Course name: OPERATING SYSTEMS [4 0 0 4]

Course code: MCA 4223

Introduction to OS

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Courtesy: Slides are adapted from the textbook "Operating System Concepts" by Silberschatz et al.

SYLLABUS

Introduction: Simple, multi-programmed batch systems, distributed systems, time-sharing & real time systems, hardware protection;

CPU Scheduling: Process concept, process state transitions, process control block, operations on processes, inter-process communication, scheduling algorithms, multilevel feedback queues;

Concurrent Process: Mutual exclusion, Precedence graphs, critical section, Dekker's algorithm, hardware solution to mutual exclusion, semaphores, process synchronization with semaphores;

Deadlocks: Deadlock characterization, resource allocation graph, deadlock prevention, avoidance, detection, Bankers algorithm and recovery from deadlock;

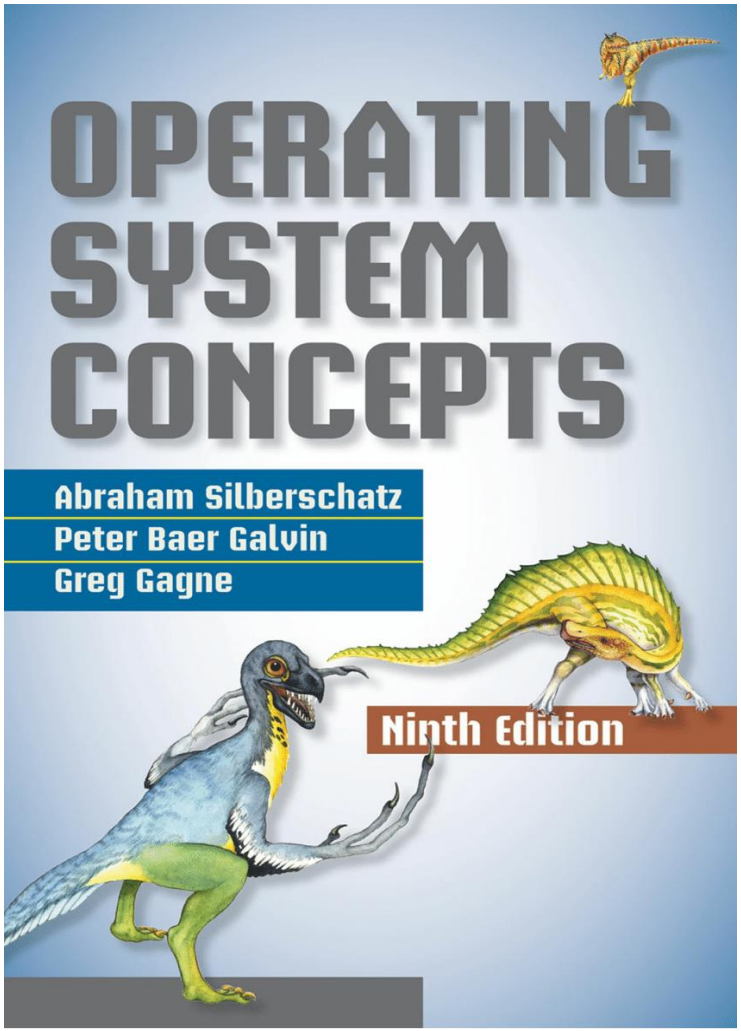
SYLLABUS

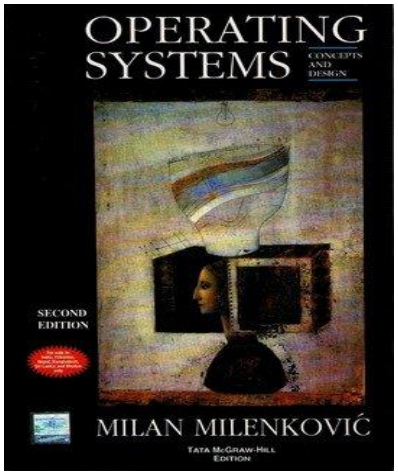
Memory management: Address binding, dynamic loading, dynamic linking, Overlays, swapping, contiguous allocation, paging, segmentation, segmentation with paging

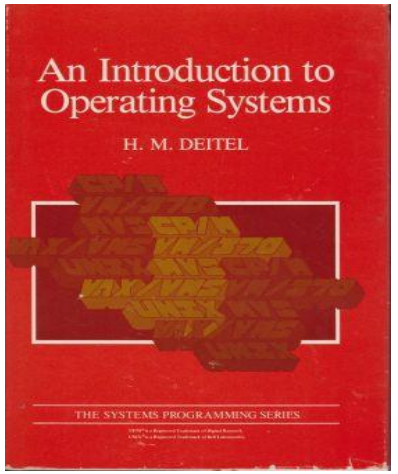
Virtual Memory: Demand paging, page replacement algorithms, thrashing;

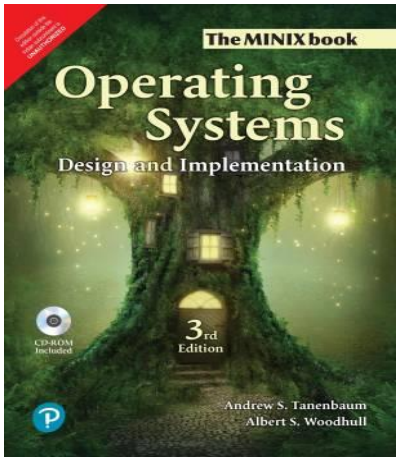
File Systems: Free space management, allocation methods, Directory structure, Disk scheduling methods.

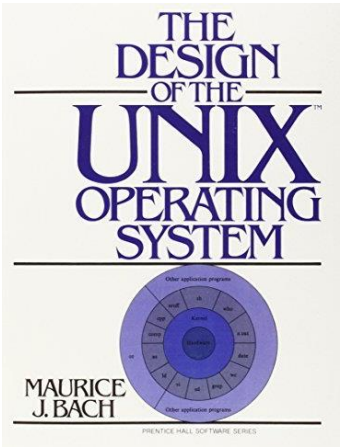
Reference Books





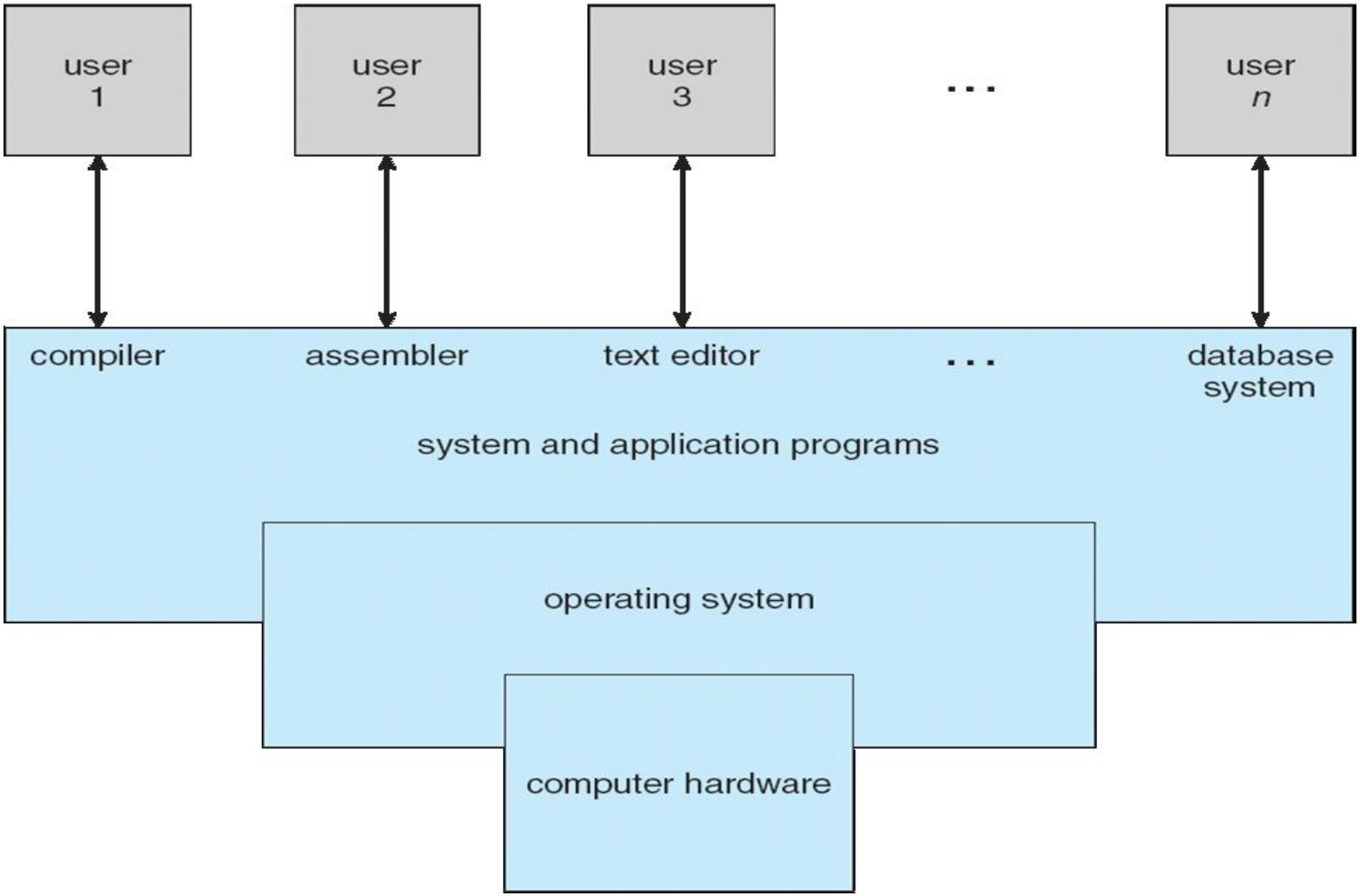






Introduction to OS

Four Components of a Computer System (Abstract view)



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
  - **System and 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

What is an Operating System?

- A program that acts as an intermediary between a user of a computer software and the computer hardware
- OS is a system software
- It provides an environment within which other programs can do useful work

- **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

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

OS Usage

- Hardware Abstraction

  turns hardware into something that applications can use

- Resource Management

  manage system's resources

Courtesy: Introduction to OS – Prof. Chester Rebeiro, IITM

A Simple Program

What is the output of the following program?

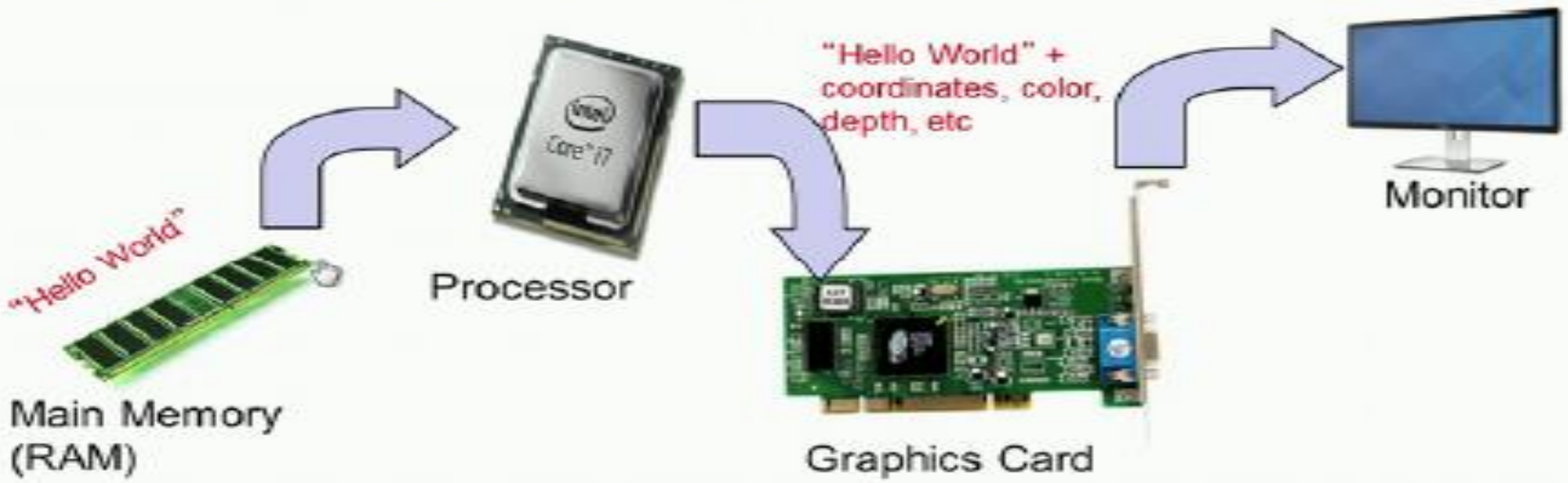
```
#include <stdio.h>

int main(){
   char str[] = "Hello World\n";
   printf("%s", str);
}
```

How is the string displayed on the screen?

Courtesy: Introduction to OS – Prof. Chester Rebeiro, IITM

Displaying on the Screen

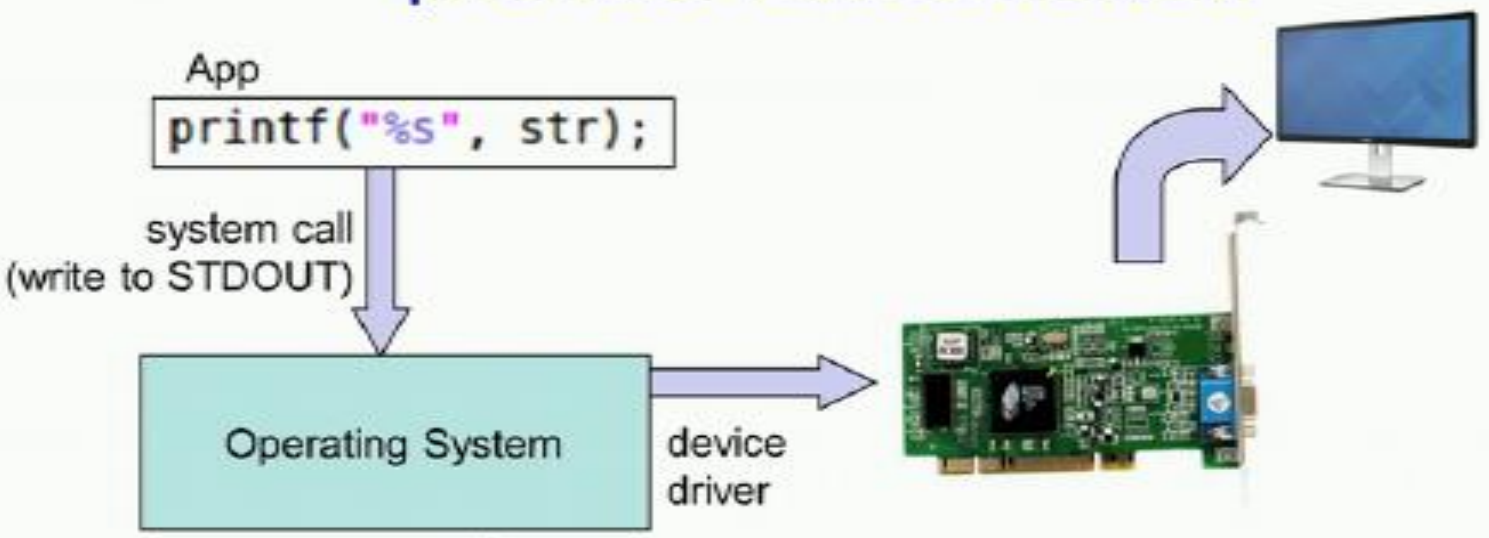


- Can be complex and tedious
- Hardware dependent

Without an OS, all programs need to take care of every nitty gritty detail

Courtesy: Introduction to OS – Prof. Chester Rebeiro, IITM

Operating Systems provide **Abstraction**

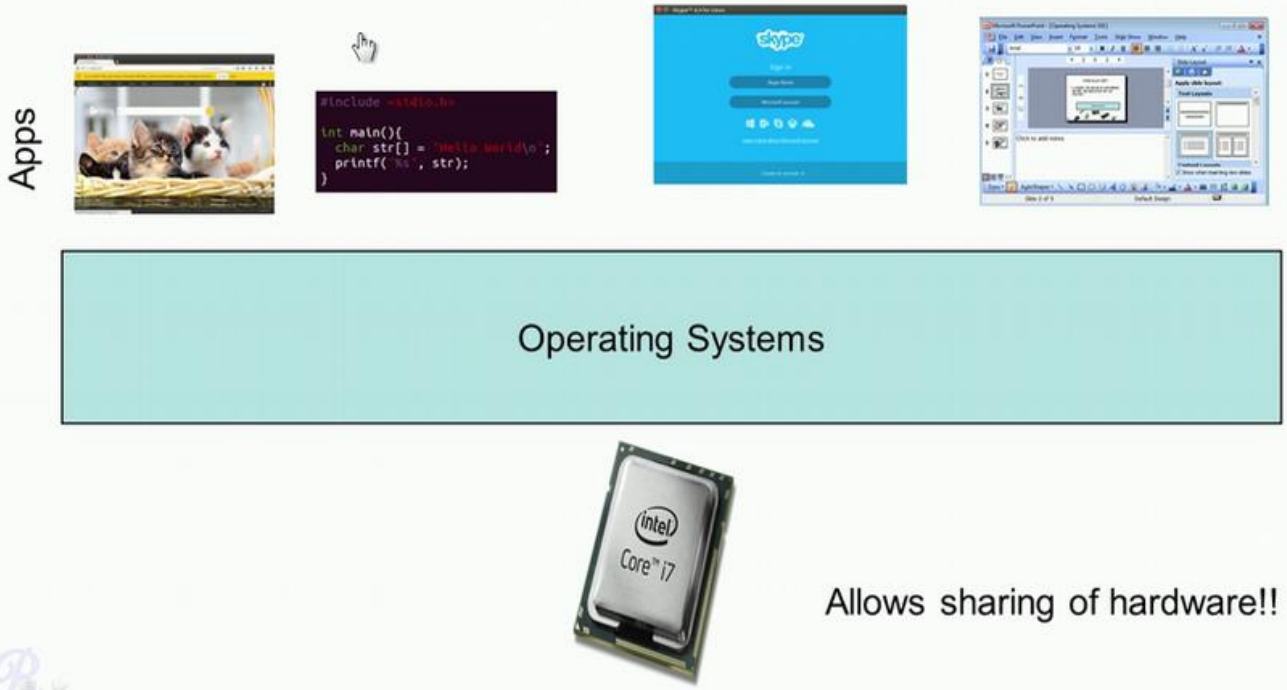


- **Easy to program apps**
  - No more nitty gritty details for programmers
- **Reusable functionality**
  - Apps can reuse the OS functionality
- **Portable**
  - OS interfaces are consistent. The app does not change when hardware changes

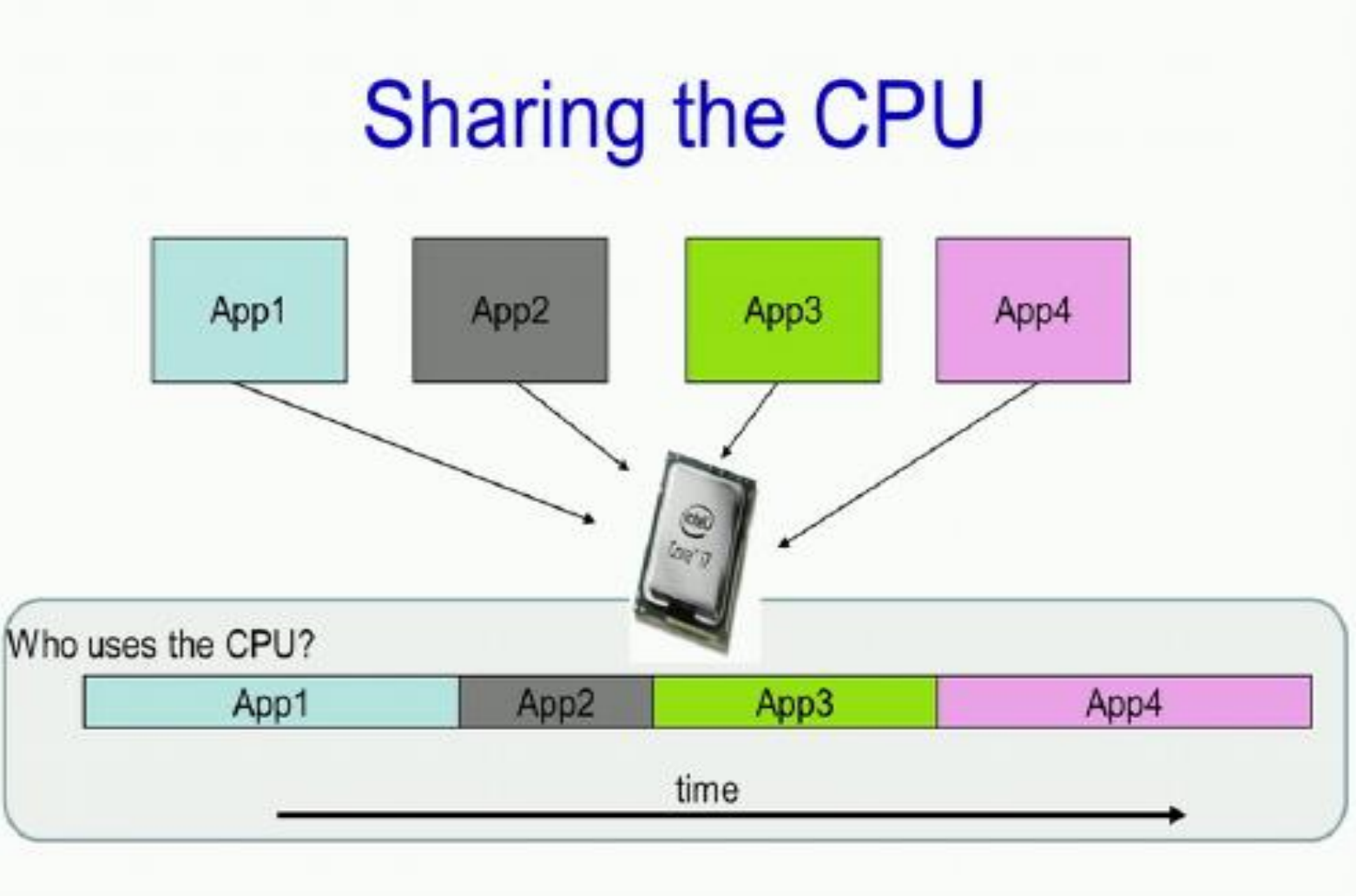
Courtesy: Introduction to OS – Prof. Chester Rebeiro, IITM

OS as a **Resource Manager**

- Multiple apps but limited hardware

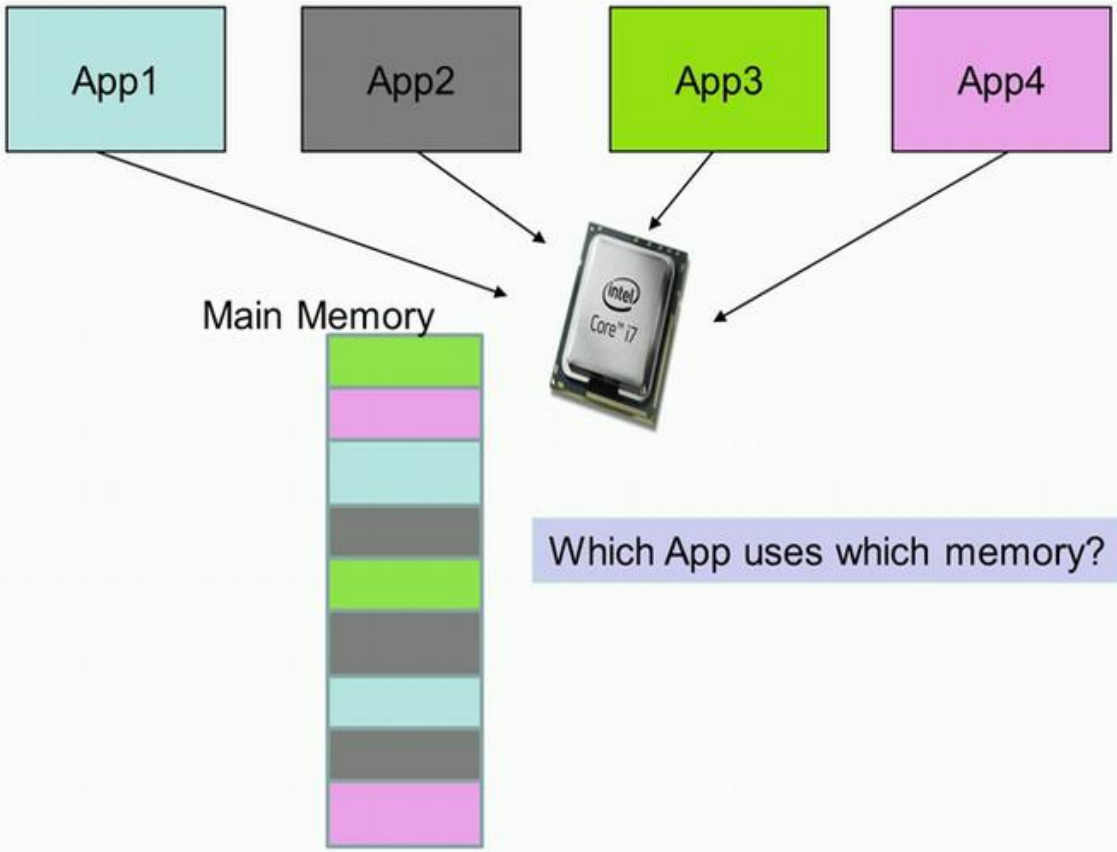


Courtesy: Introduction to OS – Prof. Chester Rebeiro, IITM



Courtesy: Introduction to OS – Prof. Chester Rebeiro, IITM

Sharing Memory



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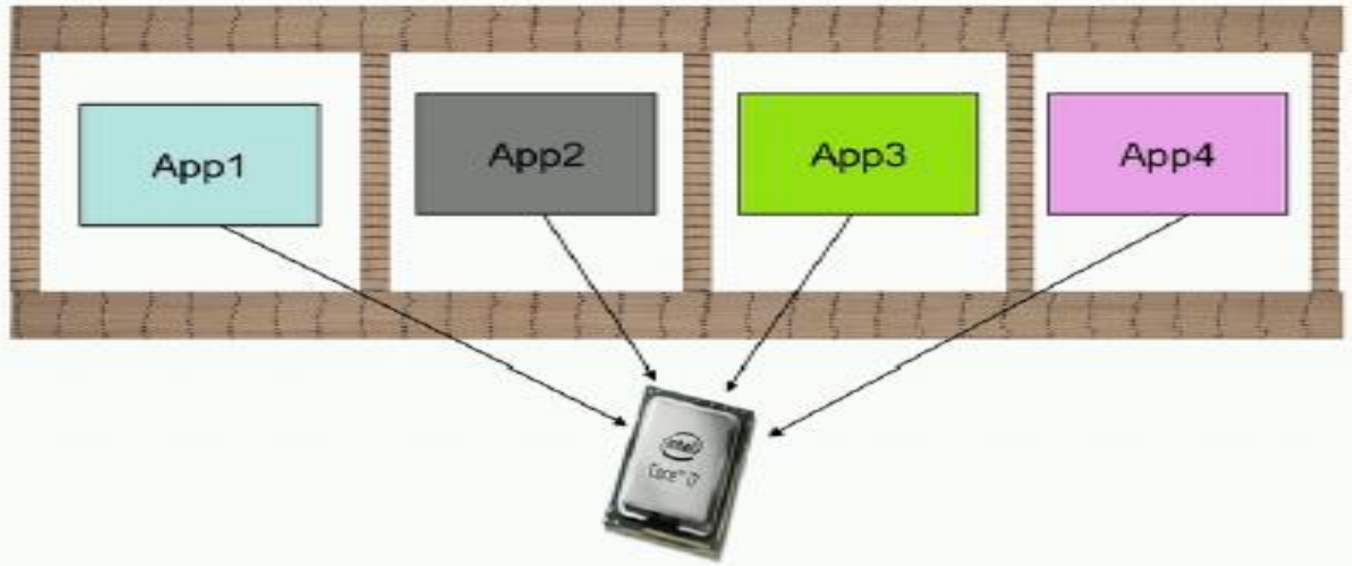
Share but Isolate



Share resources but keep applications isolated from each other

What Operating Systems Do

User View: The user's view of the computer varies according to the interface being used

- **Single User Computers (e.g., PC, workstations):** Users want convenience, **ease of use** and **good performance**
  - Don't care about **resource utilization**
- **Multi User Computers:** 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 (e.g., smartphones and tablets):** are resource poor, optimized for usability and battery life
- **Embedded Computers (e.g., Computers in home devices and automobiles):** Some computers have little or no user interface, such as embedded computers in devices and automobiles

What Operating Systems Do

System View

From the computer's point of view, the operating system is the program most intimately involved with the hardware. There are two different views:

- 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

Types of Systems and Roles of OS within each

- Simple Batch Systems
- Multiprogramming Batched Systems
- Time-Sharing Systems
- Personal-Computer Systems
- Parallel Systems
- Distributed Systems
- Real -Time Systems

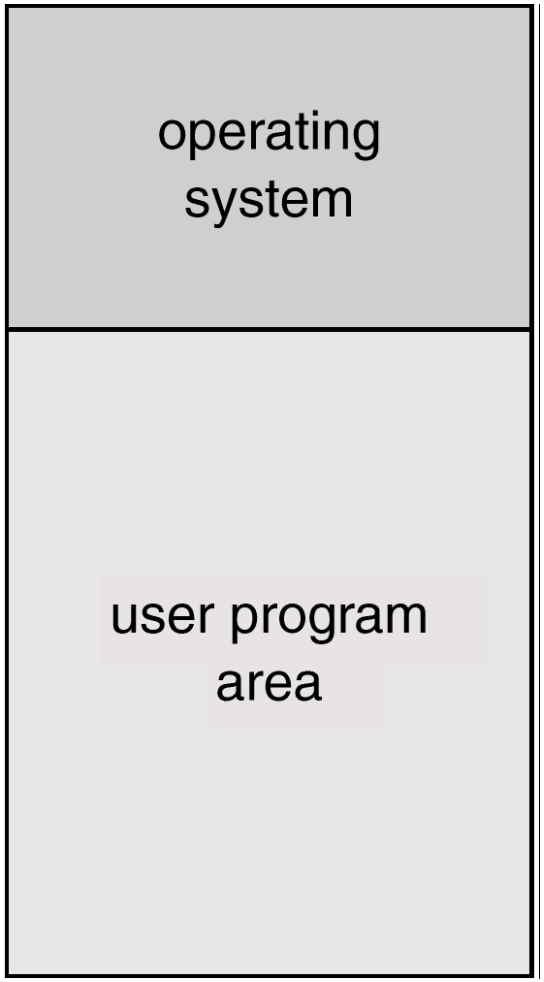
Simple Batch Systems

- Hire an operator
- User ≠ operator
- Add a card reader
- Reduce setup time by batching similar jobs
- Automatic job sequencing – automatically transfers control from one job to another. First rudimentary operating system.
- Resident monitor
  - initial control in monitor
  - control transfers to job
  - when job completes control transfers back to monitor

Simple Batch Systems

- The common input devices were card readers and tape drives.
- The common output devices were line printers, tape drives, and card punches.
- The users of such systems did not interact directly with the computer systems.
- Rather, the user prepared a job—which consisted of the program, the data, and some-control information about the nature of the job (control cards)—and submitted it to the computer operator.
- The job would usually be in the form of punch cards.
- At some later time (perhaps minutes, hours, or days), the output appeared. The output consisted of the result of the program, as well as a-dump of memory and registers in case of program error.

Memory Layout for a Simple Batch System



Simple Batch Systems

- The operating system in these early computers was fairly simple.
- Its major task was to transfer control automatically from one job to the next.
- The operating system was always (resident) in memory.
- To speed up processing, jobs with similar needs were *batched* together and were run through the computer as a group.
- Thus, the programmers would leave their programs with the operator.
- The operator would sort programs into batches with similar requirements and, as the computer, became available, would run each batch.
- The output from each job would be sent back to the appropriate programmer.

Simple Batch Systems

- Parts of resident monitor
  - Control card interpreter – responsible for reading and carrying out instructions on the cards.
  - Loader – loads systems programs and applications programs into memory.
  - Device drivers – know special characteristics and properties for each of the system's I/O devices.
- Problem: Slow Performance – I/O and CPU could not overlap ; card reader very slow.
- Solution: Off-line operation – speed up computation by loading jobs into memory from tapes and card reading and line printing done off-line.

Spooling *(simultaneous peripheral operation on-line)*

- The definitive feature of a batch system is the *lack* of interaction between the user and the job while that job is executing.
- The job is prepared and submitted, and at some later time, the output appears.
- In this execution environment, the CPU is often idle.
- This idleness occurs because the speeds of the mechanical I/O devices are intrinsically slower than those of electronic devices.
- The solution for the above problem is ***spooling*** *(* simultaneous peripheral operation on-line.)
- In spooling, data is stored first in disk and then cpu interact with disk via main memory.

Spooling *(simultaneous peripheral operation on-line)*

- Overlap I/O of one job with computation of another job.
- While executing one job, the OS.
  - Reads next job from card reader into a storage area on the disk (job queue).
  - Outputs printout of previous job from disk to printer.
- *Job pool* – data structure that allows the OS to select which job to run next in order to increase CPU utilization.

Spooling (simultaneous peripheral operation on-line)

- Spooling uses the disk as a huge buffer, for reading as far ahead as possible on input devices and for storing output files until the output devices are able to accept them.
- Spooling is also used for processing data at remote sites. The CPU sends the data via communications paths to a remote printer (or accepts an entire input job from a remote card reader).
- The remote processing is done at its own speed, with no CPU intervention. Spooling overlaps the I/O of one job with the computation of other jobs.

- **Even in a simple system, the spooler may be reading the input of one job while printing the output of a different job. During this time, still another job (or jobs) may be executed, reading their "cards" from disk and "printing" their output lines onto the disk.**

Spooling (simultaneous peripheral operation on-line)

- A pool of jobs on disk allows the operating system to select which job to run next, to increase CPU utilization.
- When jobs come in directly on cards or even on magnetic tape, it is not possible to run jobs in a different order.
- Jobs must be run sequentially, on a first-come, first-served basis.

Spooling *(simultaneous peripheral operation on-line)*

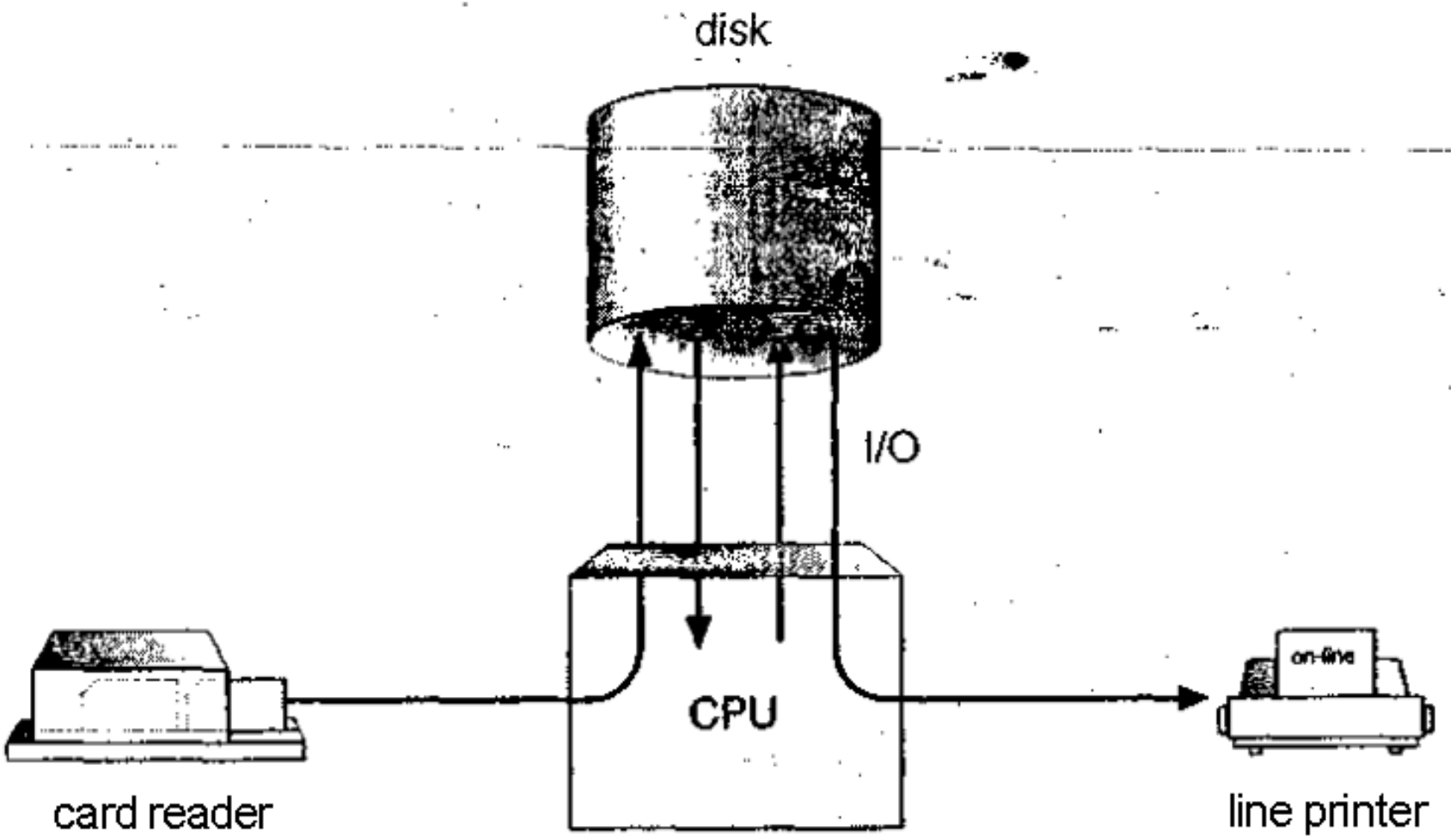


Figure 1.3 Spooling.

Spooling *(simultaneous peripheral operation on-line)*

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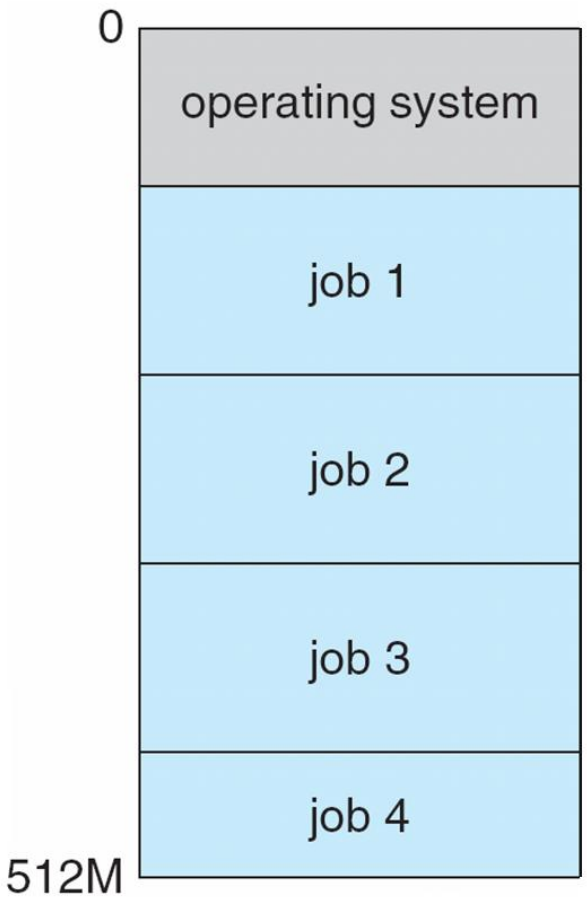
Multiprogrammed Systems

- One of the most important aspects of operating systems is the **ability to multiprogram**.
- A single program cannot, keep either the CPU or the I/O devices busy at all times
- **Multiprogramming** increases **CPU utilization** by organizing jobs (code and data) so that the **CPU always has one to execute**.
- Multiprogrammed systems provide an environment in which the various system resources (for example, CPU, memory, and peripheral devices) are utilized effectively, but
- **They do not provide for user interaction with the computer system.**

Memory Layout for Multiprogrammed System



Several jobs are kept in main memory at the same time, and the CPU is multiplexed among them.

OS Features Needed for Multiprogramming

- ***Job scheduling:*** If several jobs are ready to be brought into memory, and there is not enough room for all of them, then the system must choose among them. Making this decision is ***job scheduling***
- **Memory management:** the system must allocate the memory to several jobs.
- **CPU scheduling:** the system must choose among several jobs ready to run.
- **Degree of Multiprogramming:** Number of process in the main memory

Timesharing (multitasking)

logical extension in which CPU switches jobs so frequently that users can interact with each job while it is running, creating **interactive** computing

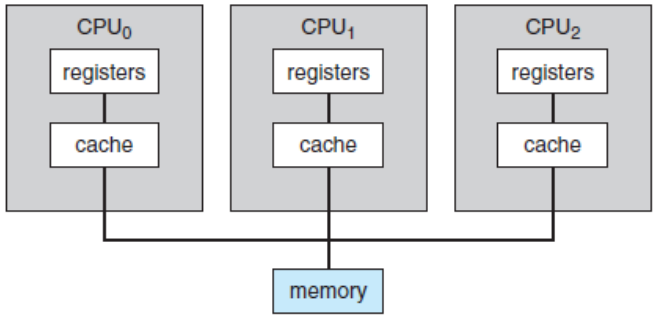
- Time sharing requires an **interactive** computer system, which provides direct communication between the user and the system.
  - **Response time** should be < 1 second
  - Each user has at least one program executing in memory ⇨**process**
  - If several jobs ready to run at the same time ⇨ **CPU 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

Time-Sharing Systems–Interactive Computing

- The CPU is multiplexed among several jobs that are kept in memory and on disk (the CPU is allocated to a job only if the job is in memory).
- A job is swapped in and out of memory to the disk.
- Time-sharing systems provide a mechanism for concurrent execution, which requires sophisticated CPU scheduling schemes.
- To ensure orderly execution, the system must provide mechanisms for **job synchronization** and **communication** and must ensure that jobs do not get stuck in a **deadlock**, forever waiting for one another

Parallel Systems

- **Multiprocessor systems** with more than one CPU in close communication.
- *Tightly coupled system* – processors share memory and a clock; communication usually takes place through the shared memory.
- Advantages of parallel system:
- **Increased *throughput*:** By increasing the number of processors, we get more work done in a shorter period of time.
- **Economical *:*** The processors can share peripherals, cabinets, and power supplies. If several programs are to operate on the same set of data, it is cheaper to store those data on one disk and to have all the processors share them, rather than to have many computers with local disks and many copies of the data.
- **Increased reliability**: If functions can be distributed properly among several processors, then the failure of one processor will not halt the system, but rather will only slow it down.



- Two types: **Symmetric and Asymmetric**

Real-Time Systems

- This system is used when there **are rigid time requirements on the operation of a processor or the flow of data**
- Sensors bring data to the computer. The computer must analyze the data and possibly adjust controls to modify the sensor inputs.
- Often used as a **control device in a dedicated application** such as controlling scientific experiments, medical imaging systems, industrial control systems, and some display systems.
- **Well-defined fixed-time constraints.**

- **Hard real-time system**
  - It guarantees that critical tasks complete on time.
  - This goal requires that all delays in the system be bounded, from the retrieval of stored data to the time that it takes the operating system to finish any request made of it.
  - It is used as a control device in a dedicated application. A hard real-time operating system has well-defined, fixed time constraints.
  - Processing *must* be done within the defined constraints, or the system will fail.
  - Secondary storage limited or absent, data stored in short-term memory, or read-only memory (ROM)

Real-Time Systems

- *Soft real-time system*
  - Limited utility in industrial control or robotics
  - Useful in applications (multimedia, virtual reality) requiring advanced operating-system features.
- Soft real-time systems have less stringent timing constraints, and do not support deadline scheduling.

Components/Functions of OS

- Process Management
- Main Memory Management
- Secondary-Storage Management
- I/O System Management
- File Management
- Protection System
- Networking
- Command-Interpreter System

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

File Management

- OS provides uniform, logical view of information storage
  - Abstracts physical properties to logical storage unit - **file**
- 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)

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

Operating System Services

• Operating systems provide an environment for execution of programs

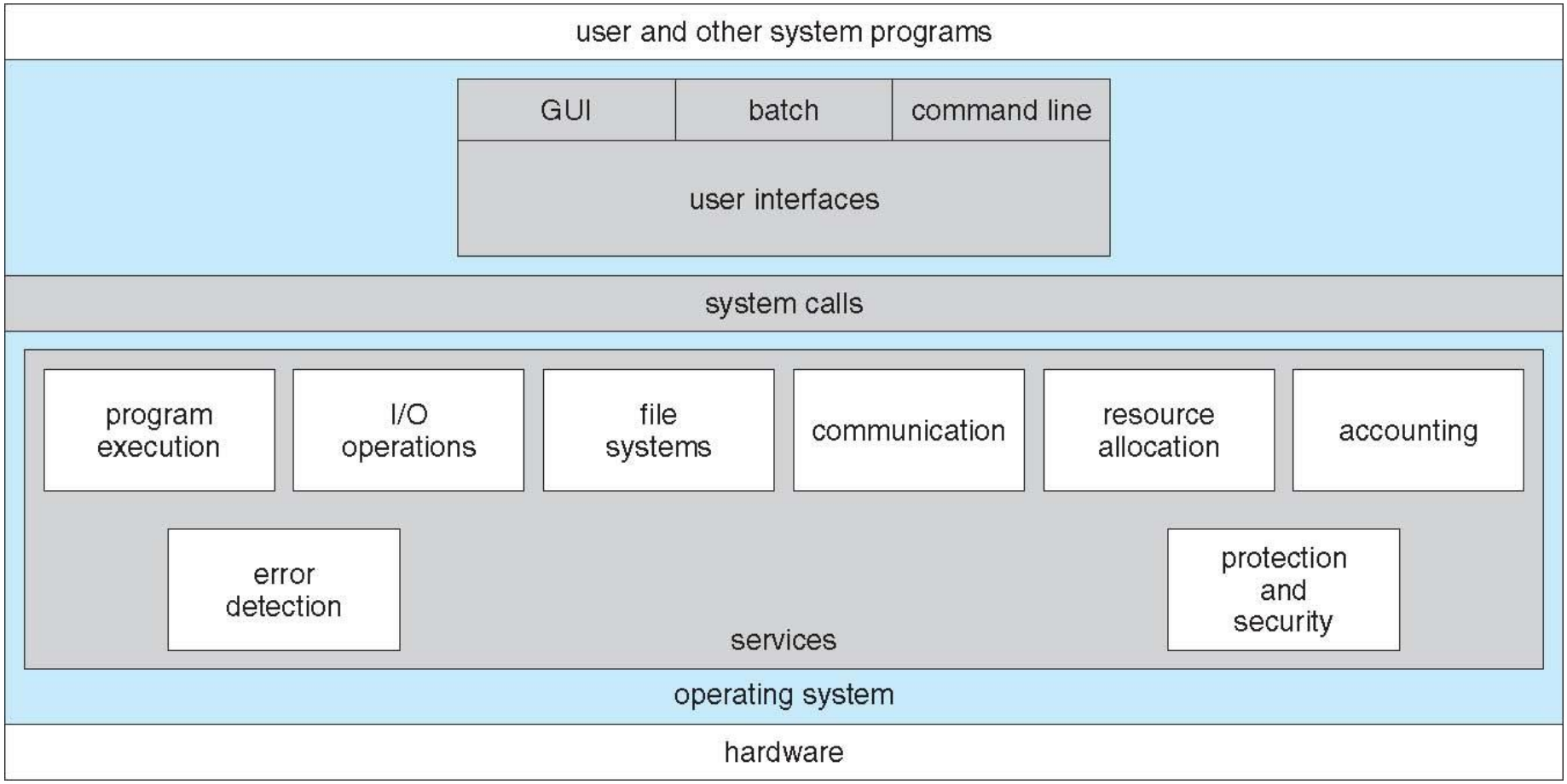
• Provides certain services to
  – Programs and
  – Users of those programs

➢ Basically two types of services:

✓ Set of OS services provides functions that are helpful to the user

✓ Set of OS functions for ensuring the efficient operation of the system itself via resource sharing

A View of Operating System Services



Operating System Services

- 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)

Operating System Services

I/O operations - A running program may require I/O, which may involve a file or an I/O device

File-system manipulation - 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)

Operating System Services

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

Operating System Services

- 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

Operating System Services

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

Operating-System Operations

- Modern operating systems are **interrupt driven**.
- Events are almost always signaled by the occurrence of an interrupt or a trap.
- A **trap** (or an **exception**) is a software-generated interrupt caused either by an error (for example, division by zero or invalid memory access) or by a specific request from a user program that an operating-system service be performed.
- Since the operating system and the users share the hardware and software resources of the computer system, we need to make sure that an error in a user program could cause problems only for the one program running

Operating-System Operations

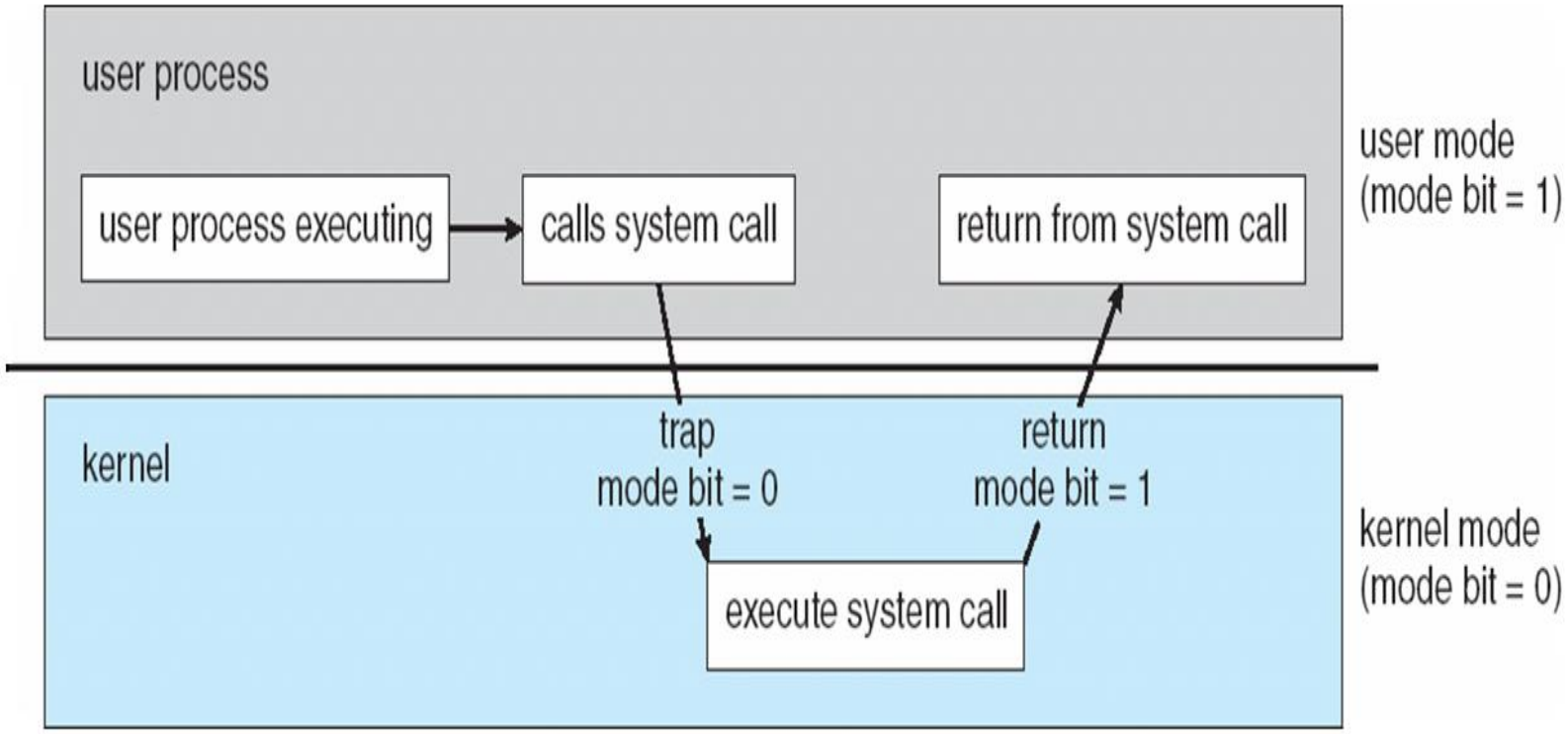
- **Dual-mode** operation allows OS to protect itself and other system components
  - **User mode** and **kernel mode**
  - **Mode bit** provided by hardware
    - Provides ability to distinguish when system is running user code or kernel code
    - Some instructions designated as **privileged**, only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

Operating-System Operations (cont.)

- 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

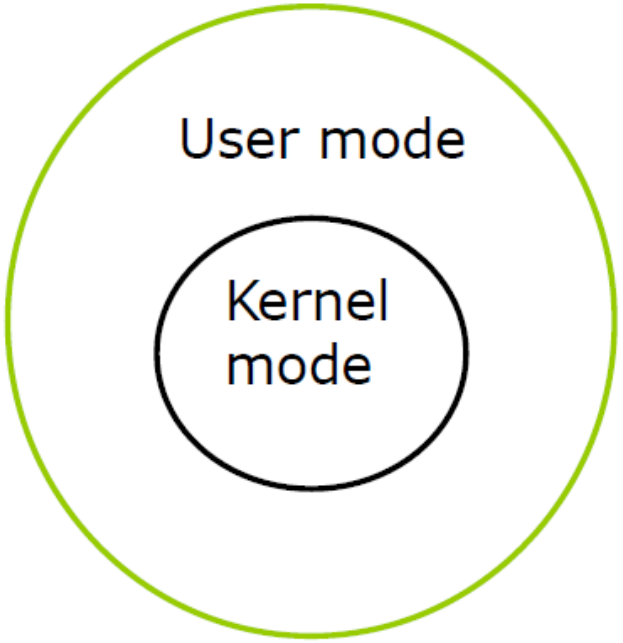
Operating-System Operations (cont.)

Transition from User to Kernel Mode



System Calls

- **It provides an interface to the services made available by an OS.** (Available as routines in C,C++,assembly languages)
- **Mode of Operation**
  - **User Mode**
    - Safer mode of operation
  - **Kernel mode**
    - Privileged mode
    - Access to all H/W resources



System Calls

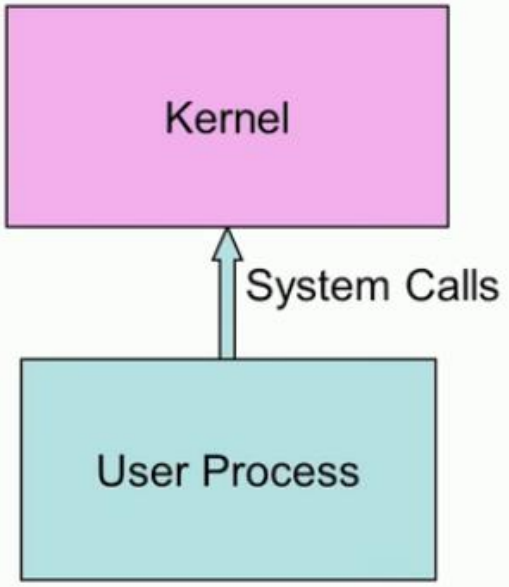
- Typically written in a high-level language (C or C++)
- Mostly accessed by programs via a high-level **Application Programming Interface (API)** rather than direct system call use
- Three most common APIs are
  - Win32 API for Windows,
  - POSIX API for POSIX-based systems (including virtually all versions of UNIX, Linux, and Mac OS X), and
  - Java API for the Java virtual machine (JVM)

System Calls

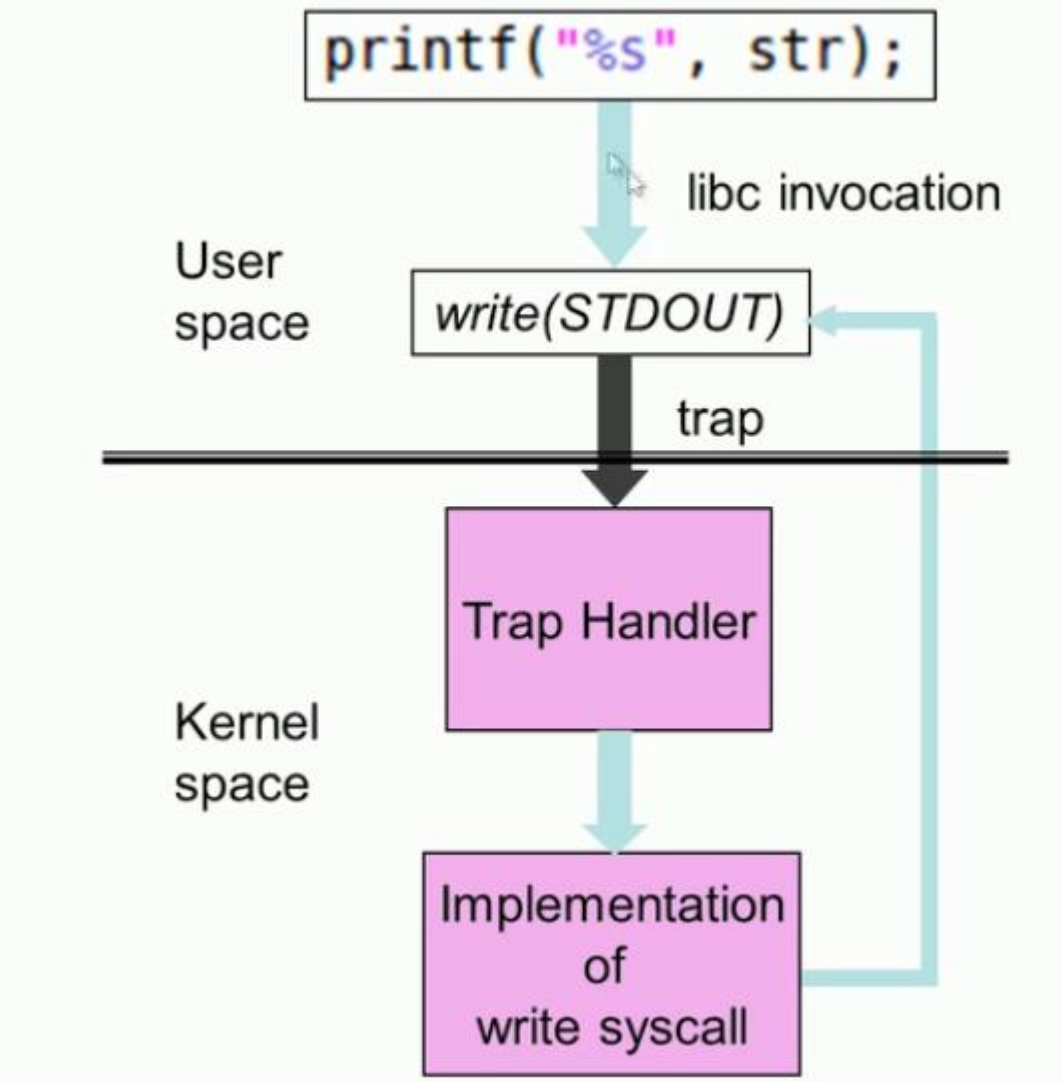
- Why would an application programmer prefer programming according to an API rather than invoking actual system calls?
  - **Program portability:** An application programmer, designing a program using an API can expect his/her program to compile and run on any system that supports the same API.
  - **Easy to work:** actual system calls can often be more detailed and difficult to work with than the API available to an application programmer

Communicating with the OS (System Calls)

- System call invokes a function in the kernel using a Trap
- This causes
  - Processor to shift from user mode to privileged mode
- On completion of the system call, execution gets transferred back to the user process



Example (write system call)

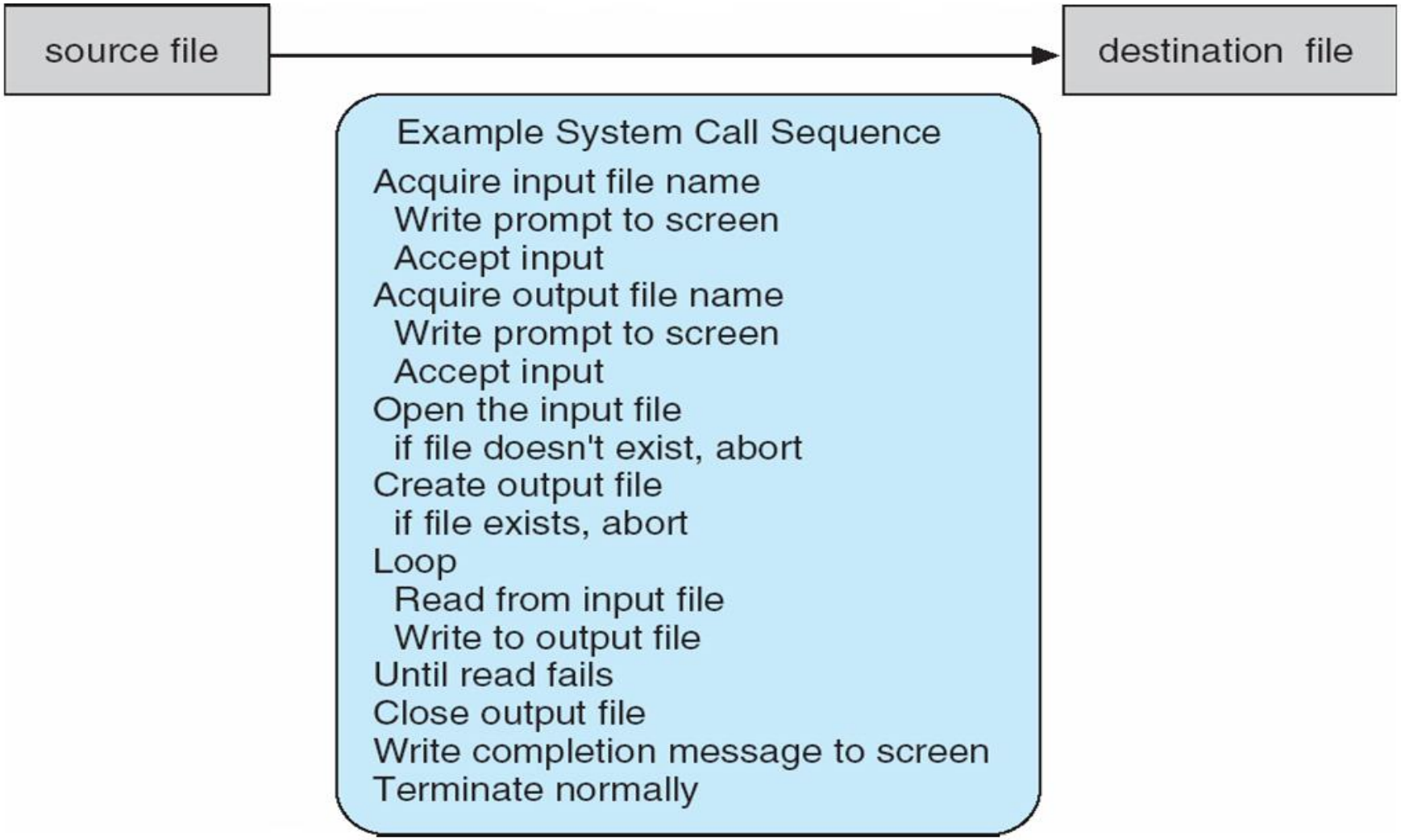


System Call vs Procedure Call

System Call	Procedure Call
Uses a TRAP instruction (such as int 0x80)	Uses a CALL instruction
System shifts from user space to kernel space	Stays in user space … no shift
TRAP always jumps to a fixed addess (depending on the architecture)	Re-locatable address

Example of System Calls

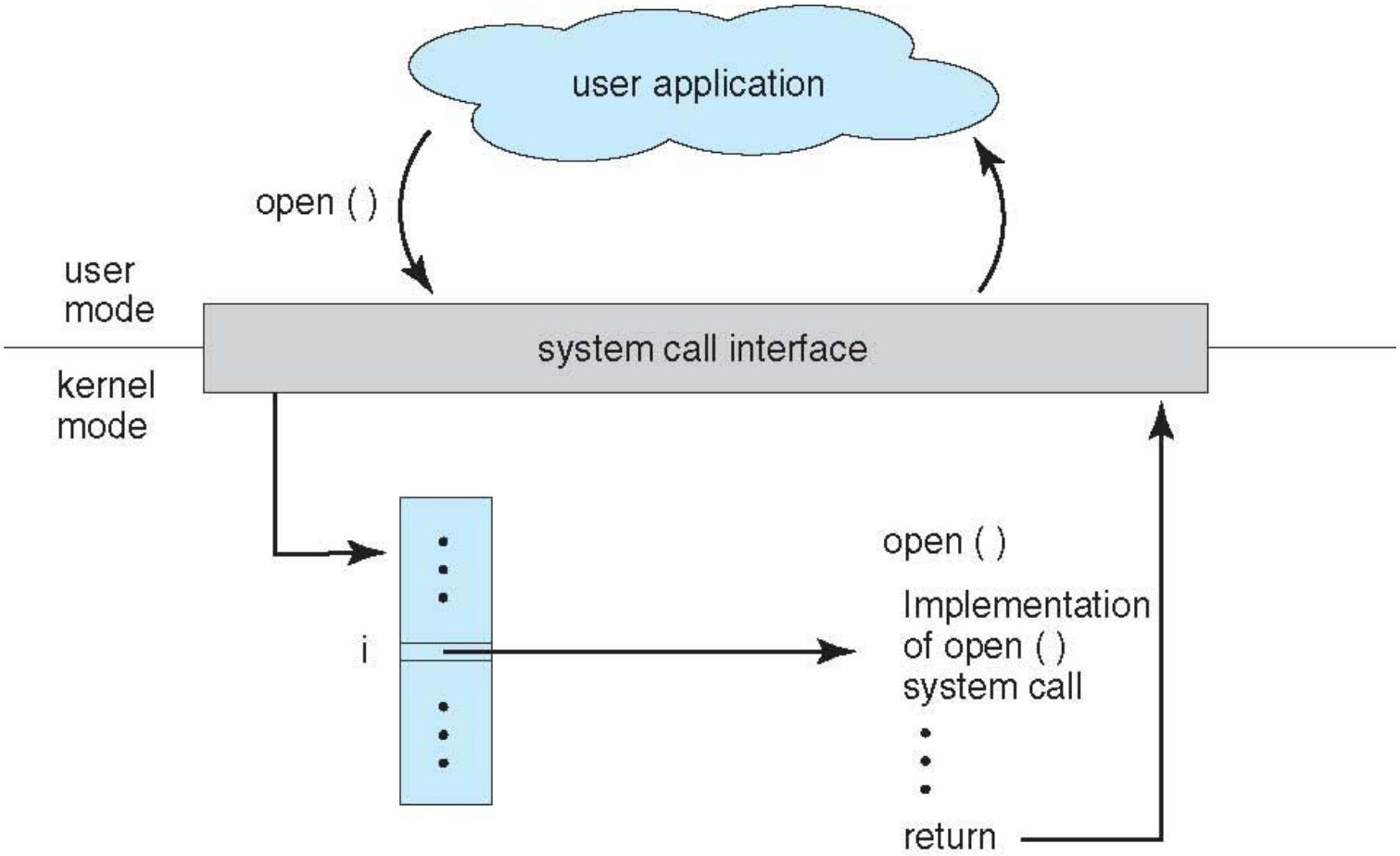
System call sequence to copy the contents of one file to another file



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)

System Call – OS Relationship



Available as routines written in C/C++

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

System Call Parameter Passing

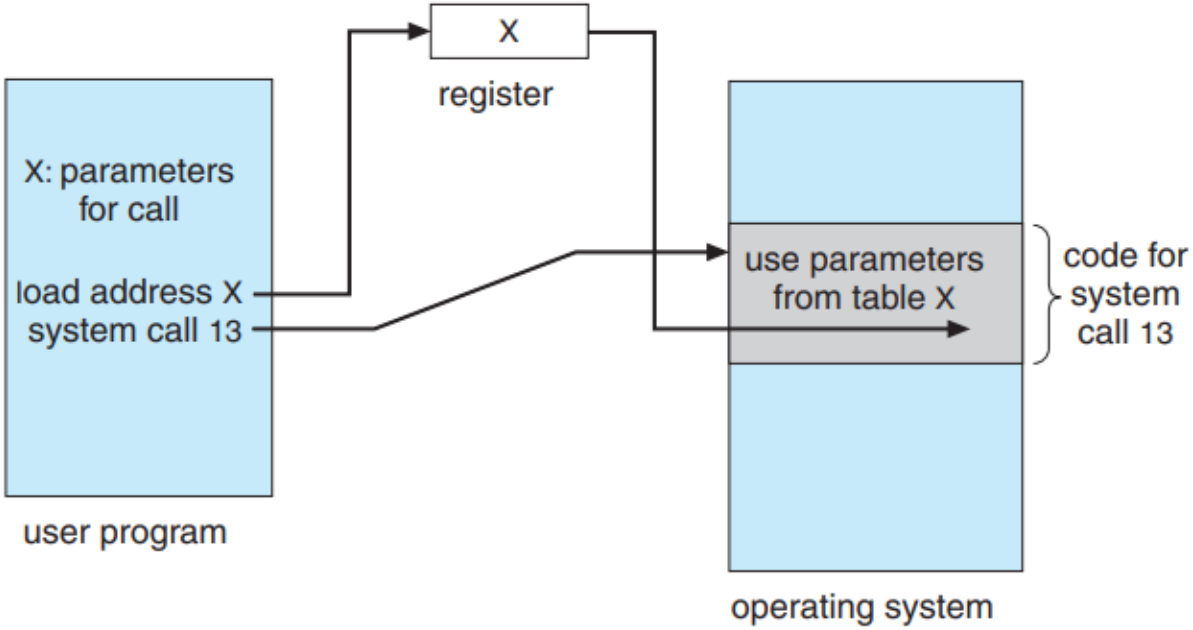


Figure 2.7 Passing of parameters as a table.

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

Standard C Library Example

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