Chapter 1: Introduction

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- 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

Objectives

- To provide a grand tour of **the major operating systems components**
- To provide coverage of basic computer system organization

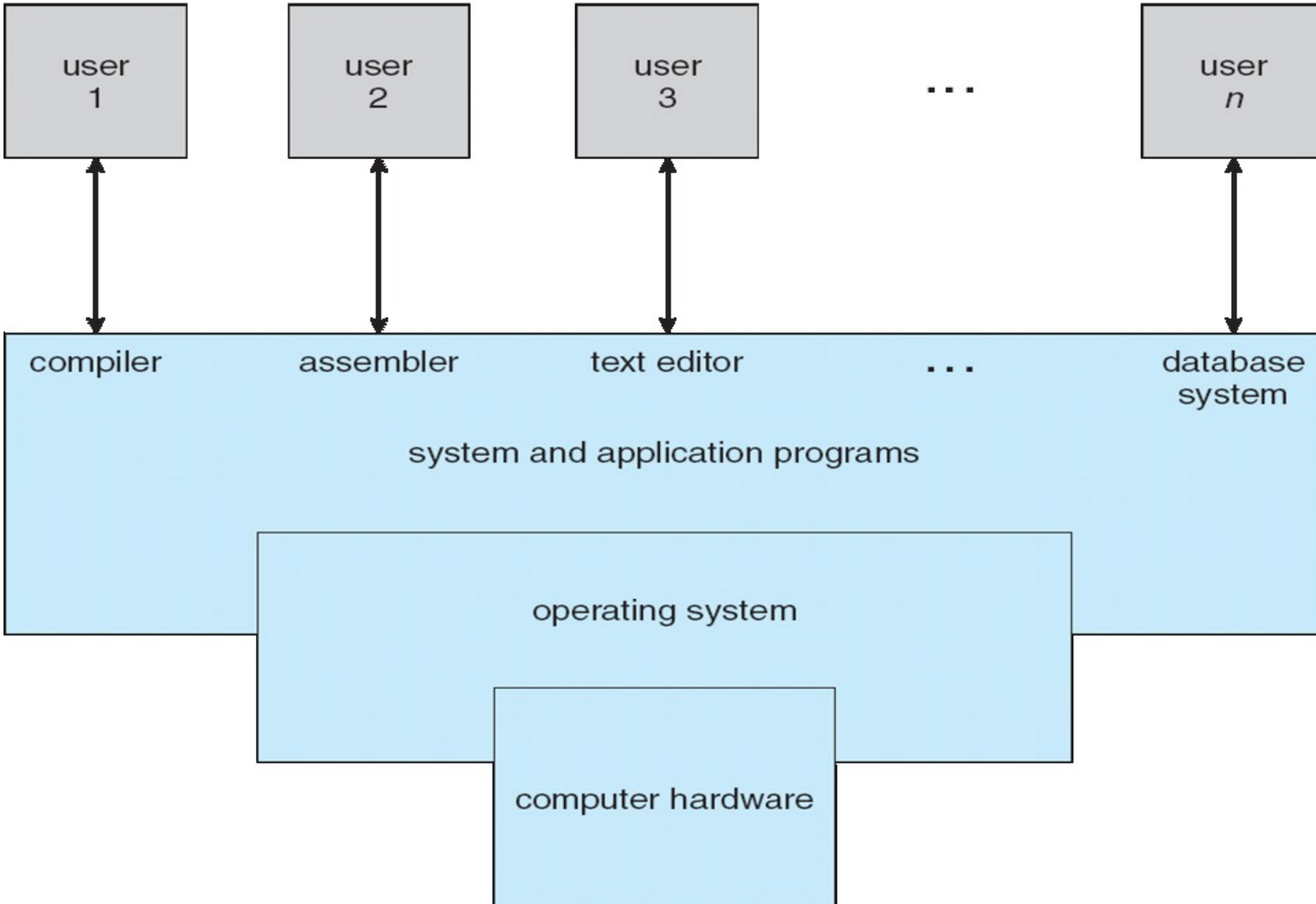
What is an Operating System?

- 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



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)

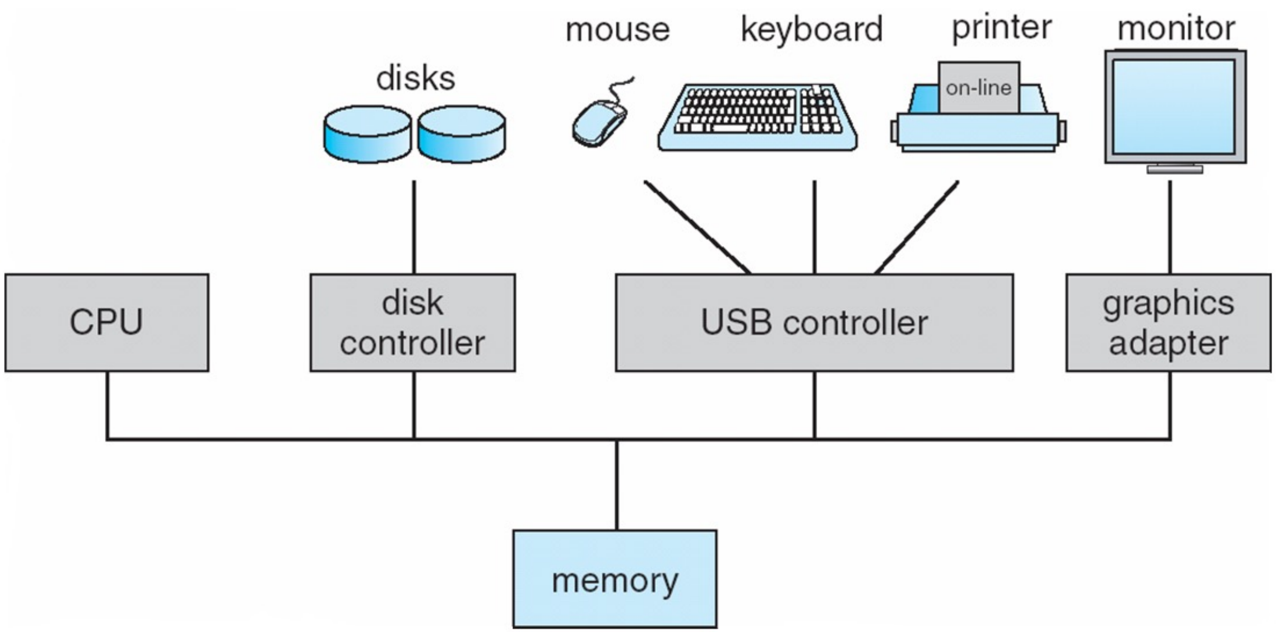
- No universally accepted definition
- "Everything a vendor ships when you order an operating system" is good approximation
  - But varies wildly
- "The one program running at all times on the computer" is the **kernel**. Everything else is either a system program (ships with the operating system) or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

Computer Startup

- **bootstrap program** is loaded at power-up or reboot
  - Typically stored in ROM or Erasble Programmable (ROM), generally known as **firmware**
  - Initializes all aspects of system such as CPU registers, device controllers, and memory contents.
  - Loads operating system kernel and starts execution

1.2 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



1.2.1 Computer-System Operation

- I/O devices and **the CPU** can **execute concurrently**
- Each device controller is in charge of a particular device type, and 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

- The occurrence of an event is usually triggered by an **interrupt**.
- Hardware may trigger an interrupt at any time by **sending a signal to the CPU**.
- Software may trigger an interrupt by **executing a system call.**
- **Interrupt** transfers **control** to the interrupt service routine generally, through the **interrupt vector**, which contains the addresses of all the service routines.
- When the interrupt service routine completes, the CPU **resumes** the interrupted computation.
- The operating system **preserves the state of the CPU** by storing registers and the program counter

Common Functions of Interrupts

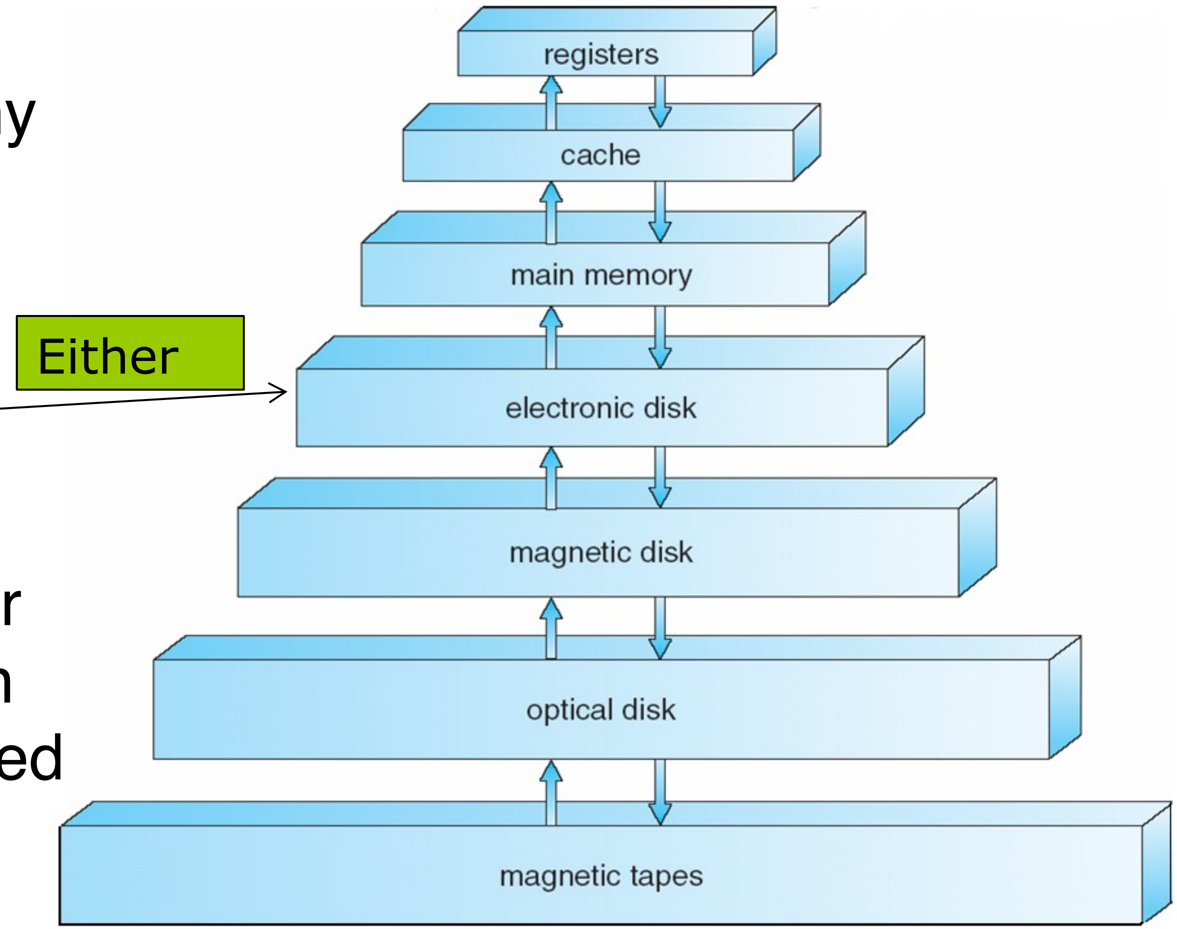
- Interrupt architecture must save the address of the interrupted instruction.
- Incoming interrupts are **disabled** while another interrupt is being processed to prevent a *lost interrupt*
- A **trap** is a software-generated interrupt caused either by an error or a user request
- An operating system is **interrupt driven**

1.2.2 Storage Structure

- **Main memory** – **ONLY** large storage media that the CPU can access directly, so any program must be stored there.
  - Also called Random-access memory (RAM).
- **Secondary storage** – extension of main memory that provides large nonvolatile storage capacity
- **Magnetic 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

Storage-Device Hierarchy

- Storage systems organized in hierarchy
  - Speed
  - Cost
  - Volatility
- **Caching** – copying information into faster storage system; main memory can be viewed as a last *cache* for secondary storage



Caching

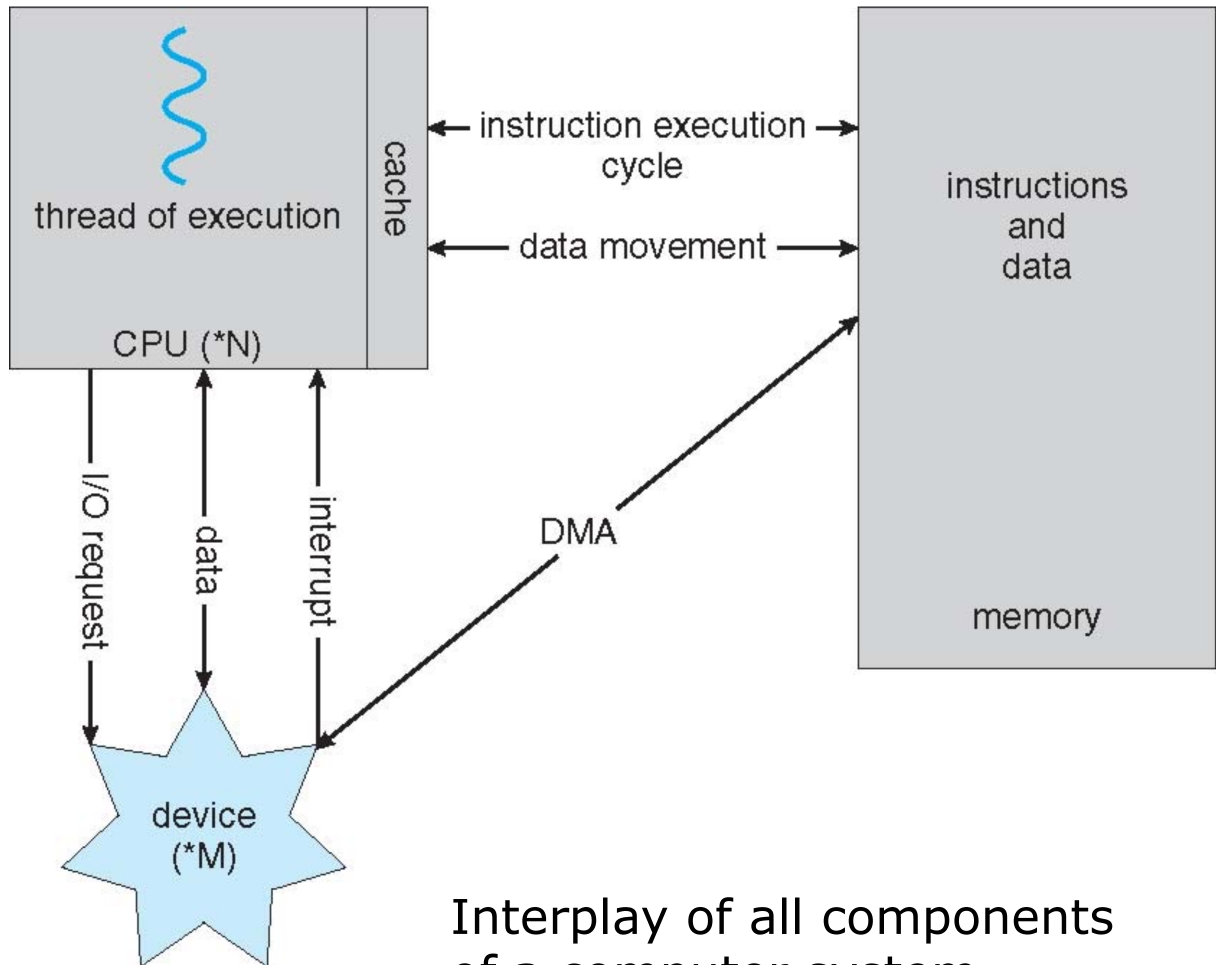
- **Important principle**, performed at many levels in a computer (in hardware, operating system, software)
- Information in use copied **from slower to faster** storage temporarily
- Faster storage (cache) checked first to determine **if information is there**
  - If it is, information used directly 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

1.2.3 I/O Structure

- A general-purpose computer system consists of **CPUs** and **multiple device controllers** that are connected through a common bus.
- Device controller is (part of device)
  - **in charge of** a specific type of device,
  - has **local buffer and register**,
  - **moves data from device to local buffer**, and
  - **informs device driver** when data transfer is complete.
- Device driver (part of OS) **understands the device controller** and **presents a uniform interface** to the device to the rest of the OS.

How a Modern Computer Works

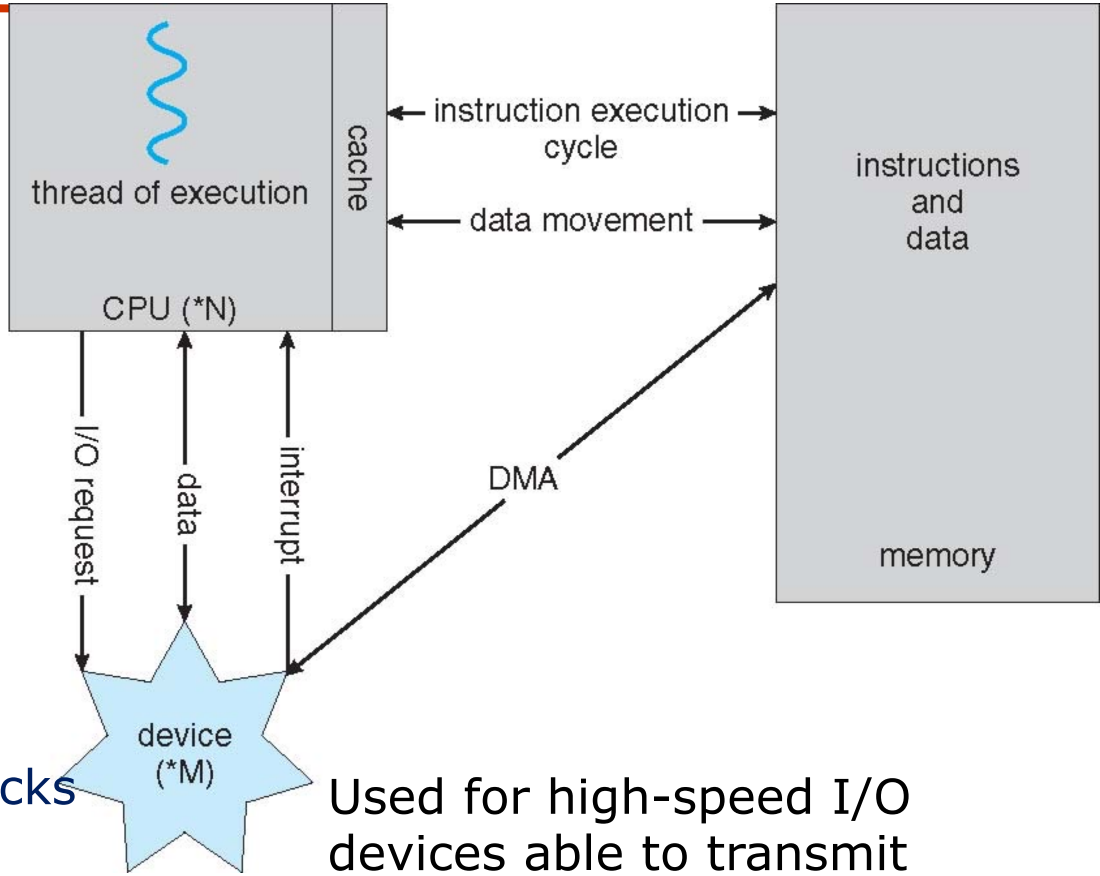
1. <u>Device driver</u> **loads** <u>controller</u> register with instruction
2. <u>Controller</u> **examines register content**.
3. <u>Controller</u> **transfer data** from device to its local buffer.
4. <u>Controller</u> **informs device driver** with an interrupt.
5. <u>Driver</u> **returns control to OS.**



Interplay of all components of a computer system.

Direct Memory Access Structure

1. Device driver **loads** controller register with instruction
2. Controller **examines register content**.
3. Controller **transfer data** from device to its local buffer.
4. Controller **informs device driver** with an interrupt.
5. Driver **returns control to OS.**



4′. Device controller transfers blocks of data from buffer directly to memory without CPU intervention
5. Only one interrupt is generated per block, rather than the one interrupt per byte

Used for high-speed I/O devices able to transmit information at close to memory speeds.

1.3 Computer-System Architecture

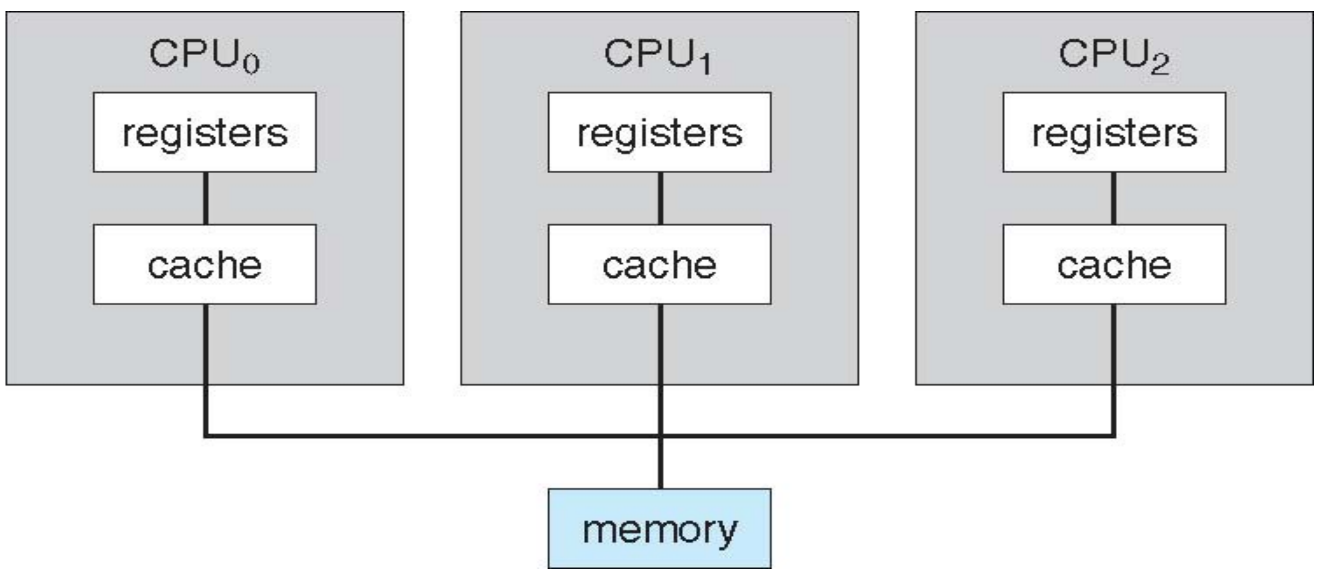
- Most systems use **a single general-purpose processor** (PDAs through mainframes)
  - Most systems have special-purpose processors as well
  - Such as a disk-controller has a microprocessor it implement its own disk queue and scheduling algorithm. This relieves the overhead of main CPU.
  - Keyboard contains a microprocessor to convert the keystrokes into codes to be sent to CPU.
- There is only one general purpose CPU.

1.3.2 Multiprocessor System

- Multiprocessors systems growing in use and importance
  - Also known as parallel systems, tightly-coupled systems
  - Such systems have **two or more processors** in **close communication**, **sharing the computer bus**, and sometimes the **clock** and memory.
  - Advantages include
    1. Increased throughput
    2. Economy of scale
    3. Increased reliability – graceful degradation or fault tolerance

1.3.2 Multiprocessor System

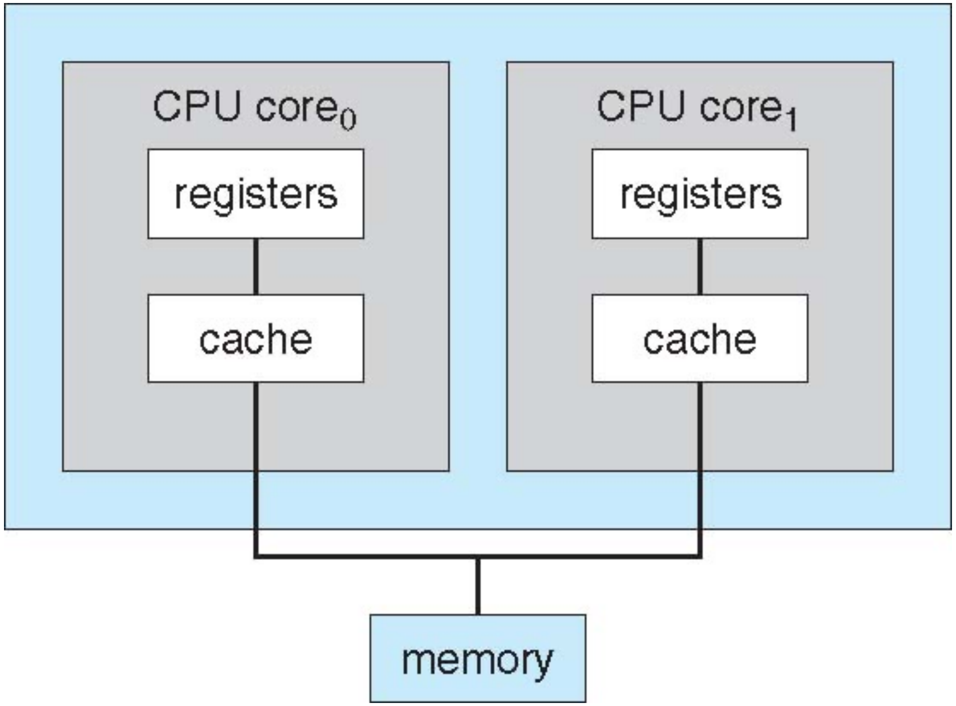
- Asymmetric multiprocessing – maintain a **master-slave** relationship. The master processor schedules and allocates work to the slave processors.
- Symmetric multiprocessing (SMP) – each processor has **its own set of registers**, as well as **local cache**. All processors share physical memory.



Symmetric multiprocessing architecture

A Dual-Core Design

- Include multiple computing cores on **a single chip**.
- More efficient than multiple chips with single cores because on-chip **communication is faster** than b/w chip communicate.
- One chip with multiple cores **uses less power**.

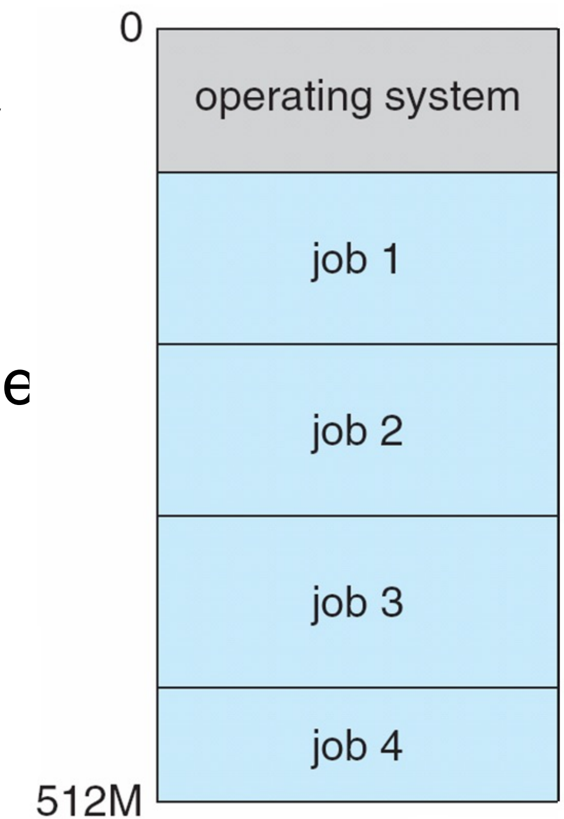


1.3.3 Clustered Systems

- Clustered computers share storage and closely linked via a local-area network (LAN).
- Like multiprocessor systems, but multiple systems working together
  - Provides a high-availability service which survives failures
    - Asymmetric clustering has one machine in hot-standby mode which monitors and backups servers.
    - 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
    - Divides a program into separate components that run in parallel on individual computers in the cluster.

1.4 Operating System Structure

- **Multiprogramming** needed for efficiency
  - Single program 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



Memory Layout for Multiprogrammed System

Operating System Structure (Cont.)

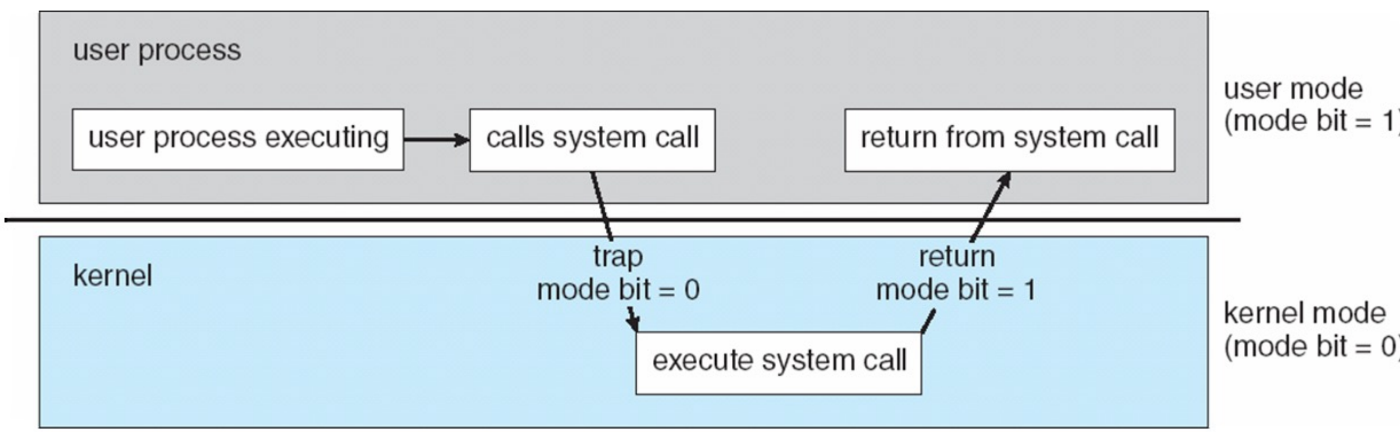
- **Timesharing (multitasking)** is logical extension in which CPU switches jobs so frequently that users can interact with each job while it is running, creating **interactive** computing
  - **Response time** should be < 1 second
  - Each user has at least one program executing in memory ⇨ **process**
  - 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

1.5 Operating-System Operations

- **Interrupt driven** by hardware
- **Software error or request** creates **exception** or **trap**
  - Division by zero, request for operating system service
- **Protection**
  - With sharing, a bug in one program could **adversely** affect many processes.
  - Other process problems include infinite loop, processes modifying each other or the operating system.
  - Need protection against these sorts of errors.

1.5.1 Transition from User to Kernel Mode

- **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



1.5.2 Timer

- Prevent a user program to get stuck in
  - An infinite loop, or
  - Fail to call system services and never return control to the OS
- A timer can be set to interrupt the computer after a specified period.
  - Operating system decrements counter
  - When counter zero generate an interrupt, control transfers to OS automatically
  - Set up before scheduling process to regain control or terminate program that exceeds allotted time

1.6 Process Management

- A process is a program **in execution**. 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.

1.6 Process Management (cond.)

- 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**

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

1.7 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 de-allocating memory space as needed

1.8 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)

1.8.1 File-System Management

- 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
    - Mapping files onto secondary storage
    - Backup files onto stable (non-volatile) storage media

1.8.2 Mass-Storage Management

- Disks are needed because main memory is too small or volatile
- Most programs are stored on a disk until loaded into memory.
- OS is responsible for
  - 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)

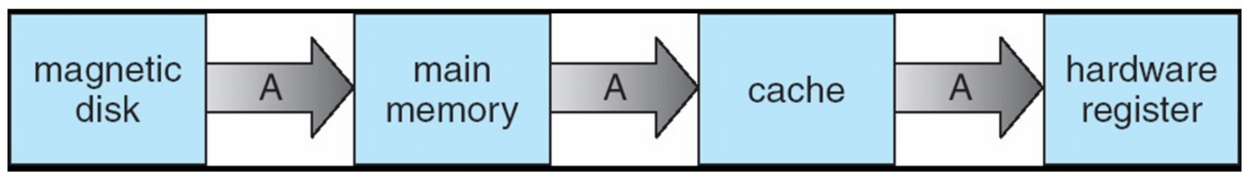
Performance of Various Levels of Storage

- Movement between levels of storage hierarchy can be explicit or implicit

Level	1	2	3	4
Name	registers	cache	main memory	disk storage
Typical size	< 1 KB	> 16 MB	> 16 GB	> 100 GB
Implementation technology	custom memory with multiple ports, CMOS	on-chip or off-chip CMOS SRAM	CMOS DRAM	magnetic disk
Access time (ns)	0.25 – 0.5	0.5 – 25	80 – 250	5,000.000
Bandwidth (MB/sec)	20,000 – 100,000	5000 – 10,000	1000 – 5000	20 – 150
Managed by	compiler	hardware	operating system	operating system
Backed by	cache	main memory	disk	CD or tape

Migration of Integer 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
  - When a replica is updated in one place, all other replicas are brought up to date as soon as possible.

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

Protection and Security

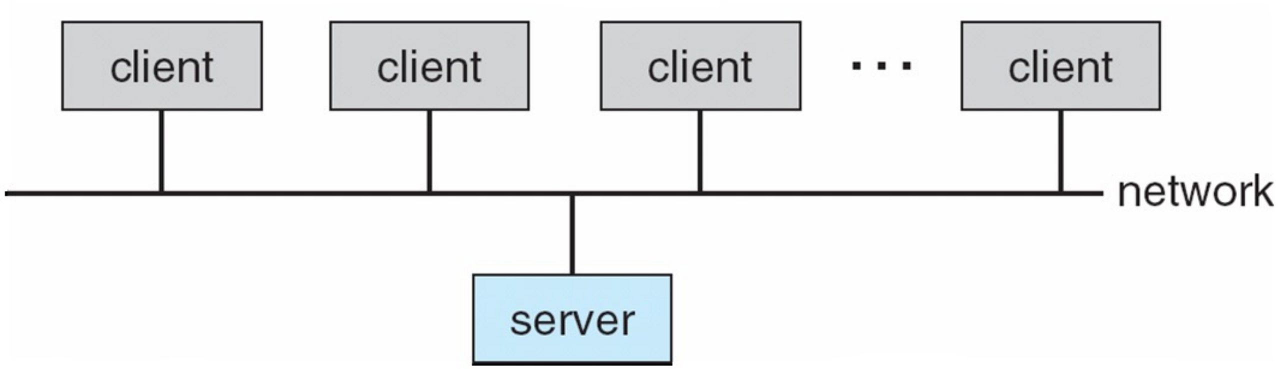
- Systems generally first distinguish among users, to determine who can do what
  - User identities (**user IDs**, security IDs) include name and associated number, one per user
  - User ID then associated with all files, processes of that user to determine access control
  - Group identifier (**group 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

Computing Environments

- Traditional computer
  - Blurring over time
  - Office environment
    - PCs connected to a network, terminals attached to mainframe or minicomputers providing batch and timesharing
    - Now portals allowing networked and remote systems access to same resources
  - Home networks
    - Used to be single system, then modems
    - Now firewalled, networked

Computing Environments (Cont)

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



Peer-to-Peer Computing

- 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*

Web-Based Computing

- Web has become ubiquitous
- PCs most prevalent devices
- More devices becoming networked to allow web access
- New category of devices to manage web traffic among similar servers: **load balancers**
- Use of operating systems like Windows 95, client-side, have evolved into Linux and Windows XP, which can be clients and servers

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, BSD UNIX (including core of Mac OS X), and Sun Solaris

End of Chapter 1