
California
NULL
Accord
V6
TOURING

What is my role?

What is my role?

Multi-faceted:

- Instructor
- Assessment
- Guide

What is your role?

What is your role?

- Absorb material so that the key ideas stay with you for a long time
- Perform well in the assessments

Don’t be passive!

- Ask questions
- Do the reading and the work
- Challenge yourself
- Don’t be afraid to try things
  - Or to throw out code

In the beginning…

Uniprocessors

- No real OS … (machine-level) programs access hardware directly
- Execute one program at a time
- I/O very slow
- Program waits for I/O

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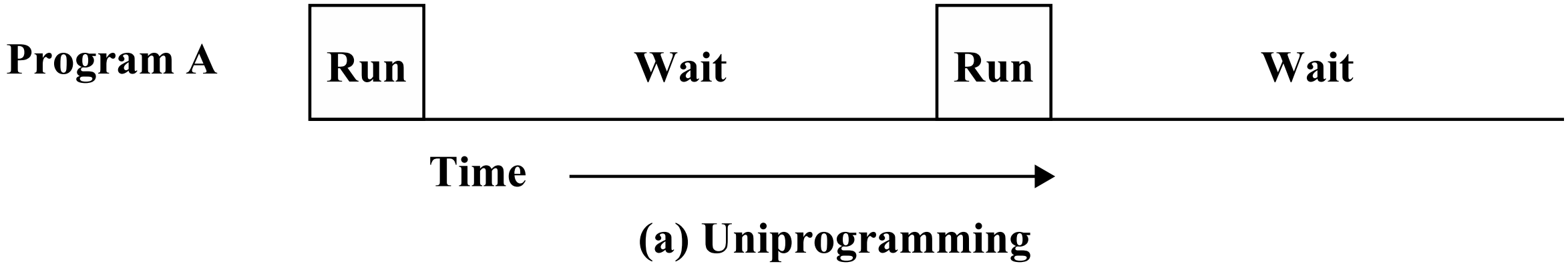
Uniprocessors

Imagine a program that must wait for every I/O operation

Read one record from file	15 µs
Execute 100 instructions	1 µs
Write one record to file	15 µs
TOTAL	31 µs

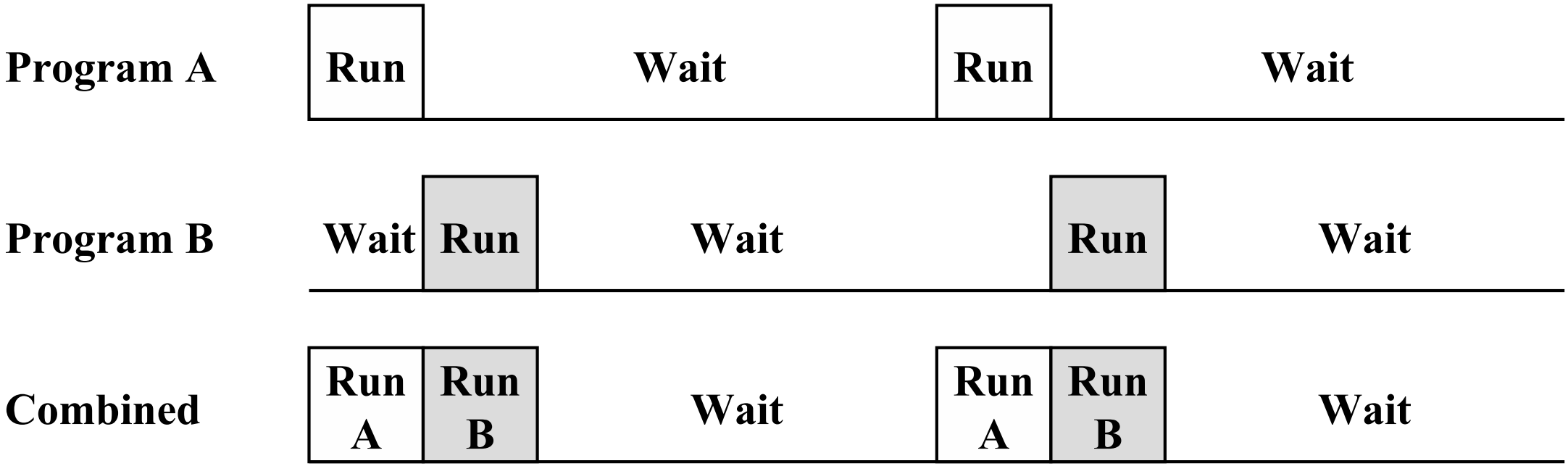
$$\text{Percent CPU Utilization} = \frac{1}{31} = 0.032 = 3.2\%$$

CPU Utilization with I/O Bound Programs



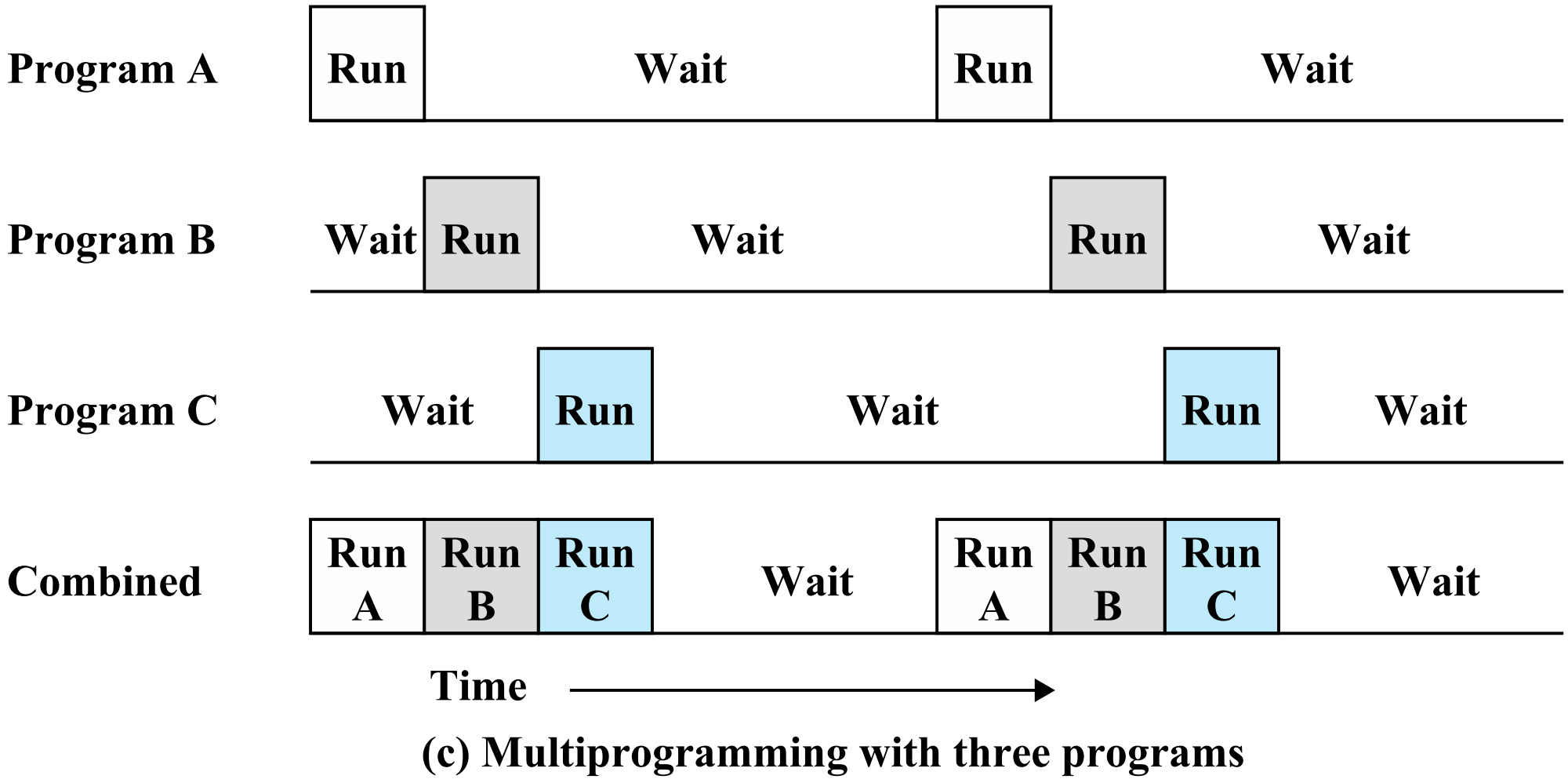
(a) Uniprogramming

Multiprogramming



(b) Multiprogramming with two programs

Multiprogramming



(c) Multiprogramming with three programs

Multiprogramming

In order to get this to work, we must have:

- A way to figure out which job to switch to next
- The memory space to fit the jobs being executed
- A mechanism that performs the switching between the jobs

These functions are provided by the OS

Processes

- A ***process*** is a program in execution:
  - It is a unit of work within the system.
  - Program is a passive entity, process is the active entity
- Process needs resources to accomplish its task
  - CPU, memory, I/O, files
- OS manages these resources
  - Process termination requires the OS to reclaim of any reusable resources

Processes

- Single-threaded process has:
  - One program counter specifying location of next instruction to execute
    - Process executes instructions sequentially, one at a time, until completion
  - One execution stack

- Typically a system has many processes
  - Some user, some OS-related
  - These are running concurrently on one or more CPUs

Multi-Threading

Even more complicated systems support ***multi-threaded processes***: a process has one program counter per thread

- Allows execution of many closely-linked tasks in parallel
- One stack per thread
- However, the memory space is shared across all the threads

Process Management Activities

The OS is responsible for:

- Creating and deleting both user and system processes
- Suspending and resuming processes
- Scheduling processes to have access to resources, including the CPU
- Providing mechanisms for process synchronization and deadlock handling
- Providing mechanisms for process communication

Making Efficient Use of a CPU

- Multiprogramming:
  - Switch between processes as CPU becomes idle (e.g., if a process is waiting for I/O)
  - Scheduling processes is relatively straight-forward

- Multitasking:
  - Switch quickly between processes automatically
    - Processes have a fixed upper bound of time before needing to wait again
  - Allows processes to appear like they are responding in real time (at least to a user)
  - Scheduling processes and their memory use is a challenge

Protection with Processor Modes

Dual-mode operation allows the OS to protect itself and other system components

- Mode bit provided in the hardware:
  - User mode and kernel (privileged) mode
- Provides ability to distinguish when system is running user code versus kernel code
- Some instructions designated as privileged and can only be executed in kernel mode
- Hardware generally can only be manipulated in privileged mode
- User mode process is restricted in the types of memory that it can access

Protection with Processor Modes

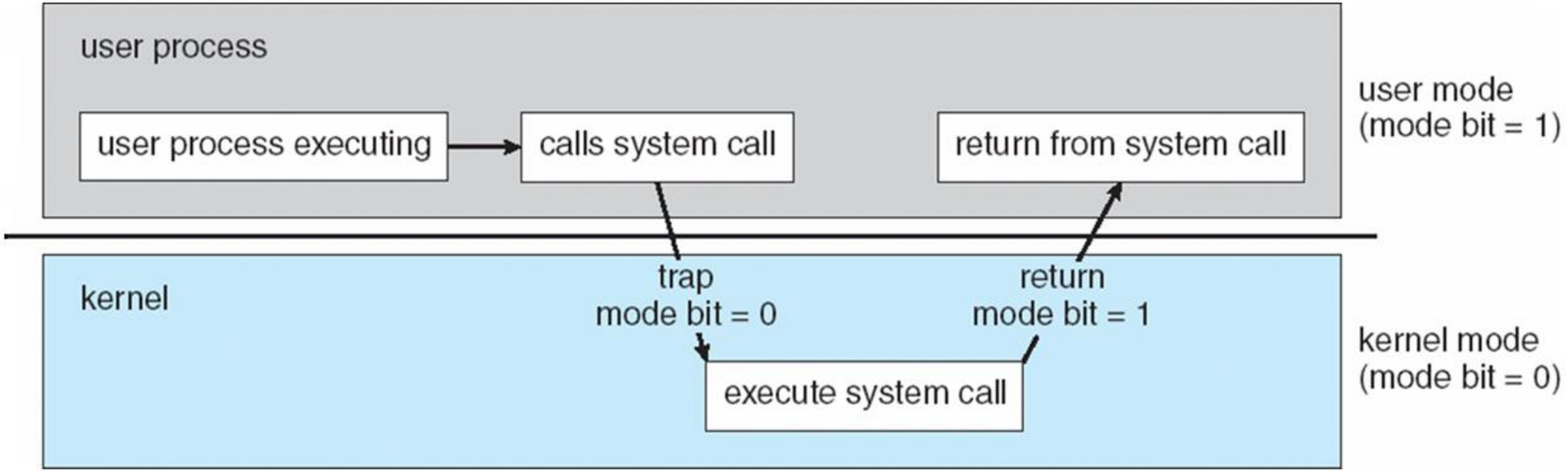
- ***System calls*** change mode from user to kernel
  - Allow safe manipulation of kernel data structures and hardware
  - Return from call resets mode to user

- Increasingly, CPUs support multi-mode operations
  - For example: virtual machine manager (VMM) mode for guest VMs

System Calls

System calls allow a user program to request services from the kernel

- Including I/O and process management services

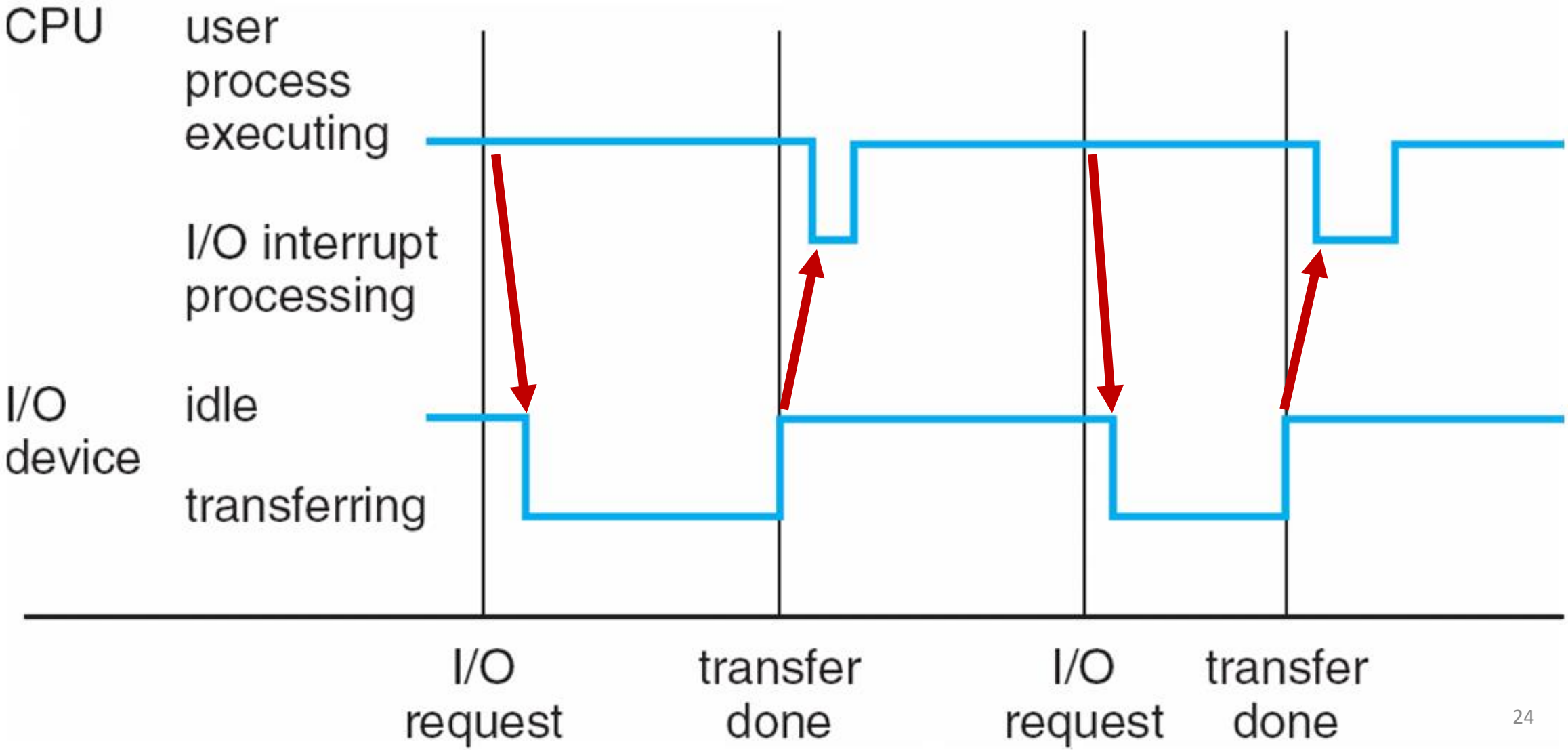


Interrupts

An operating system is **interrupt driven**

- Interrupts are key to addressing hardware/software events quickly
- An interrupt transfers control from the currently executing program to the appropriate interrupt service routine (a special function)
- Interrupt architecture must save the address of the interrupted instruction, as well as the state of the registers
- A **trap** or **exception** is a software-generated interrupt caused either by an error or a user request

Interrupt Timeline for I/O



I/O Structure

- User program does not have direct access to the devices (it is prevented explicitly!)
- Instead, a request for access is made to the OS through the use of a system call
  - Special function that is able to access the kernel-level data structures and I/O system
- After I/O starts, control returns to user program without waiting for I/O completion

Storage Definitions

Storage Definitions

- Bit: contains a value of 0 or 1
- Byte: 8-bits. Fundamental unit of memory
- Word: multiple bytes (system dependent)
  - In modern laptops: 8 bytes
- 2^10 bytes: kilobyte
- 2^20 bytes: megabyte
- 2^30 bytes: gigabyte
- 2^40 bytes: terabyte

Storage Types

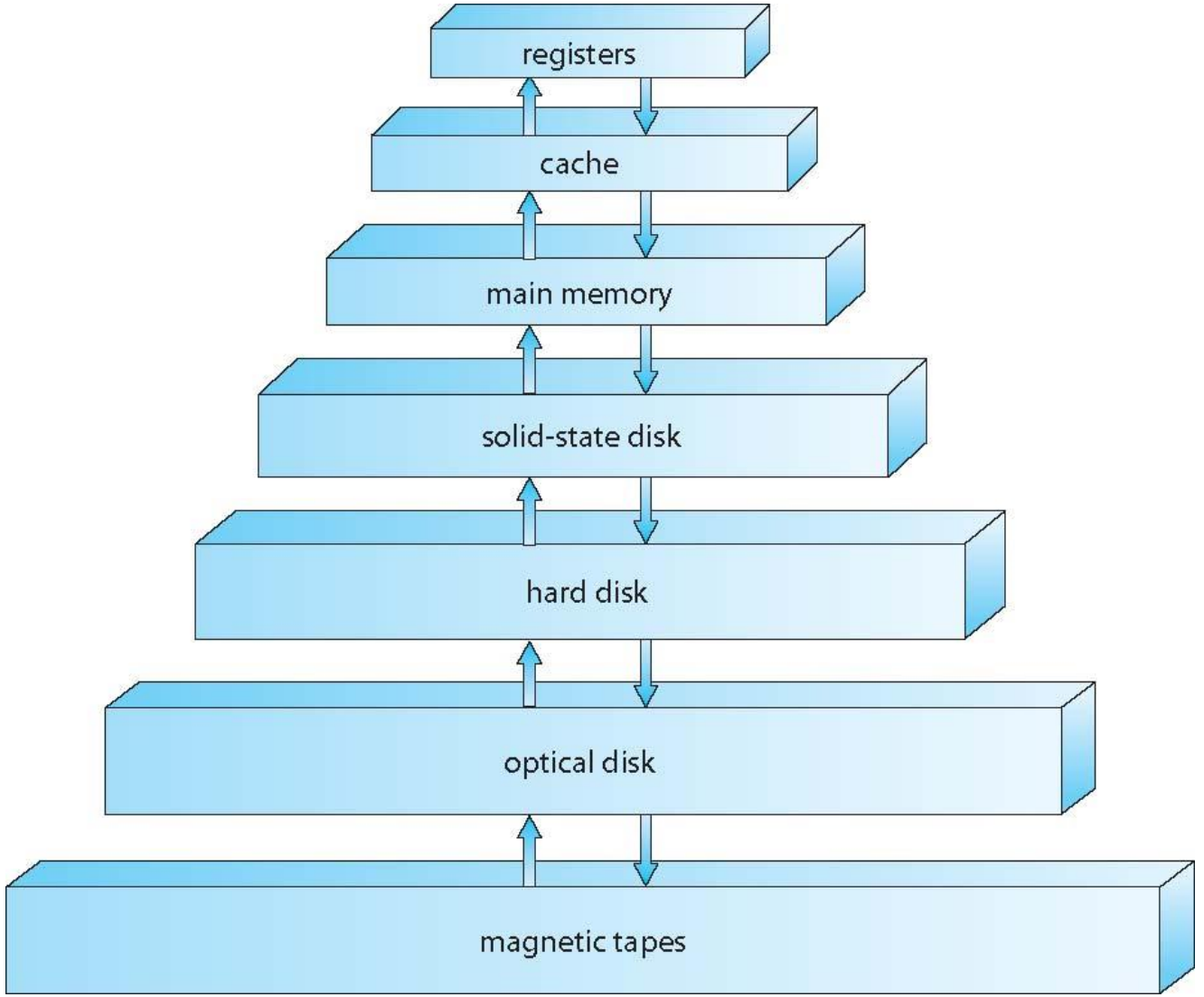
Storage Types (some)

- 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
- Solid-state disks – faster than hard disks, nonvolatile
  - Various technologies
  - Expensive relative to hard disks

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

Storage-Device Hierarchy



Storage Hierarchy

- Storage systems organized in hierarchy. Each level involves trade-offs:
  - Speed
  - Cost
  - Volatility
- **Caching** – copying information into faster storage system
  - Allows faster access to and alterations of data
  - Main memory can be viewed as a cache for secondary storage

Caching

Information in use copied from slower to faster storage temporarily

- Important principle, performed at many levels in a computer (in hardware, operating system, software)
- 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 from there
- Cache management is an important design choice
  - Including: cache size and replacement policy

Storage Management

- OS provides uniform, logical view of information storage
  - Abstracts physical properties to logical storage unit
  - These physical 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

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

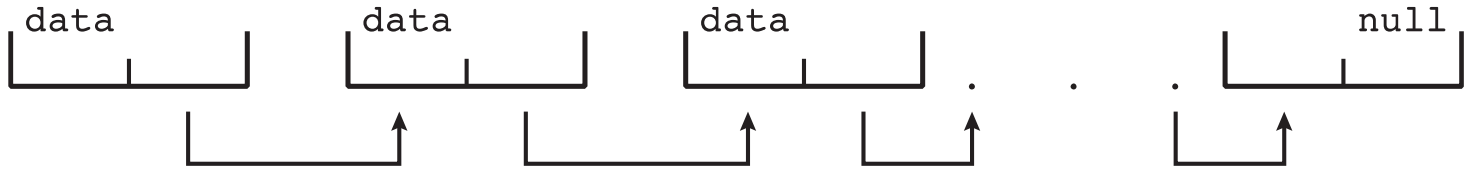
Kernel-Level Data Structures

Requirements

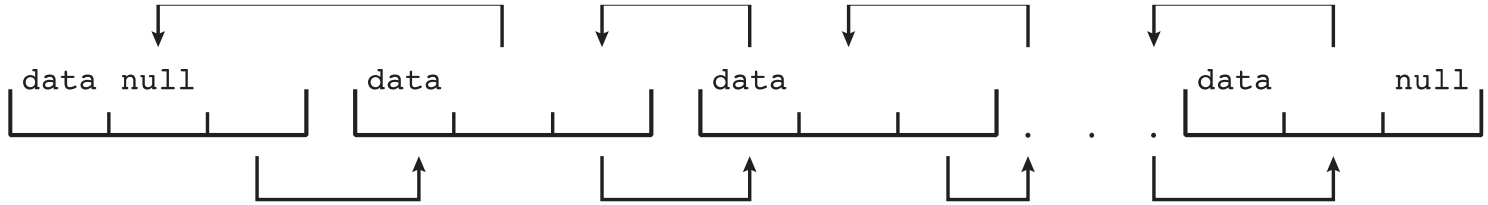
- Space efficient
- Time efficient
  - Many data structures exist over the lifetime of the system
  - Queries and small changes to the data structure must be quick
- Secure
  - Manipulated only in kernel mode
  - Changes must leave the data structure in a proper state

Kernel Data Structures

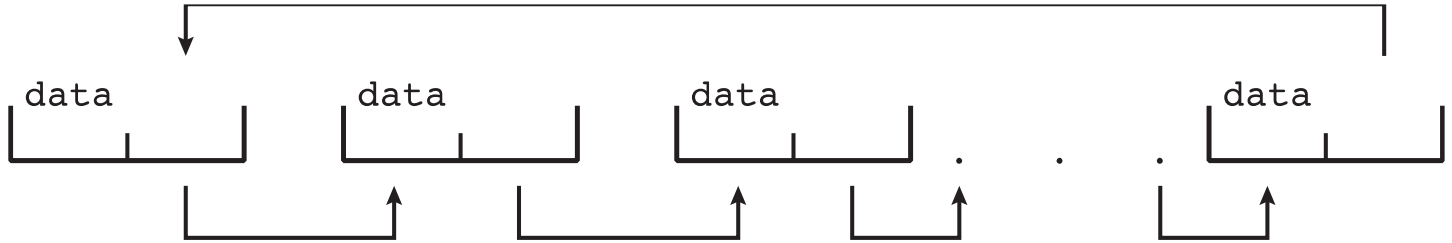
- Singly linked list



- Doubly linked list

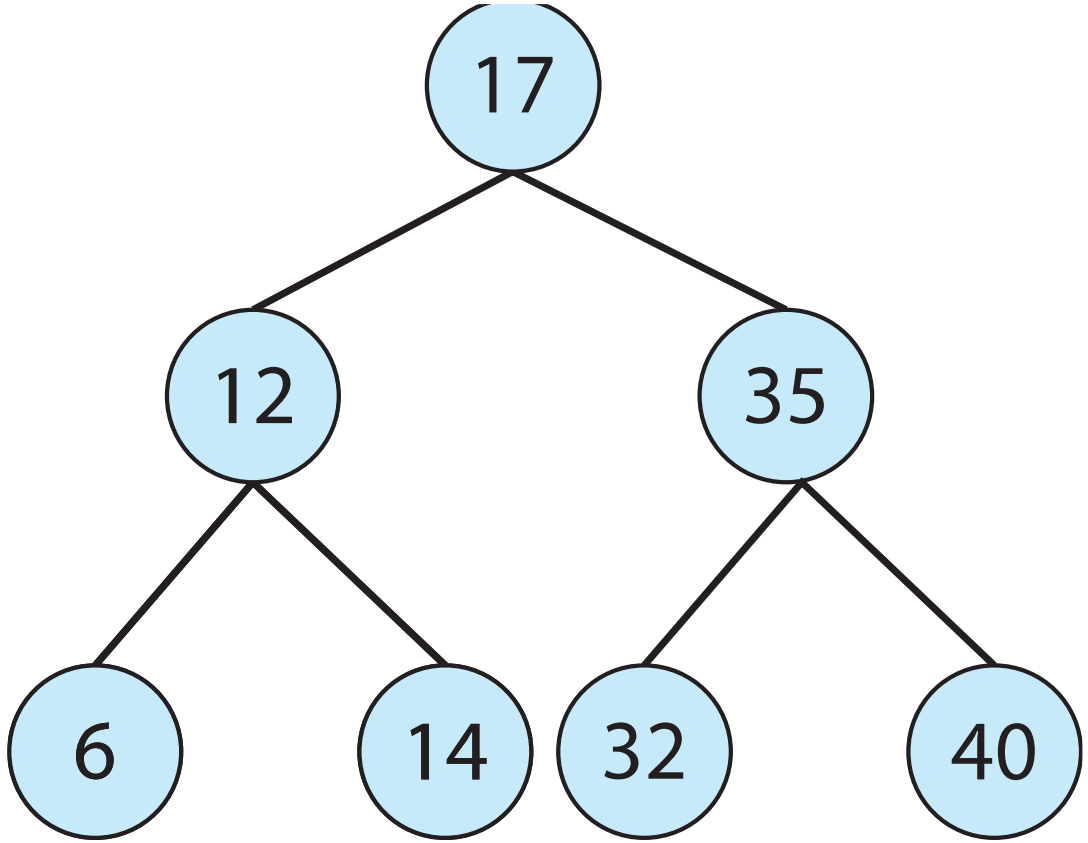


- Circular linked list



Kernel Data Structures

- Linear list
  - Search performance is O(n)
- Binary search tree
  left <= right
  - Balanced binary search tree access is O(ln n)



Kernel Data Structures

- Hash functions:
  - Translate some many-byte data structure into a short hash value
  - Small changes in the data structure mean substantial changes in the hashed value
  - These are typically one-way functions!
- Hash maps:
  - Associate a hash value with some other data structure
  - O(1) lookup and storage
  - Hash table must be large relative to the number of items stored

Kernel Data Structures

Bitmaps

- A word is composed of k bits
- If we need to store a set of Boolean values, we can map each to one of these bits
- Example: allocation table for k blocks on a hard disk
  - Each bit indicates whether the corresponding block is used by a file or is free to be allocated to new files
  - Example: 0xF7: blocks 3, 4 and 5 are free to be used

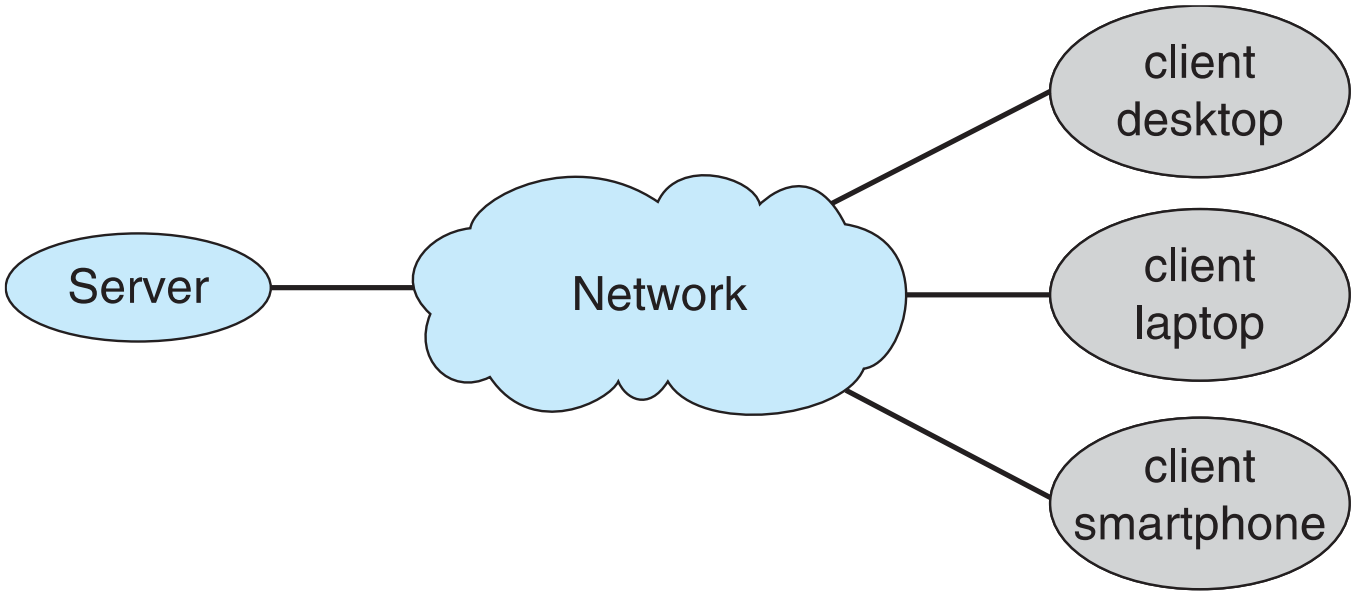
Distributed Computing

- Collection of separate, possibly heterogeneous, systems networked together
- Goals: achieve the illusion of a single system
- Network is a communications path, TCP/IP most common protocol
  - Local Area Network (LAN)
  - Wide Area Network (WAN)
  - Metropolitan Area Network (MAN)
  - Personal Area Network (PAN)

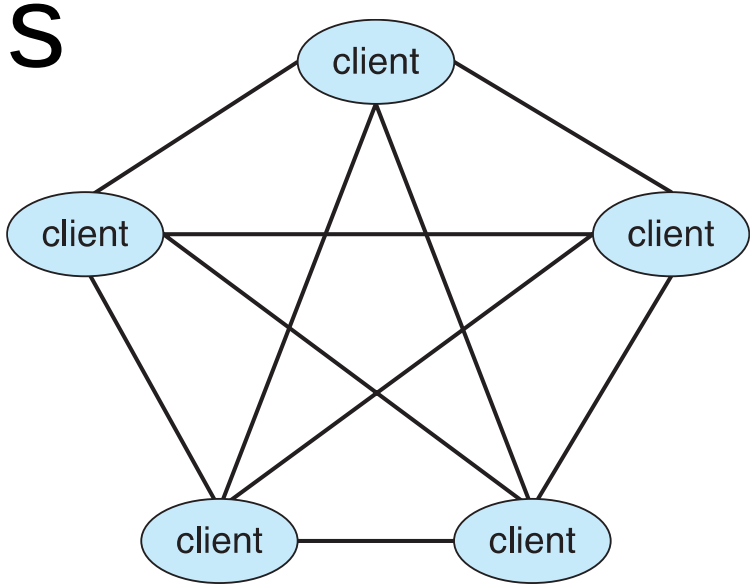
Client-Server Computing

Remote server provides some service to many different clients

- File system: storage and retrieval of files
- Database
- Map services
- Image recognition
- Messaging



Peer-to-Peer Systems



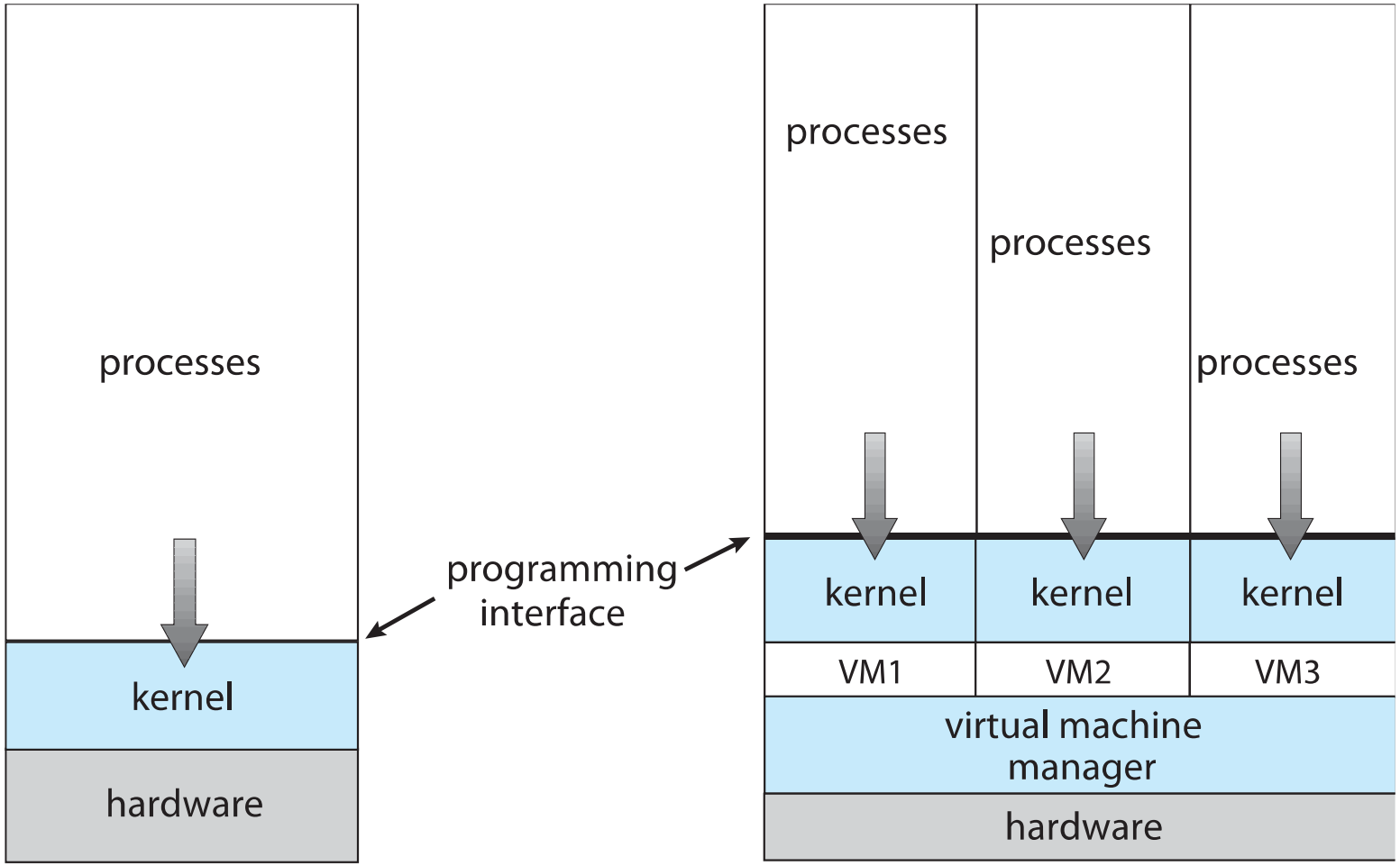
P2P does not distinguish clients and servers

- 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

Virtualization

- Allows an operating system to run applications within other OSes
- ***Emulation*** used when source CPU type different from target type (i.e. PowerPC to Intel x86)
  - Generally slow
  - When computer language not compiled to native code, ***Interpretation*** is required
- ***Virtualization***: OS natively compiled for CPU, running guest OSes that are also natively compiled
  - VMware running WinXP guests, each running applications, all on native WinXP host OS
  - VMM (virtual machine Manager) provides virtualization services

Virtualization



(a) (b)

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)

Open Source Operating Systems

Full source code is available for some OSes

- Individuals can make changes to the source & build their own OS version
- These changes can be integrated back to the main distribution
- Many “eyes” on the source code: improve quality of the code
  - Just discovered at Def Con (last year): malicious code was inserted into Linux component that allows administrator-level privileges under certain conditions

Next Week

Practicalities of writing and executing code

- System calls for I/O
- Linux environment
- Writing and compiling code
- Low-level data representation in C