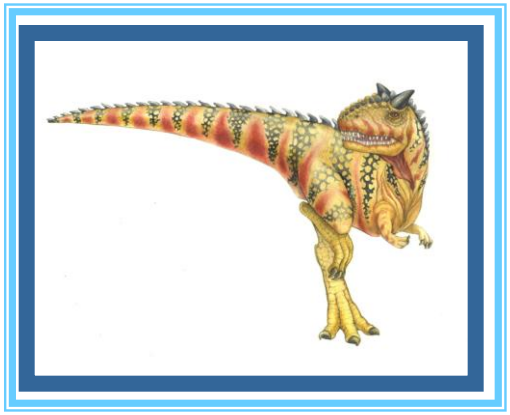
Chapters 1-2: Introduction



Why take this course?

- It is very useful for a number of advanced courses, for example, Real-Time Systems, Distributed Systems, Compilers and Computer Networks.
- Your (future) employer expects you to know the subject
- Because you use an Operating System every day… ☺

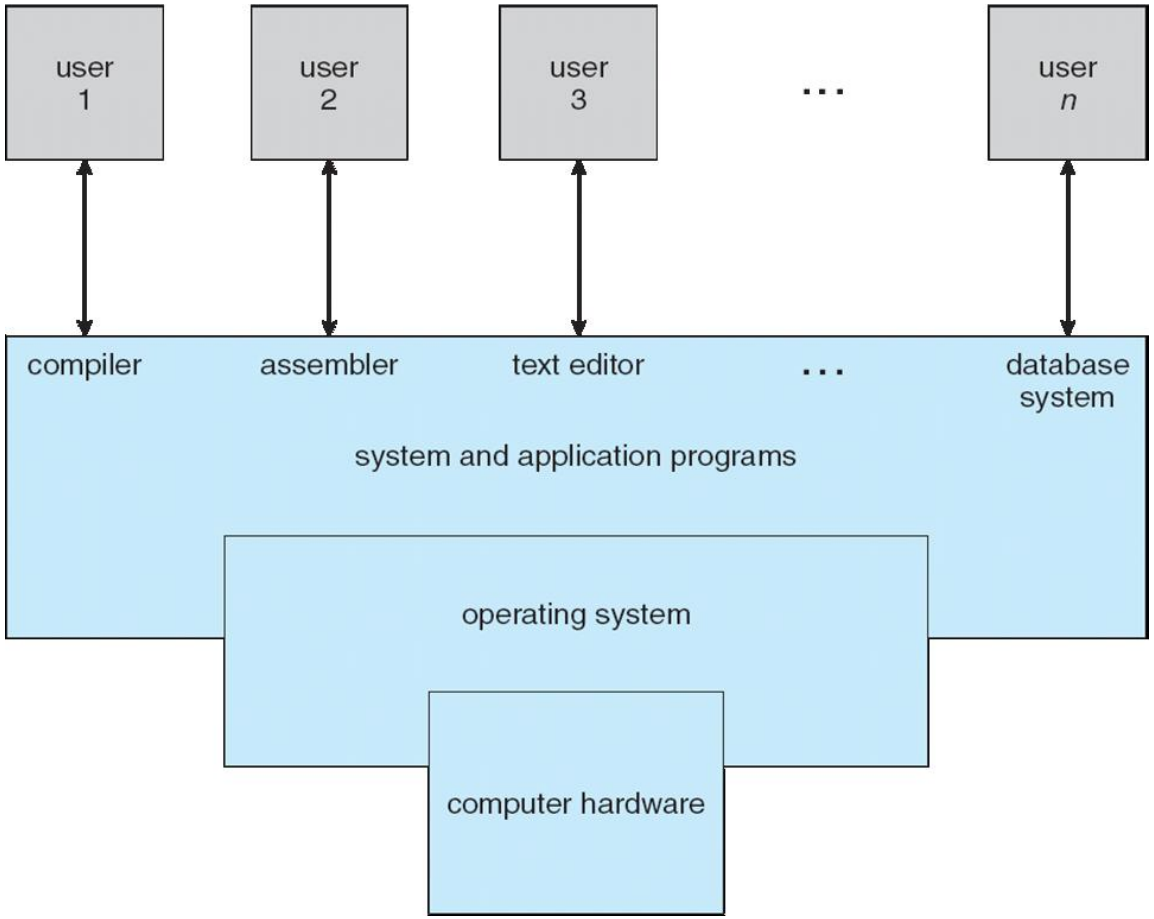
What is an Operating System?

- A program that acts as an intermediary between a user and the hardware
- Operating system goals:
  - Execute user programs and make solving user problems easier
  - Make the computer system convenient to use
  - Use the hardware in an efficient manner

Computer System Structure

- Computer systems can be divided into four main components:
  - Hardware, which provides basic computing resources, e.g. CPU, memory, I/O devices
  - Operating system, which controls and coordinates use of hardware among various applications and users
  - Application programs, such as word processors, compilers, web browsers, database systems, video games …
  - Users, such as people, machines, other computers

The Components of a Computer System



Operating System Definition

The two main functions of an Operating System (OS) are:

- Resource allocation
  - The OS manages all resources
  - The OS decides between conflicting requests for efficient and fair resource usage
- Control
  - The OS controls execution of programs to prevent errors and improper use of the computer

More on Operating System Definition

- No universally accepted definition – no standard!
- "Everything a vendor ships when you order an operating system" (… it varies a lot).
- The one program running at all times on the computer is the kernel. Everything else is either a system program or an application.

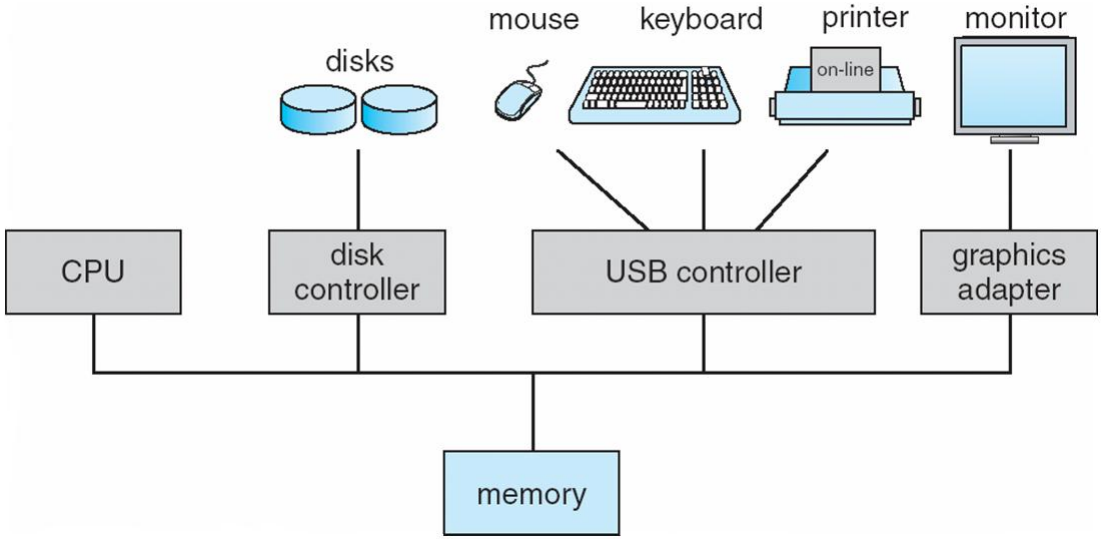
Computer Startup

- A bootstrap program (*bios - basic input-output system*) is loaded at power-up or reboot
  - Typically stored in ROM or EPROM
  - Initializes all aspects of the system
  - Loads the kernel from the hard-drive and starts execution

"lift oneself by the bootstraps"

Computer System Organization

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



Computer System Operation

- The 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
- The CPU moves data from/to main memory to/from local buffers
- I/O is done from the device to the local buffer of controller
- The device controller informs the CPU that it has finished its operation by generating an interrupt
- An operating system is interrupt driven

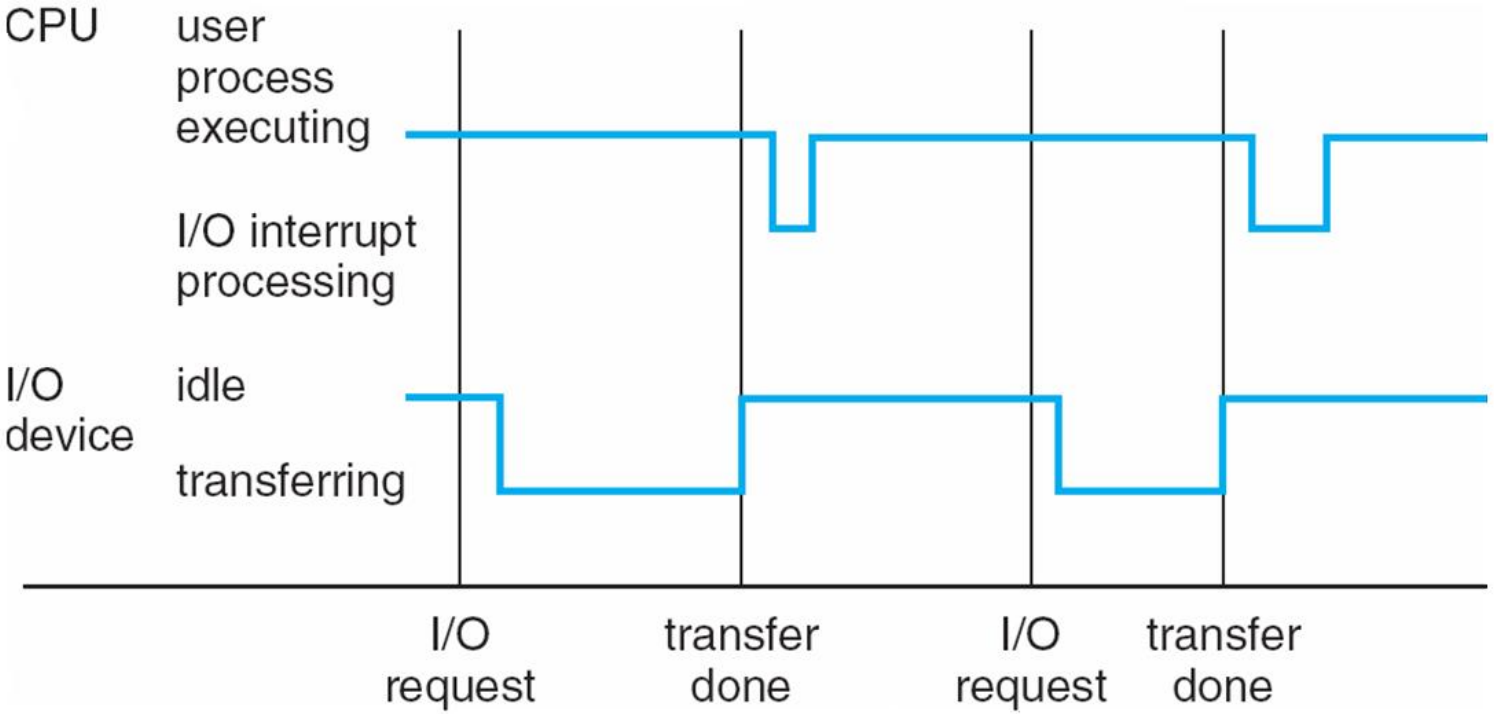
Common Functions of Interrupts

- An interrupt transfers control to the corresponding service routine through the interrupt vector, which contains the addresses of all the service routines.
- The interrupt handling procedure must save the address of the interrupted instruction. Moreover, incoming interrupts are *disabled* while an interrupt is being processed to prevent a *loss* of interrupts.
- A trap is a software-generated interrupt caused either by an error or a user request

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 (i.e. service routines)

Interrupt Timeline



Direct Memory Access (DMA)

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

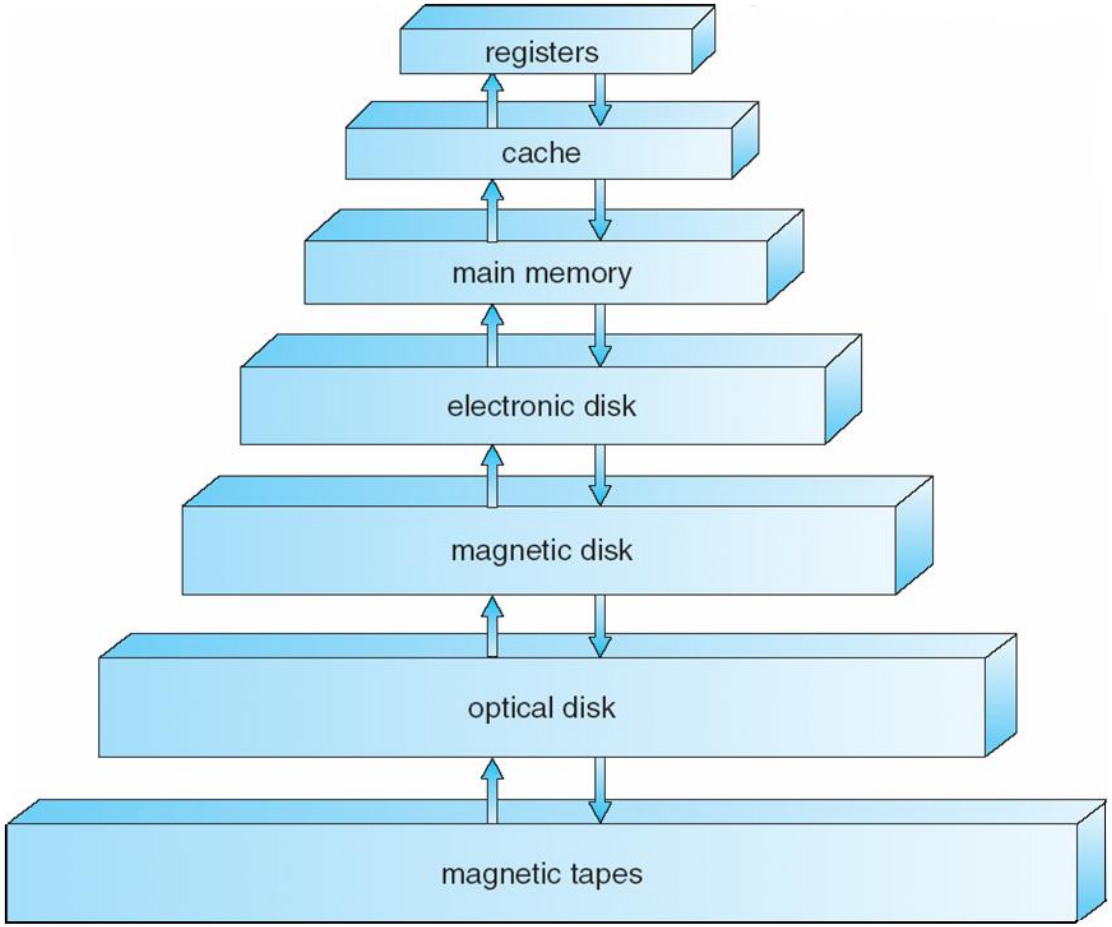
Storage Structure

- Main memory (MM) – the only large storage media that the CPU can access directly
- Secondary storage – extension of the MM that provides large non-volatile storage capacity (typically a hard-drive)
- Magnetic disks – rigid metal or glass platters covered with magnetic recording material
  - The disk surface is logically divided into *tracks*, which are subdivided into *sectors*
  - The *disk controller* determines the interaction between the device and the CPU

Storage Hierarchy

- Storage systems organized in hierarchy according to:
  - Speed
  - Cost
  - Volatility
- Caching – copying information into faster storage, e.g. the main memory can be viewed as a cache for secondary storage

Storage-Device Hierarchy

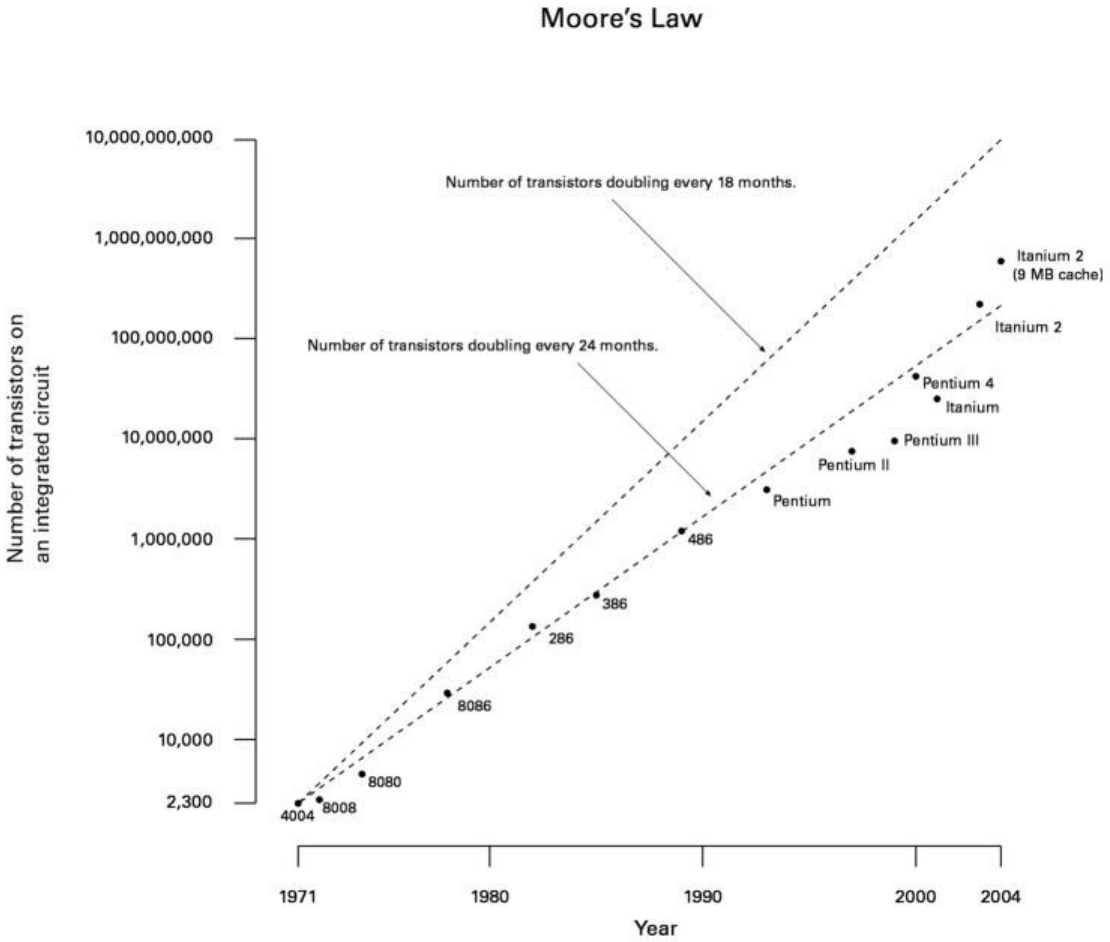


Performance of Various Levels of Storage

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

Moore's Law

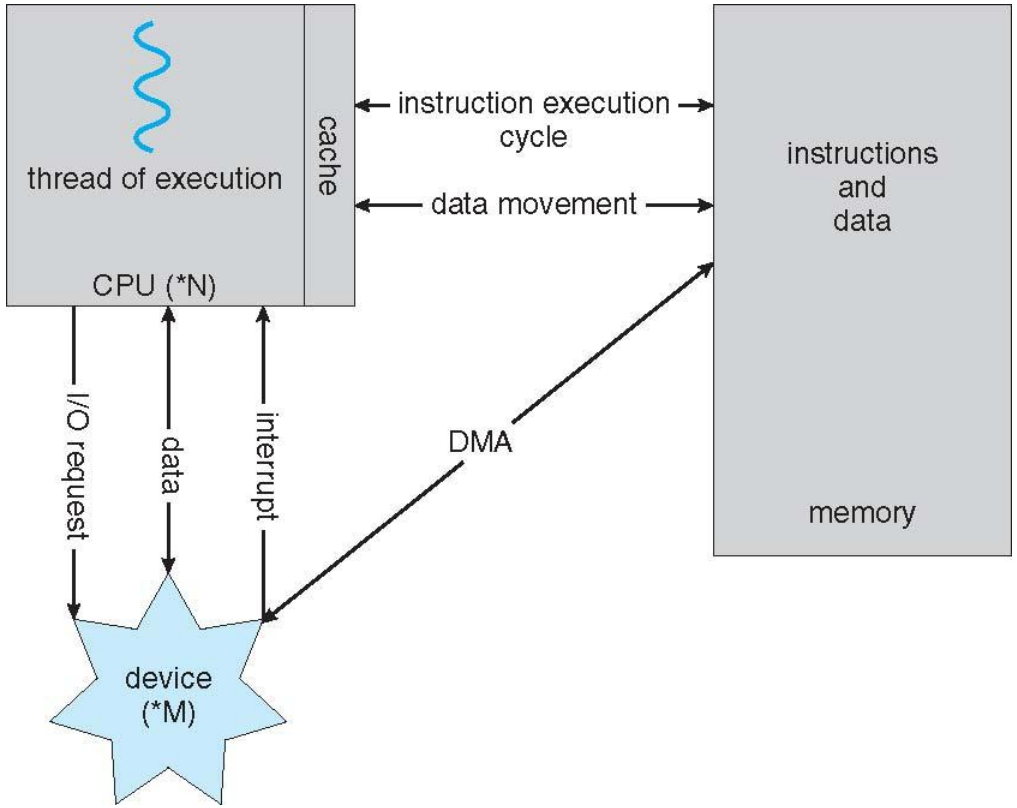
(Intel co-founder Gordon Moore wrote in a 1965 article that the number of transistors on a chip would double every 24 months.)



Caching

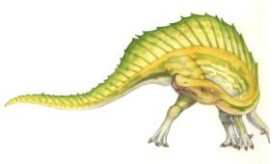
- Important principle, performed at many levels in a computer (in hardware, operating system, software)
- Information in use copied from slower to faster storage temporarily
- Faster storage (cache) checked first to determine if information is there
  - If it is, information used directly from the cache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

How a Modern Computer Works

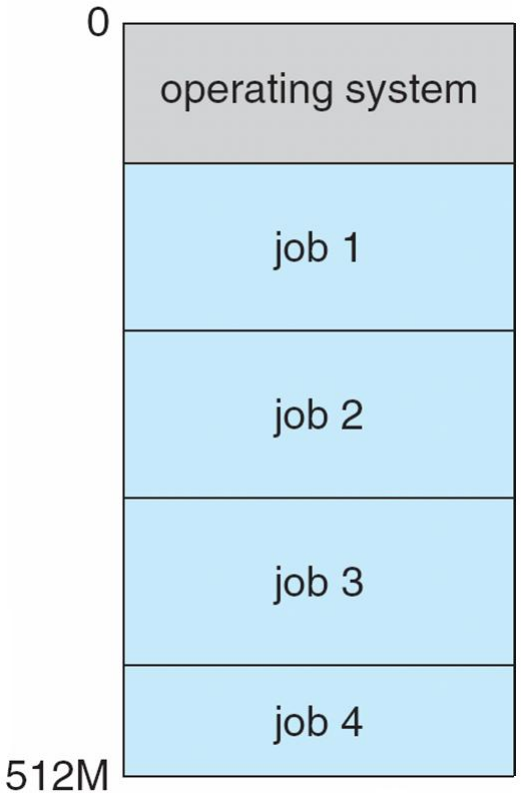


Multiprogramming

- Multiprogramming (i.e. having several programs "in execution") is needed for efficiency
  - A single user cannot keep the CPU and the 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), the OS switches to another job



The Memory Layout for a Multiprogrammed System

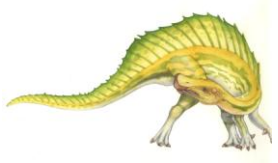


Timesharing

- 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 (i.e. process)
  - If several jobs are ready to run at the same time, CPU scheduling is needed
  - If processes do not fit in the MM, swapping moves them in and out to run
  - Virtual memory allows execution of processes which are not completely in the MM

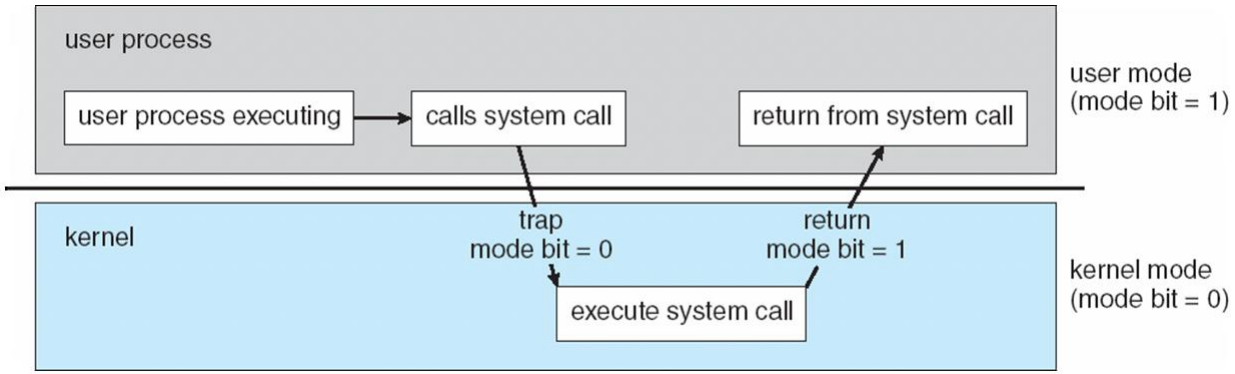
Operating-System Operations

- Interrupt driven by hardware
- Software error or request creates exception or trap
  - Division by zero, request for operating system service
- Other process problems include infinite loop, processes modifying each other or the operating system
- Dual-mode operation allows the OS to protect itself and other system components
  - User and kernel mode
  - Mode bit (provided by hardware):
    - Makes it possible to distinguish when the system is running user code or kernel code
    - Some instructions are designated as privileged, i.e. they are only executable in kernel mode
    - System call changes mode to kernel, return from call resets it to user



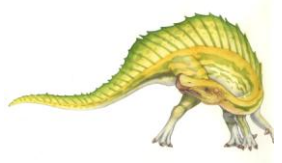
Transition from User to Kernel Mode

- A timer is used to prevent infinite loops or processes hogging resources
  - Set interrupt after specific period
  - The OS decrements counter
  - When the counter is 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 OS. A program is a *passive entity*, while a process is an *active entity*.
- A process needs resources to accomplish its task, e.g. CPU, memory, I/O, and files. Process termination requires reclaim of any reusable resources.
- A single-threaded process has one program counter specifying location of next instruction to execute. A process executes instructions sequentially, one at a time, until completion.
- A multi-threaded process has one program counter per thread.
- Typically a system has many processes, some user, some operating system running concurrently on one or more CPUs. Concurrency is achieved by multiplexing the CPUs among the processes and threads.



Process Management

The OS is responsible for:

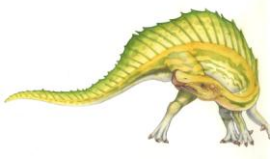
- Creating and deleting both user and system processes
- Suspending and resuming processes
- Providing mechanisms for process synchronization
- Providing mechanisms for process communication
- Providing mechanisms for deadlock handling

Memory Management

- All data in memory before and after processing
- All instructions in memory in order to execute
- Memory management determines what is in the MM 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 de-allocating memory space as needed

Storage Management

- The OS provides uniform, logical view of information storage
  - Abstracts physical properties to logical storage unit - file
  - Each medium is controlled by device (i.e., disk drive, tape drive)
    - Varying properties include access speed, capacity, data-transfer rate, access method (sequential or random)
- File-System management
  - Files usually organized into directories
  - Access control on most systems to determine who can access what
  - OS activities include
    - Creating and deleting files and directories
    - Primitives to manipulate files and dirs
    - Mapping files onto secondary storage
    - Backup files onto stable (non-volatile) storage media



Mass-Storage Management

- Usually disks are used to store data that does not fit in the MM or data that must be kept for a "long" period of time
- The speed of the computer system is dependent on the disk subsystem and its algorithms
- OS activities
  - Free-space management, storage allocation and disk scheduling
- Some storage does not need to be fast
  - Tertiary storage, includes optical storage, magnetic tape
  - Varies between WORM (write-once, read-many-times) and RW (read-write)

I/O Subsystems

- One purpose of the OS is to hide peculiarities of the hardware devices from the user
- An I/O subsystem is 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

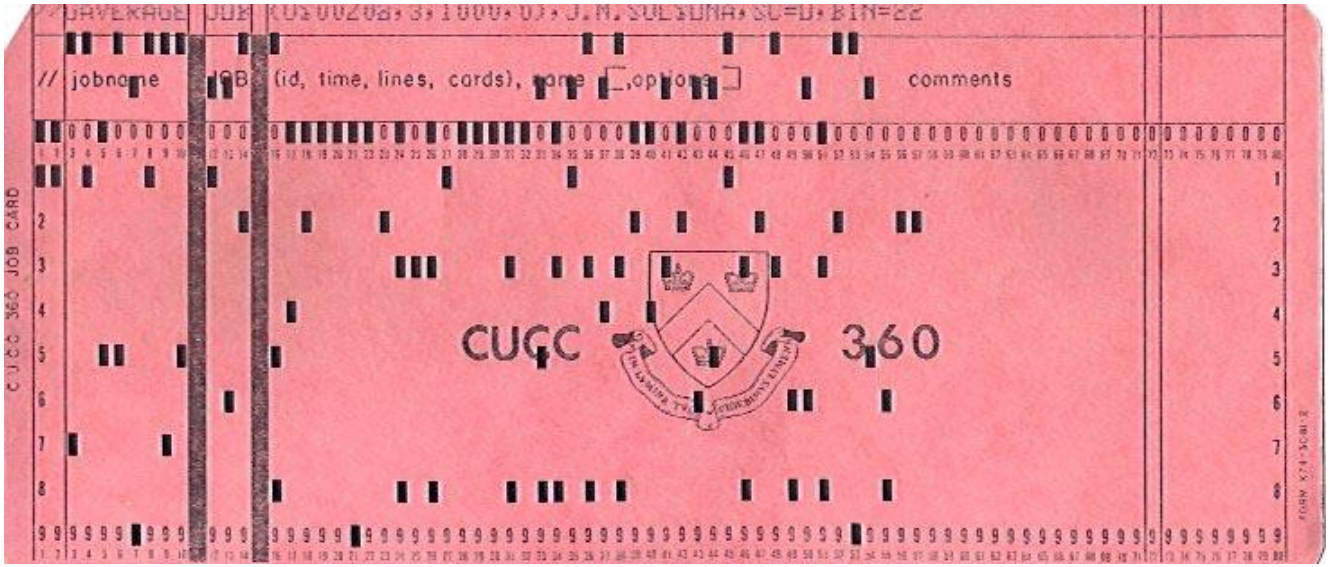
- Protection – any mechanism for controlling the access of processes or users to resources managed by the OS
- Security – the defense of the system against internal and external attacks
  - Huge range, including: denial-of-service, worms, viruses, identity theft, theft of service

Domain of Protection

- Systems generally 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 the user to change to an ID with "more rights" (e.g. administrator)

Front Panel (ti980)

Punch Cards


// jobname JOB (id, time, lines, cards), name [,options]
comments
CUCC
360

Keypunch

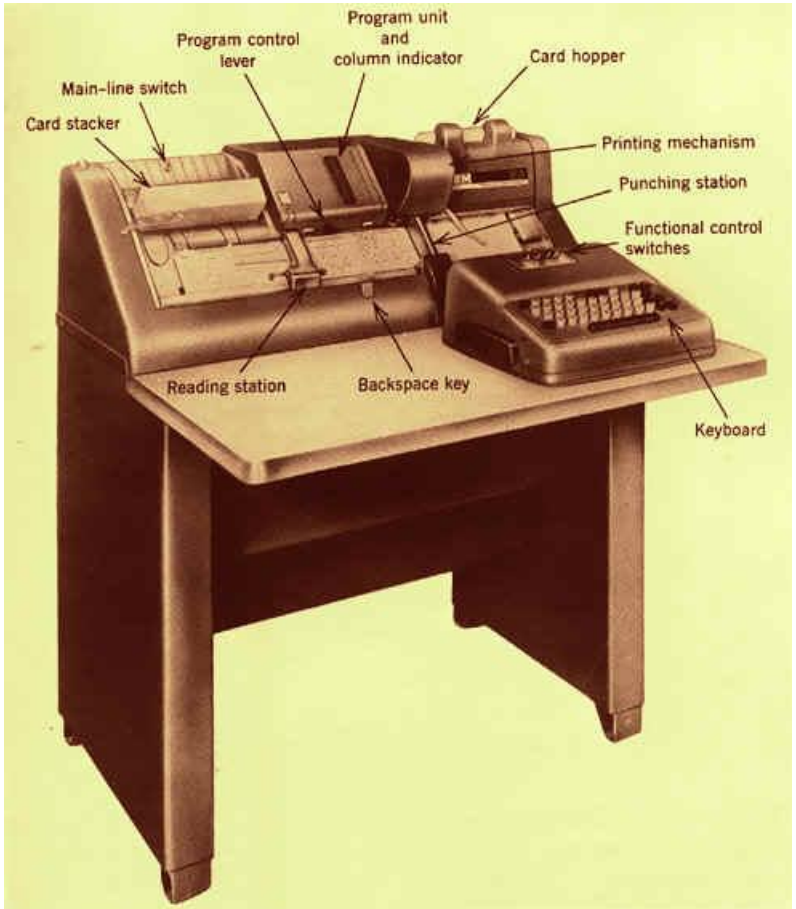


FIGURE 4.11 IBM 026 Keypunch (Courtesy IBM).

What are they doing?