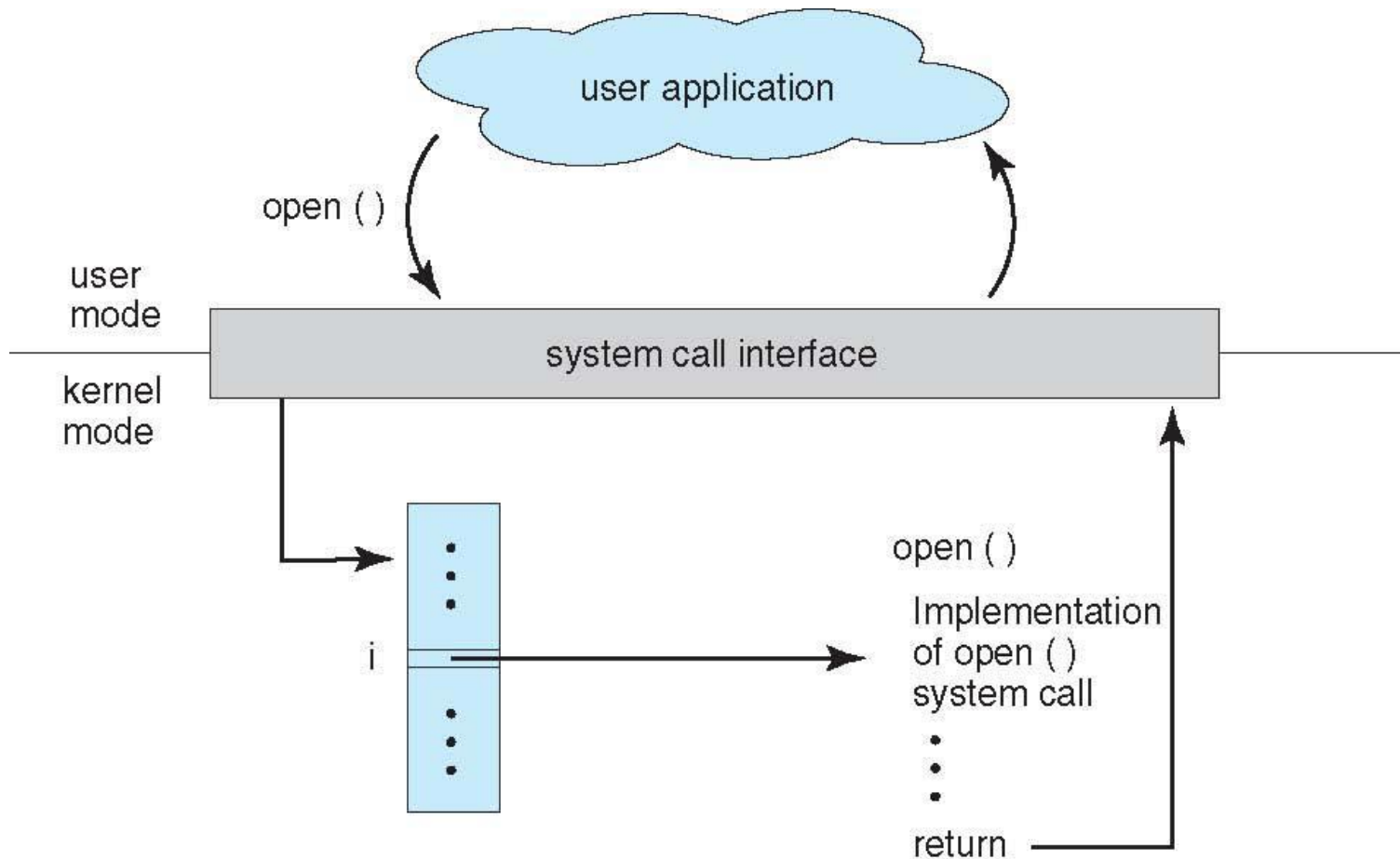
- `int fd`—the file descriptor to be read
- `void *buf`—a buffer where the data will be read into
- `size_t count`—the maximum number of bytes to be read into the buffer

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)

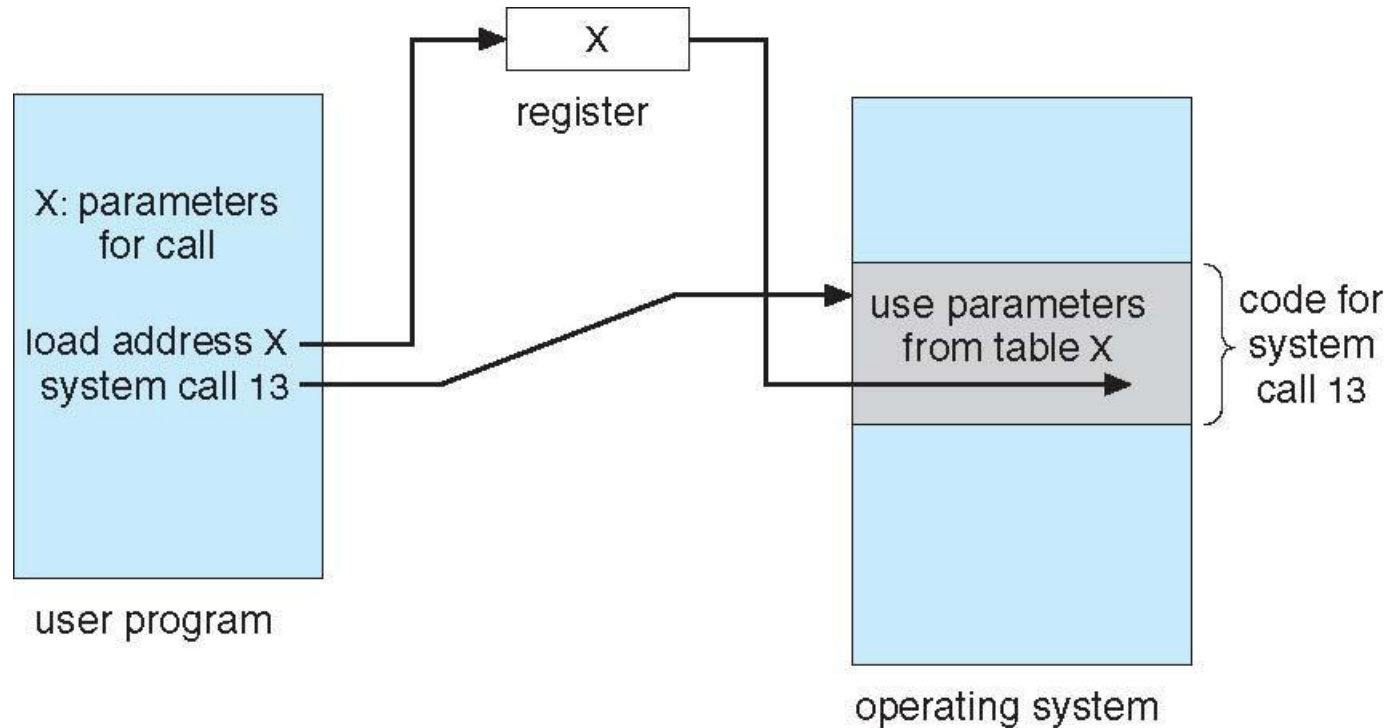
API – System Call – OS Relationship



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



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.)

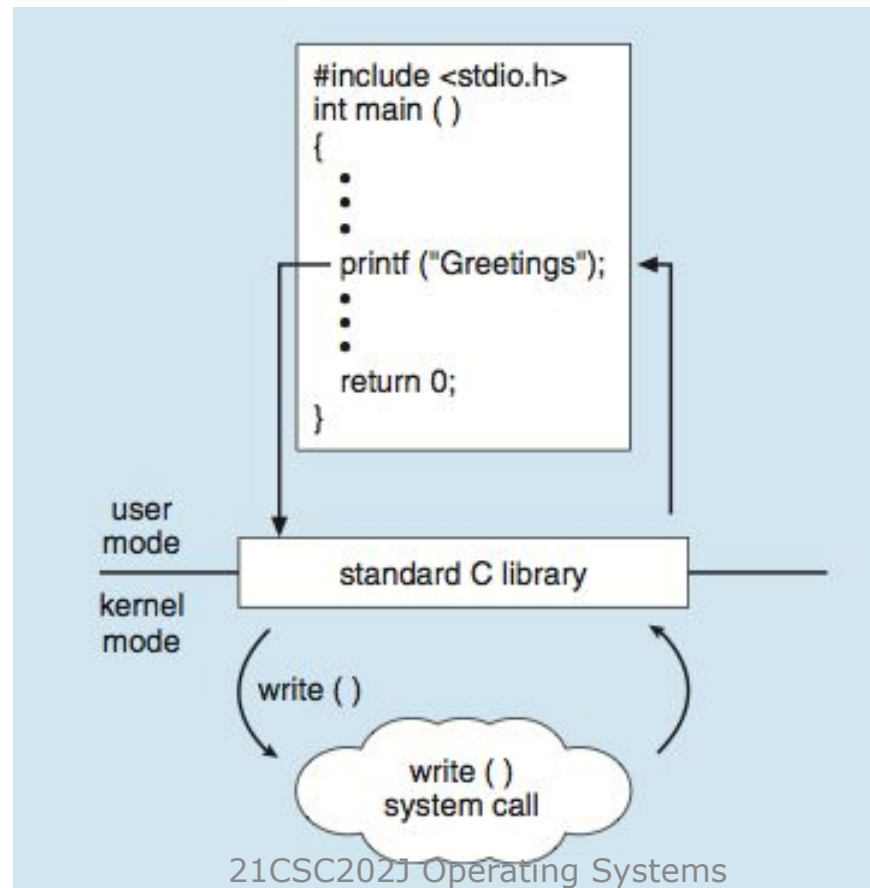
- Protection
 - Control access to resources
 - Get and set permissions
 - Allow and deny user access

Examples of Windows and Unix System Calls

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

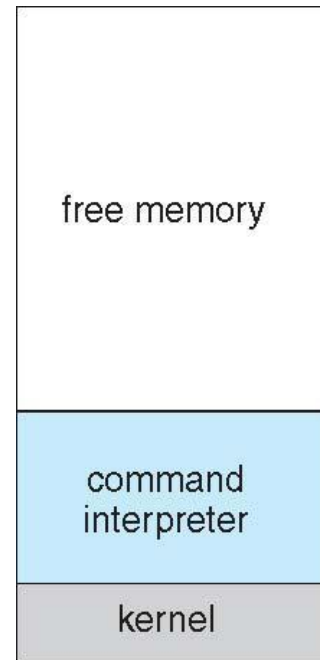
Standard C Library Example

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



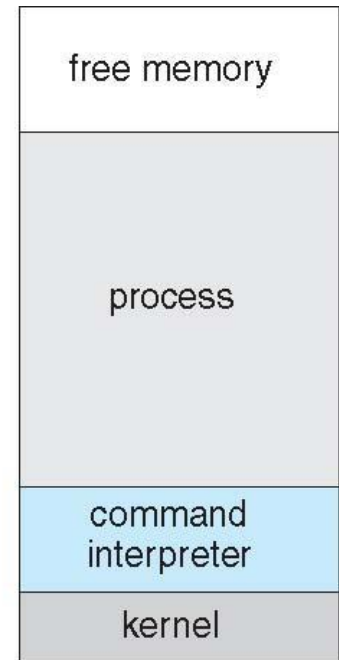
Example: MS-DOS

- 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



(a)

At system startup

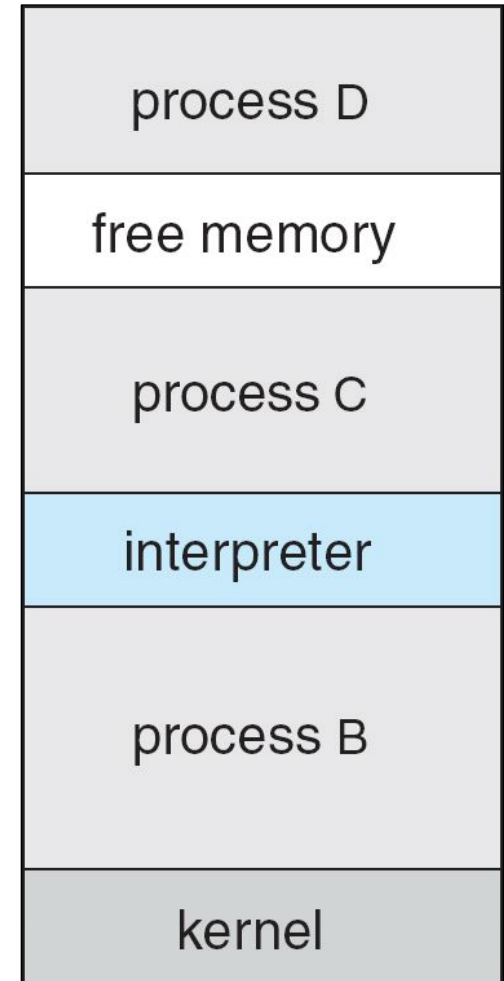


(b)

running a program

Example: 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

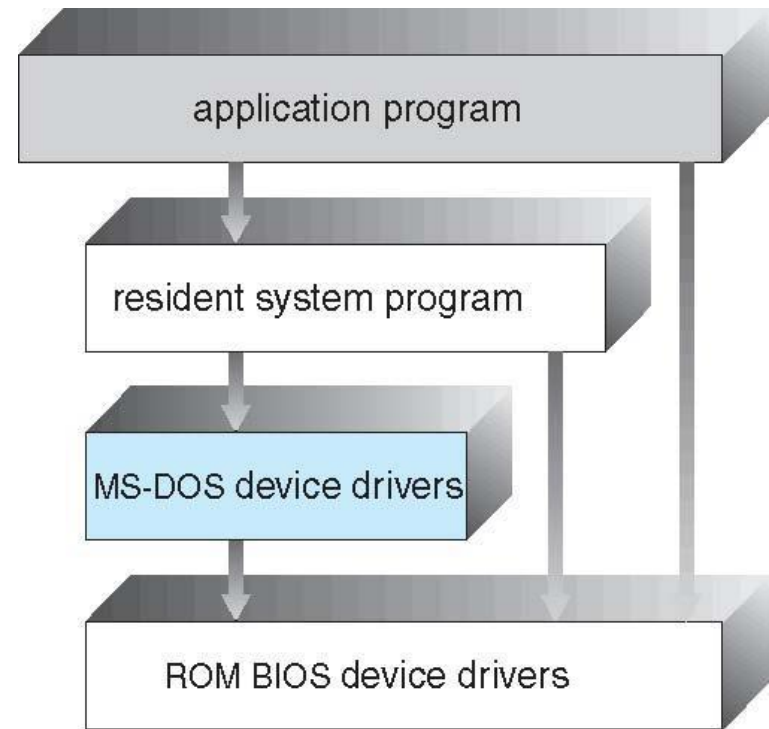
- Much variation
 - Early OSes in assembly language
 - Then system programming languages like Algol, PL/1
 - Now C, C++
- Actually usually a mix of languages
 - Lowest levels in assembly
 - Main body in C
 - Systems programs in C, C++, scripting languages like PERL, Python, shell scripts
- More high-level 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

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



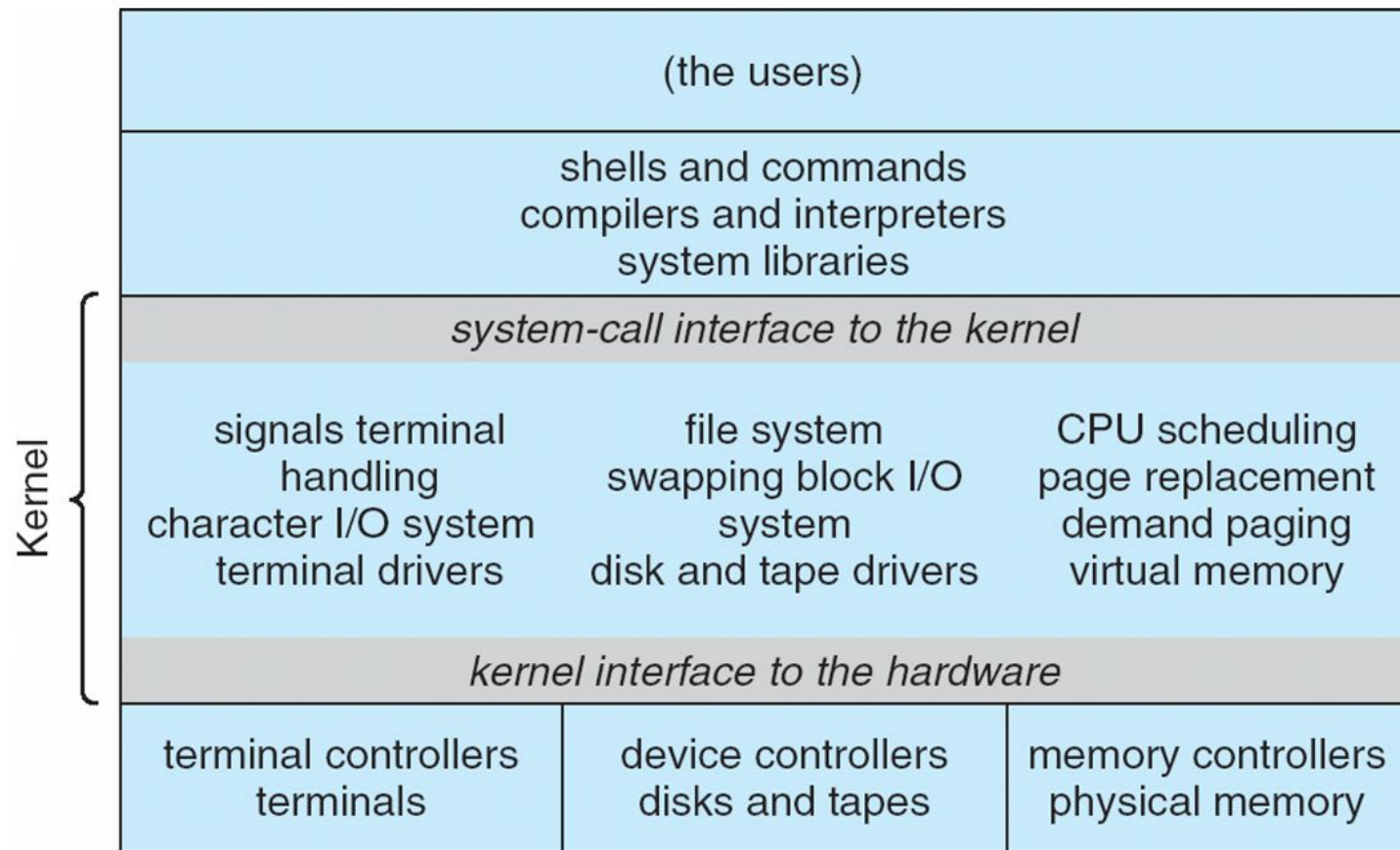
Non Simple Structure -- UNIX

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

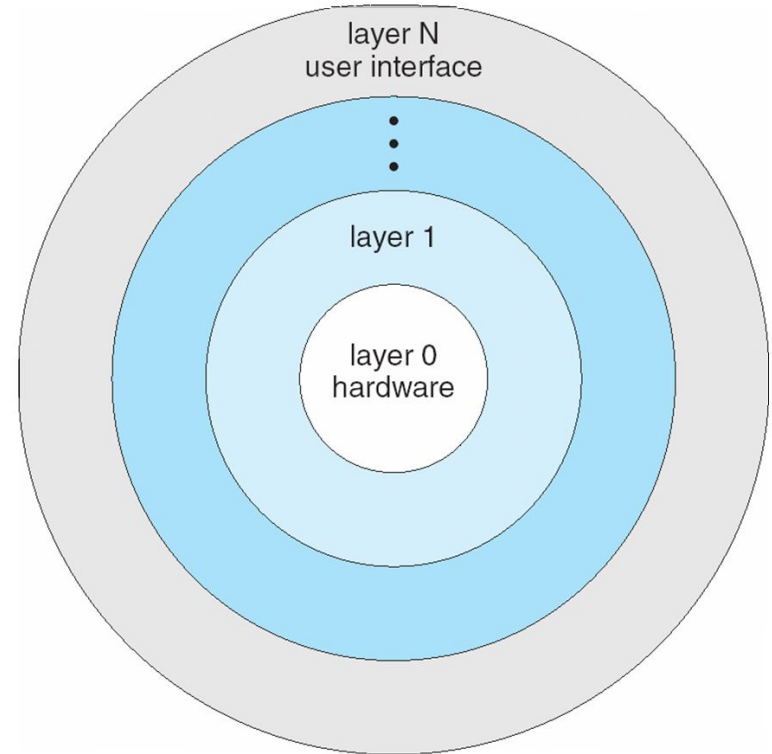
Traditional UNIX System Structure

Beyond simple but not fully layered



Layered Approach

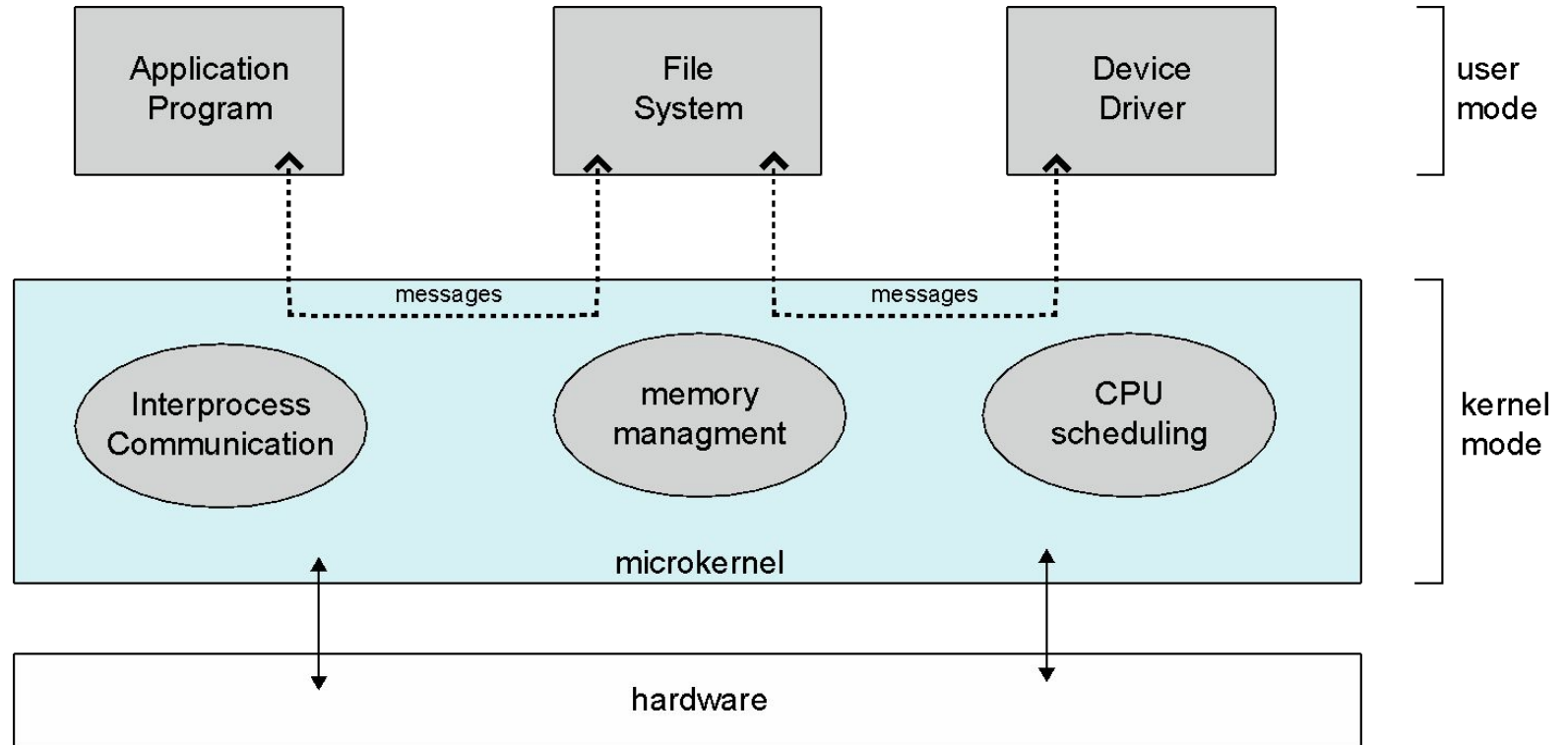
- The operating system is divided into a number of layers (levels), each built on top of lower layers. The bottom layer (layer 0), is the hardware; the highest (layer N) is the user interface.
- With modularity, layers are selected such that each uses functions (operations) and services of only lower-level layers



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

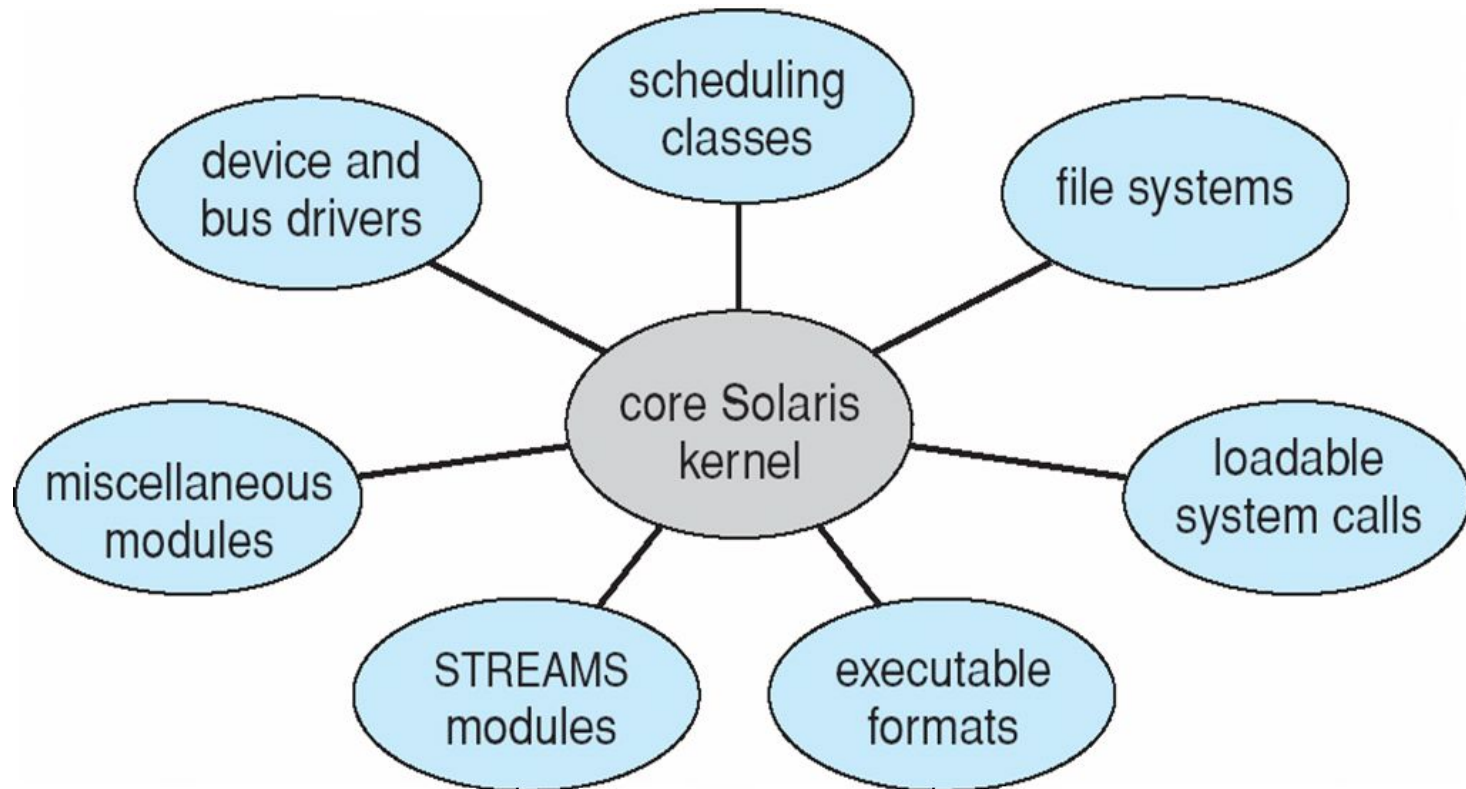
Microkernel System Structure



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

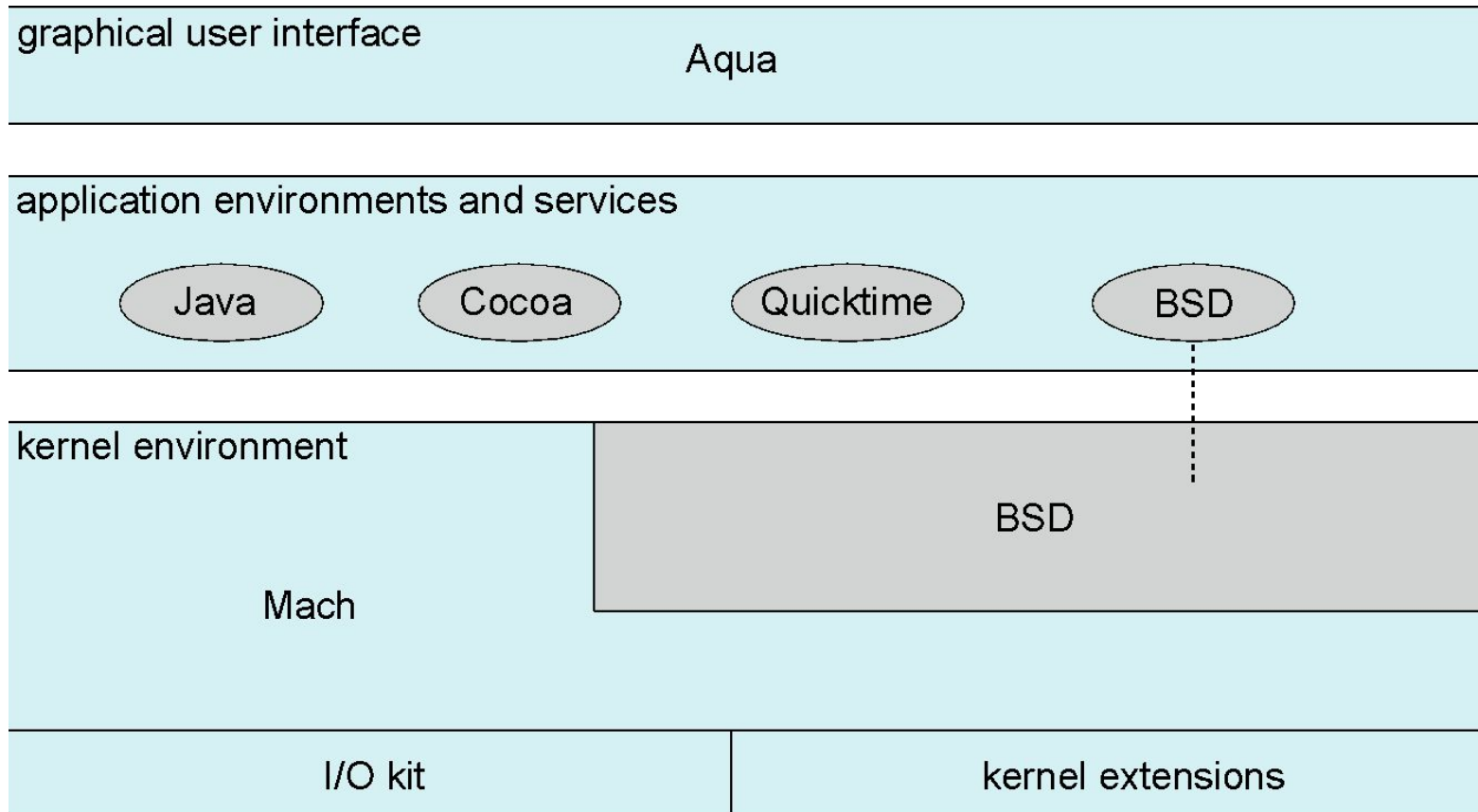
Solaris Modular Approach



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

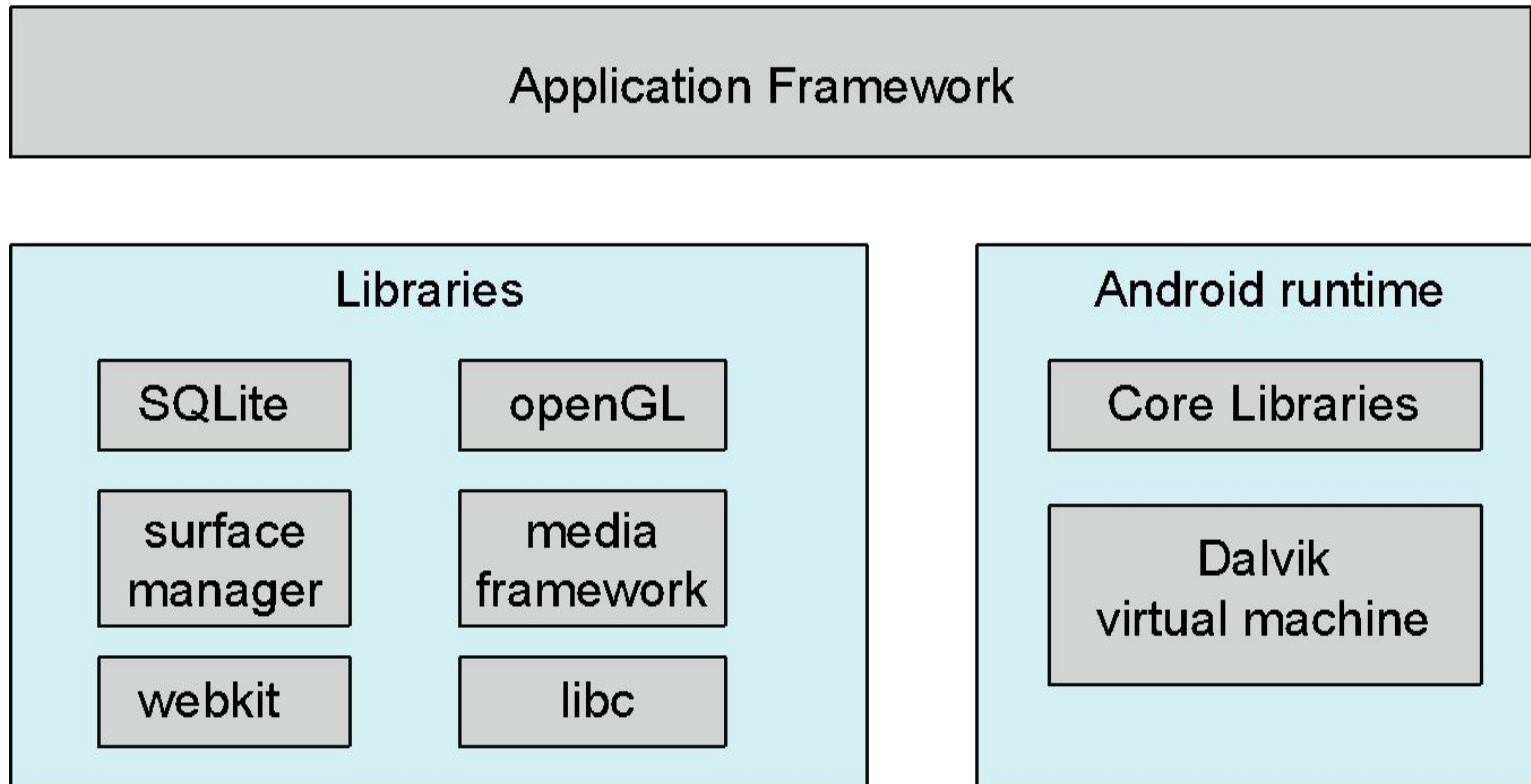
Core Services

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 then runs in Dalvik VM
- Libraries include frameworks for web browser (webkit), database (SQLite), multimedia, smaller libc

Android Architecture



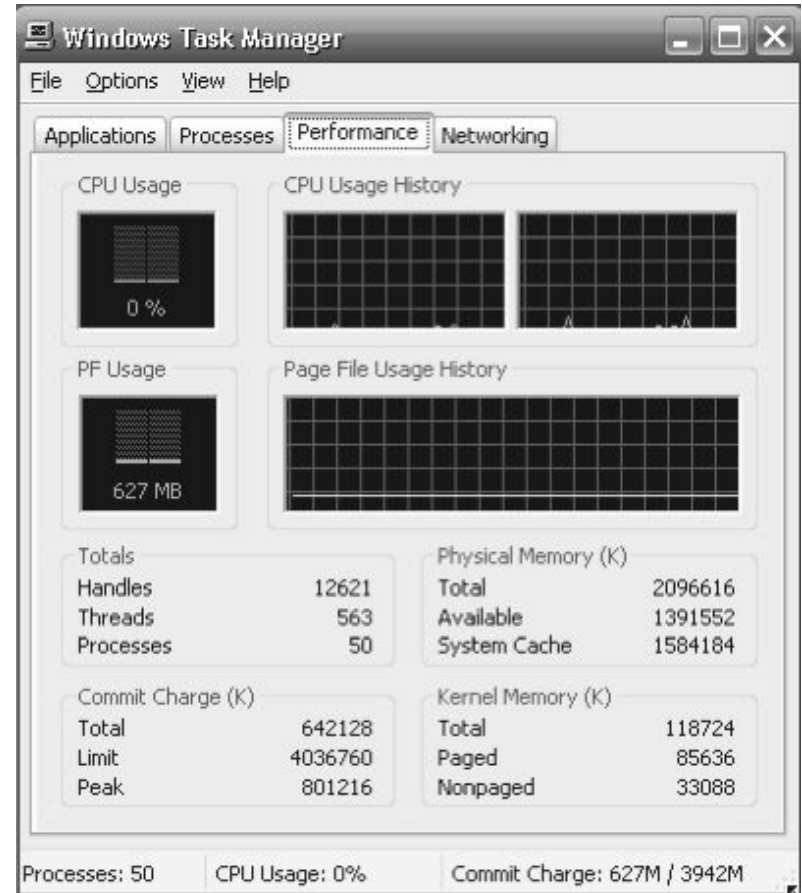
Operating-System Debugging

- **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
 - Sometimes using *trace listings* of activities, recorded for analysis
 - **Profiling** is periodic sampling of instruction pointer to look for statistical trends

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."

Performance Tuning

- Improve performance by removing bottlenecks
- OS must provide means of computing and displaying measures of system behavior
- For example, “top” program or Windows Task Manager



DTrace

- DTrace tool in Solaris, FreeBSD, Mac OS X allows live instrumentation on production systems
- **Probes** fire when code is executed within a **provider**, capturing state data and sending it to **consumers** of those probes
- Example of following XEventsQueued system call move from libc library to kernel and back

```
# ./all.d 'pgrep xclock' XEventsQueued
dtrace: script './all.d' matched 52377 probes
CPU FUNCTION
0 -> XEventsQueued U
0 -> _XEventsQueued U
0 -> _X11TransBytesReadable U
0 <- _X11TransBytesReadable U
0 -> _X11TransSocketBytesReadable U
0 <- _X11TransSocketBytesreadable U
0 -> ioctl U
0 -> ioctl K
0 -> getf K
0 -> set_active_fd K
0 <- set_active_fd K
0 <- getf K
0 -> get_udatamodel K
0 <- get_udatamodel K
...
0 -> releasef K
0 -> clear_active_fd K
0 <- clear_active_fd K
0 -> cv_broadcast K
0 <- cv_broadcast K
0 <- releasef K
0 <- ioctl K
0 <- ioctl U
0 <- _XEventsQueued U
0 <- XEventsQueued U
```

Dtrace (Cont.)

- DTrace code to record amount of time each process with UserID 101 is in running mode (on CPU) in nanoseconds

```

sched:::on-cpu
uid == 101
{
    self->ts = timestamp;
}

sched:::off-cpu
self->ts
{
    @time[execname] = sum(timestamp - self->ts);
    self->ts = 0;
}

```

```

# dtrace -s sched.d
dtrace: script 'sched.d' matched 6 probes
^C

```

gnome-settings-d	142354
gnome-vfs-daemon	158243
dsdm	189804
wnck-applet	200030
gnome-panel	277864
clock-applet	374916
mapping-daemon	385475
xscreensaver	514177
metacity	539281
Xorg	2579646
gnome-terminal	5007269
mixer applet2	7388447
java	10769137

Figure 2.21 Output of the D code.

Operating System Generation

- Operating systems are designed to run on any of a class of machines; the system must be configured for each specific computer site
- **SYSGEN** program obtains information concerning the specific configuration of the hardware system
 - Used to build system-specific compiled kernel or system-tuned
 - Can generate more efficient code than one general kernel

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
- 111
- Kernel loads and system is then **running**