

Operating System Concepts

Tei-Wei Kuo

ktw@csie.ntu.edu.tw

Dept. of Computer Science and
Information Engineering
National Taiwan University

Contents

1. Introduction
2. System Structures
3. Process Concept
4. Multithreaded Programming
5. Process Scheduling
6. Synchronization
7. Deadlocks
8. Memory-Management Strategies
9. Virtual-Memory Management
10. File System
11. Mass-Storage Structures
12. I/O Systems
13. Protection, Security, Distributed Systems 2

Chapter 1. Introduction

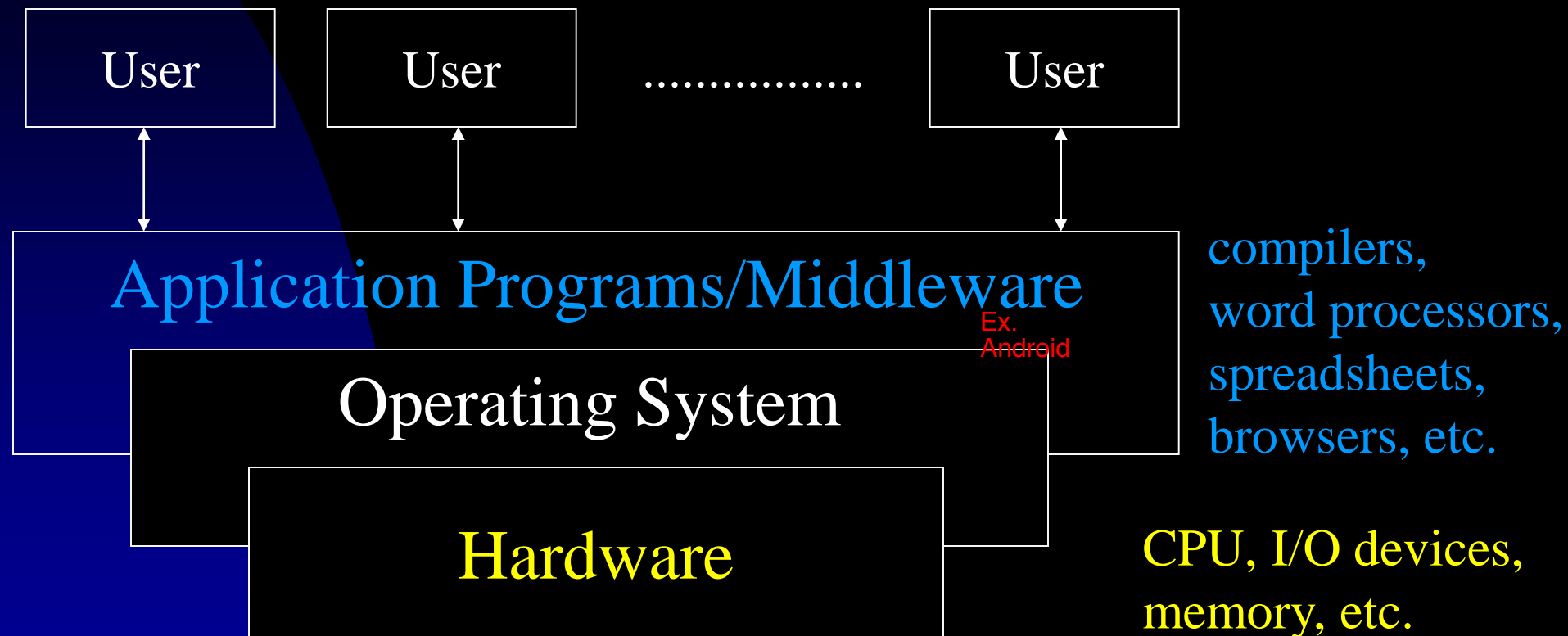
Introduction

- What is an Operating System?
 - A basis for application programs
 - An intermediary between users and hardware
- Amazing variety
 - Mainframe, personal computer (PC), handheld computer, embedded computer without any user view

大型主機

Convenient vs Efficient

Computer System Components



- OS – a government/environment provider

User View

- The user view of the computer varies by the interface being used!
- Examples:
 - Personal Computer → Ease of use
 - Mainframe or minicomputer → maximization of resource utilization
 - Efficiency and fair share
 - Workstations → compromise between individual usability & resource utilization
 - Handheld computer → individual usability
 - Embedded computer without user view → run without user intervention

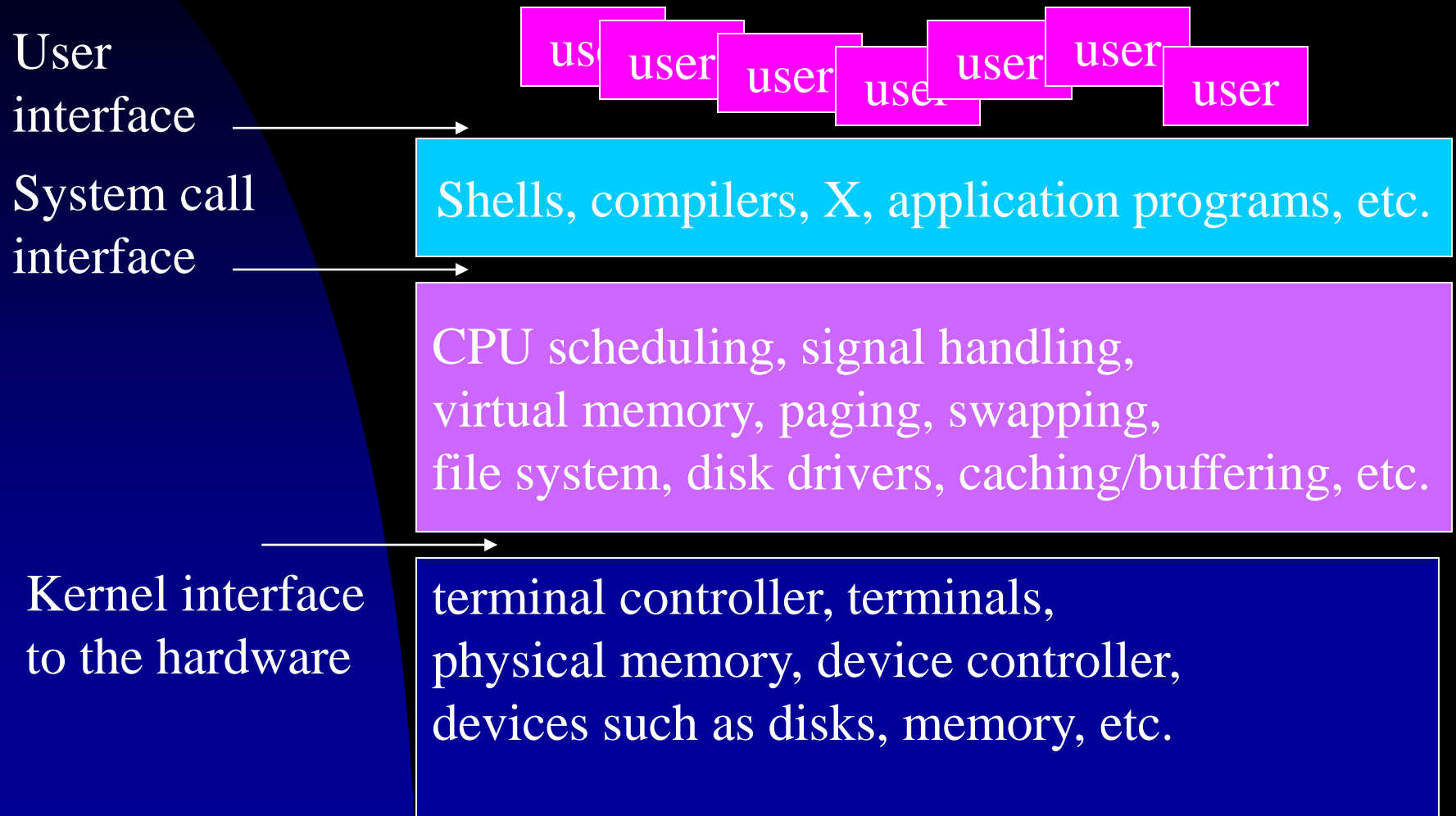
System View

- A Resource Allocator
 - CPU time, Memory Space, File Storage, I/O Devices, Shared Code, Data Structures, and more
- A Control Program
 - Control execution of user programs
 - Prevent errors and misuse
- OS definitions – US Dept.of Justice against Microsoft in 1998
 - The stuff shipped by vendors as an OS
 - Run at all time

System Goals

- Two Conflicting Goals:
 - Convenient for the user!
 - Efficient operation of the computer system!
- We should
 - recognize the influences of operating systems and computer architecture on each other
 - and learn why and how OS's are by tracing their evolution and predicting what they will become!

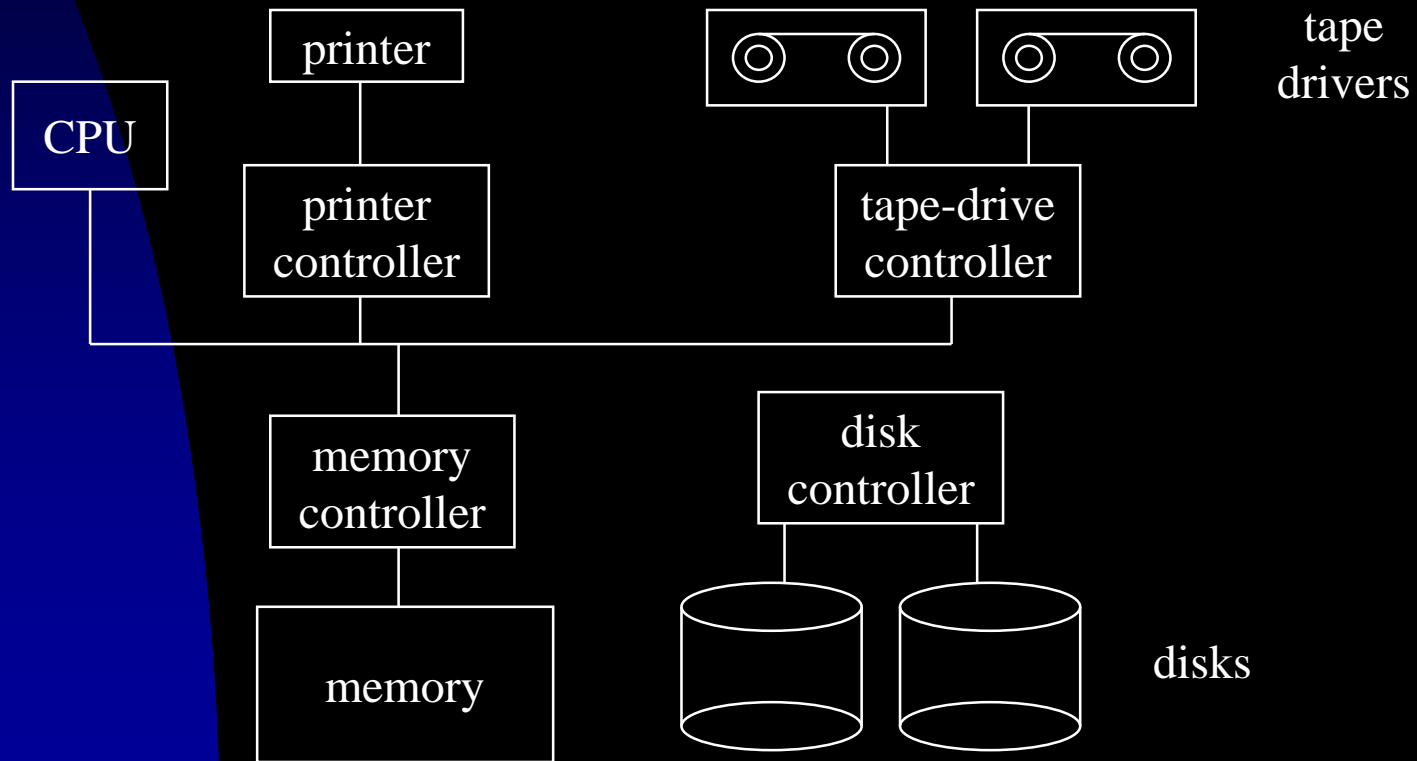
UNIX Architecture



UNIX

Computer-System Organization

- Objective: General knowledge of the structure of a computer system.



- Device controllers: synchronize and manage access to devices.

Booting

- Bootstrap program:
 - Initialize all aspects of the system, e.g., CPU registers, device controllers, memory, etc.
 - Load and run the OS
- Operating system: run *init* to initialize system processes, e.g., various daemons, login processes, after the kernel has been bootstrapped.
(/etc/rc* & init or /sbin/rc* & init)

Interrupt

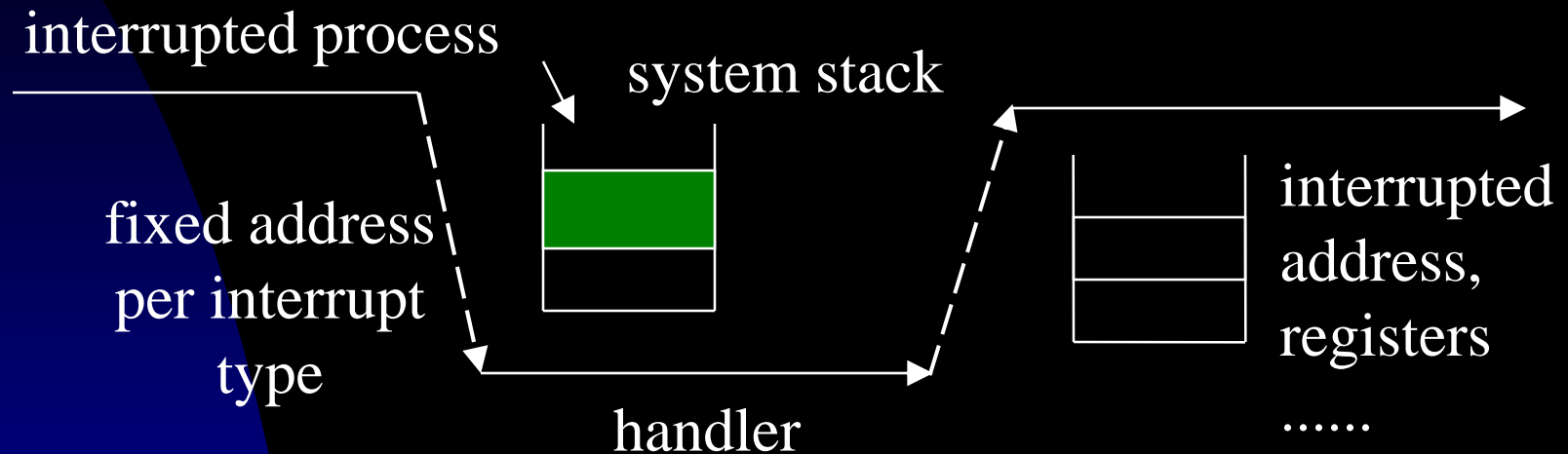
- Hardware interrupt, e.g. services requests of I/O devices
- Software interrupt, e.g. signals, invalid memory access, division by zero, system calls, etc – (trap)




- Procedures: generic handler or interrupt vector (MS-DOS, UNIX)



Interrupt Handling Procedure

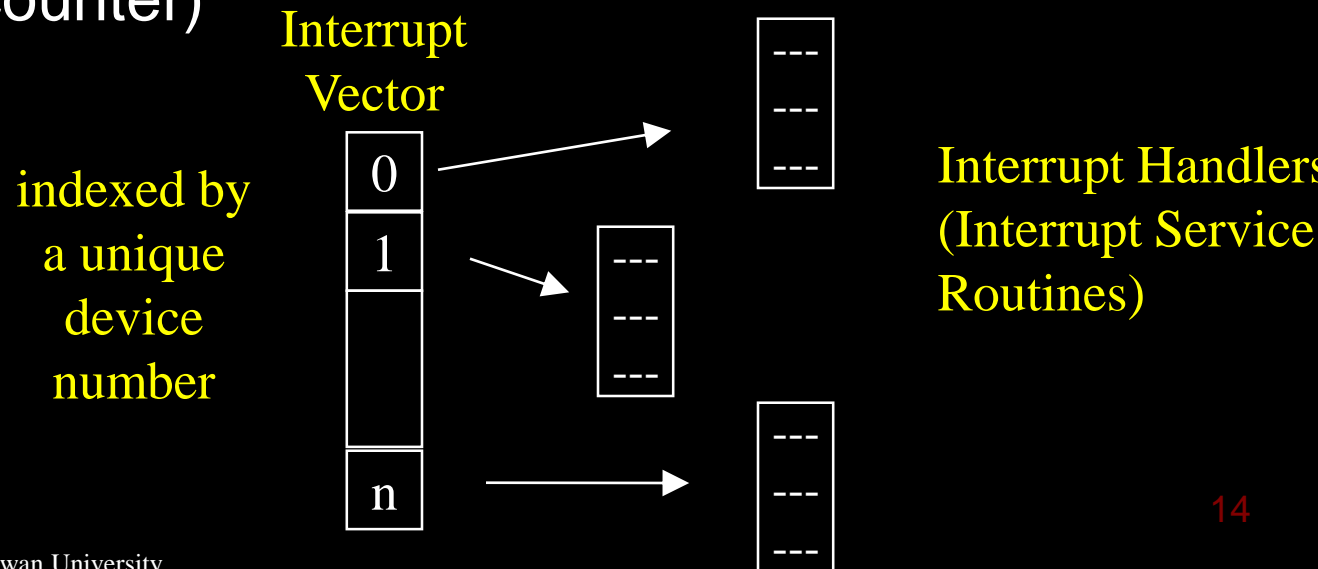


- Saving of the address of the interrupted instruction: fixed locations or stacks
- Interrupt disabling or enabling issues: lost interrupt?! 

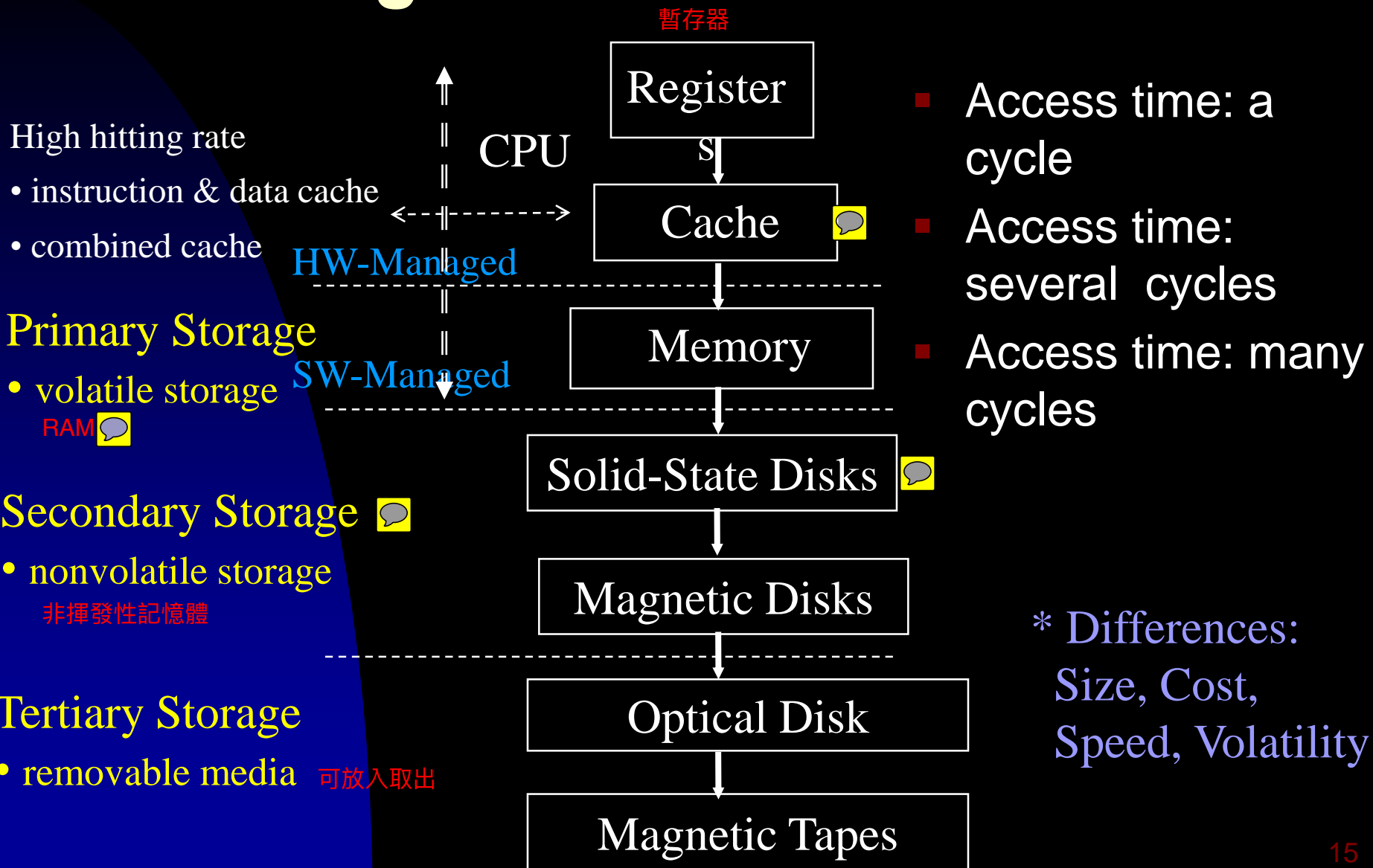
prioritized interrupts → masking

Interrupt Handling Procedure

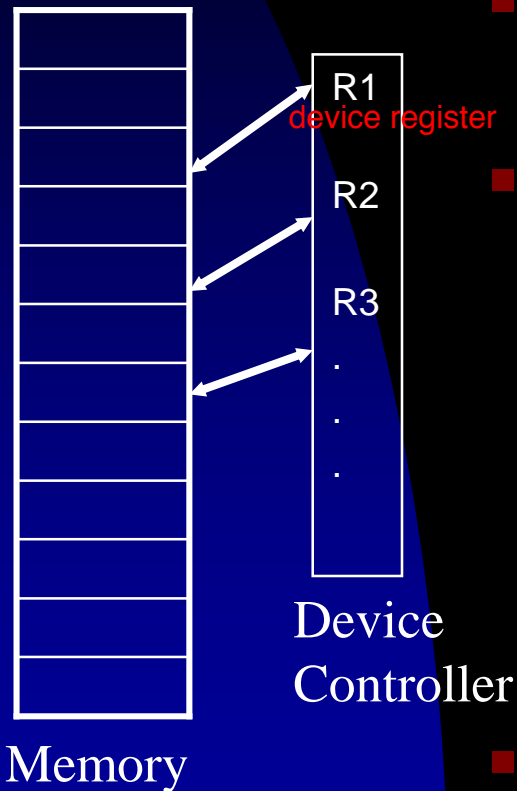
- Interrupt Handling
 - ➔ Save interrupt information
 - ➔ OS determine the interrupt type (by polling)
 - ➔ Call the corresponding handlers
 - ➔ Return to the interrupted job by the restoring important information (e.g., saved return addr. ➔ program counter)



Storage Structure

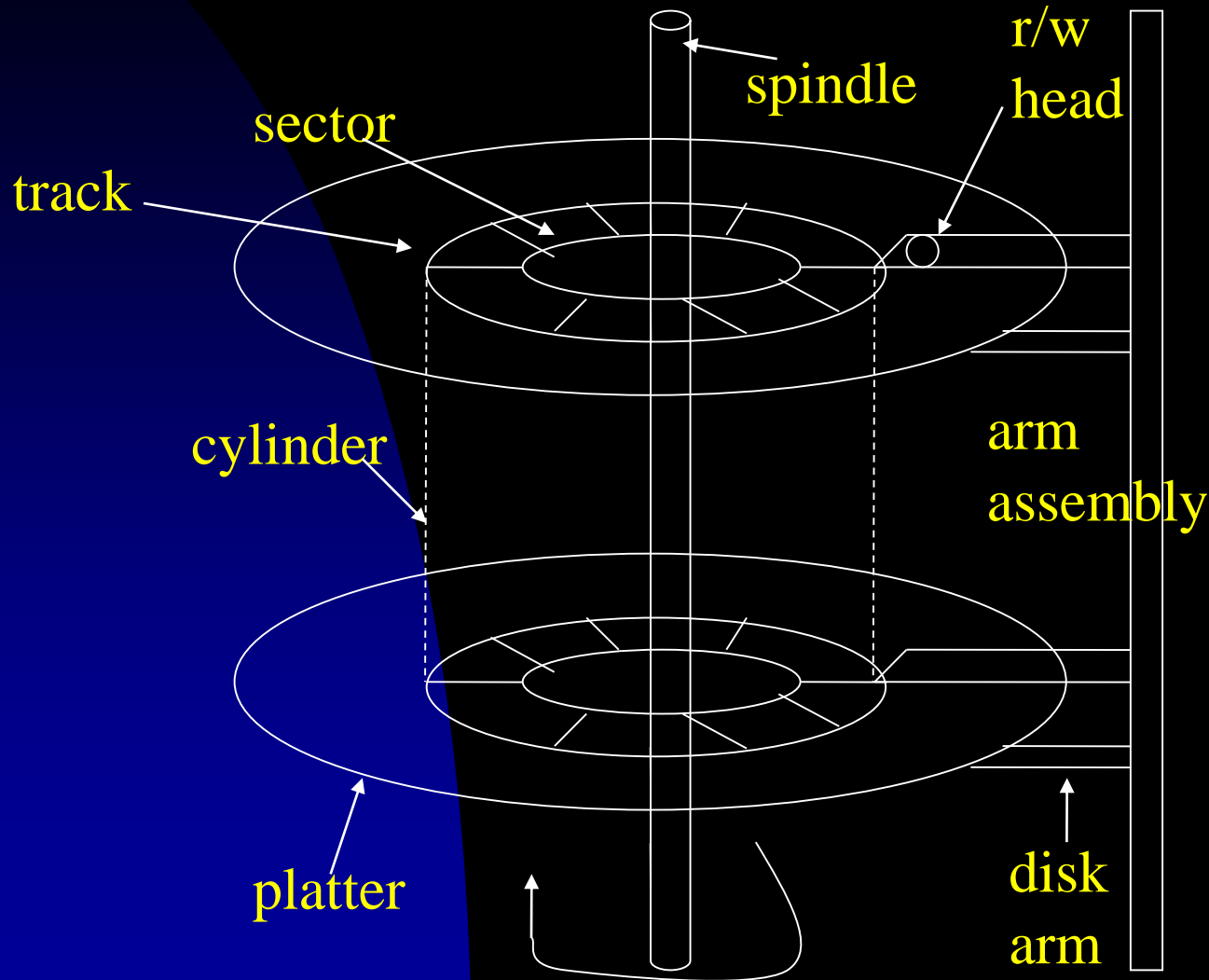


Memory



- Processor can have direct access!
- Intermediate storage for data in the registers of device controllers
- Memory-Mapped I/O (PC & Mac)
 - (1) Frequently used devices
 - (2) Devices must be fast, such as video controller, or special I/O instructions is used to move data between memory & device controller registers
- Programmed I/O – polling
 - or interrupt-driven handling

Magnetic disks



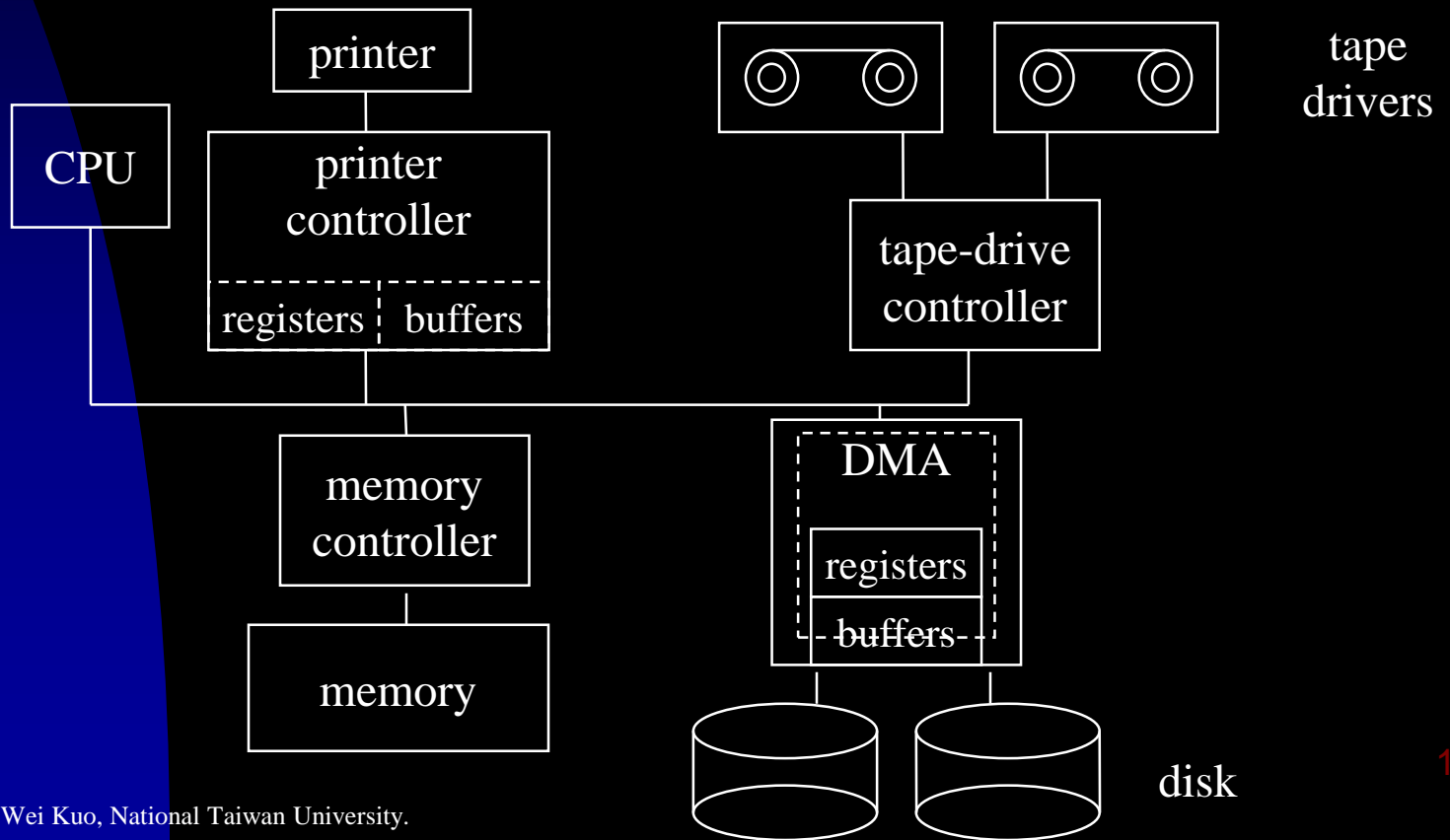
- Transfer Rate
- Random-Access Time
 - Seek time in x ms
 - Rotational latency in y ms
 - 60~200 times/sec

Magnetic Disks

- Disks
 - Fixed-head disks:
 - More r/w heads v.s. fast track switching
 - Moving-head disks (hard disk)
 - Primary concerns:
 - Cost, Size, Speed
 - Computer → host controller → disk controller → disk drives (cache ↔ disks)
- Floppy disk
 - slow rotation, low capacity, low density, but less expensive
- Tapes: backup or data transfer bet machines

I/O Structure

- Device controllers are responsible of moving data between the peripheral devices and their local buffer storages.



I/O Structure

- I/O operation

- a. CPU sets up specific controller registers within the controller.

- b. Read: devices → controller buffers → **memory**

- Write: **memory** → controller buffers → devices



- c. Notify the completion of the operation by triggering an interrupt

DMA

直接記憶體存取

一次做完I/O，再中斷，而不是每一次都中斷

- Goal: Release CPU from handling excessive interrupts!
 - E.g. 9600-baud terminal
 - 🗨 2-microsecond service / 1000 microseconds
 - High-speed device:
 - 50%時間處理中 斷 2-microsecond service / 4 microseconds
- Procedure
 - Execute the device driver to set up the registers of the DMA controller.
 - DMA moves blocks of data between the memory and its own buffers.
 - Transfer from its buffers to its devices.
 - Interrupt the CPU when the job is done.



Single-Processor Systems

- Characteristics: One Main CPU
 - Special-Purpose Processors, e.g., Disk-Controller Microprocessors.
- Examples:
 - Personal Computers (Since 1970's), Mainframes.
- Operating Systems
 - Batching → Multiprogramming → Time-Sharing

Multiprocessor/Parallel Systems

- Tightly coupled: have more than one processor in close communication sharing computer bus, clock, and sometimes memory and peripheral devices
- Loosely coupled: otherwise
- Advantages
 - Speedup – Throughput
 - Lower cost – Economy of Scale
 - More reliable – Graceful Degradation → Fail Soft (detection, diagnosis, correction)
 - A Tandem or HP-NonStop fault-tolerance solution

Multiprocessor/Parallel Systems

- Symmetric multiprocessing model: each processor runs an identical copy of the OS
- Asymmetric multiprocessing model: a master-slave relationship
 - ~ Dynamically allocate or pre-allocate tasks
 - ~ Commonly seen in extremely large systems
 - ~ Hardware and software make a difference?
- Trend: the dropping of microprocessor cost
→ OS functions are offloaded to slave processors (back-ends)

Multiprocessor/Parallel Systems

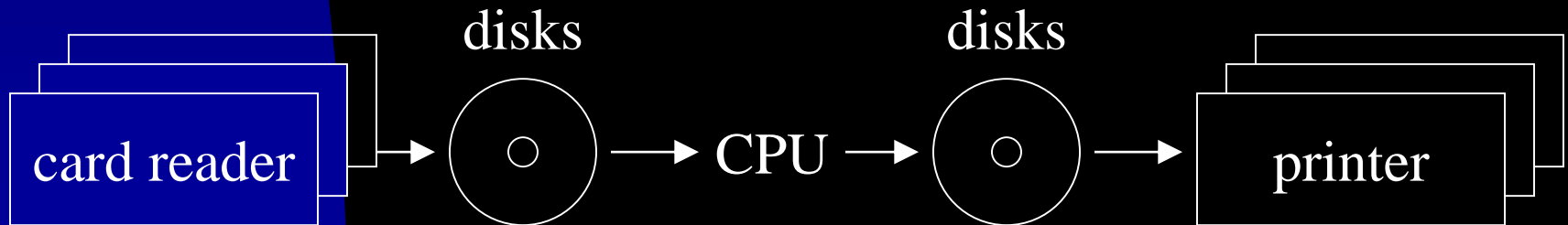
- The Recent Trend:
 - Hyperthreading Processors
 - Multiple Cores over a Single Chip
 - N Standard Processors!
- Loosely-Coupled Systems
 - Processors do not share memory or a clock
 - Blade Servers
 - Each blade-processor board boots independently and runs its own OS.

Clustered Systems

- Definition: Clustered computers which share storage and are closely linked via LAN networking.
- Advantages: high availability, performance improvement, etc.
- Types
 - Asymmetric/symmetric clustering
 - Parallel clustering – multiple hosts that access the same data on the shared storage.
- Distributed Lock Manager (DLM)
 - Oracle

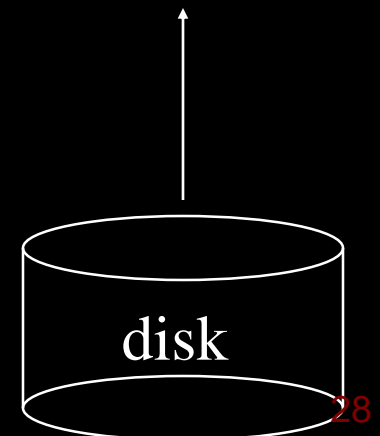
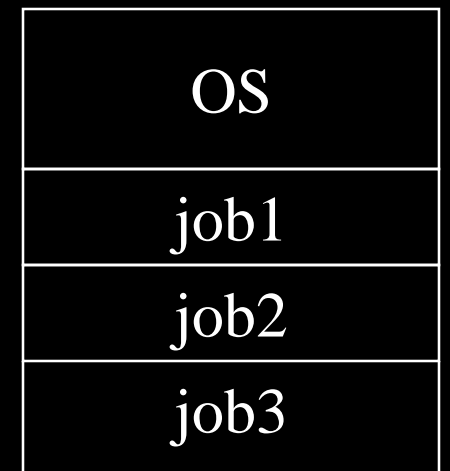
Operating-System Structure

- Simple batch systems
 - Resident monitor – Automatically transfer control from one job to the next
- Spooling (Simultaneous Peripheral Operation On-Line)
 - Replace sequential-access devices with random-access device



Operating-System Structure

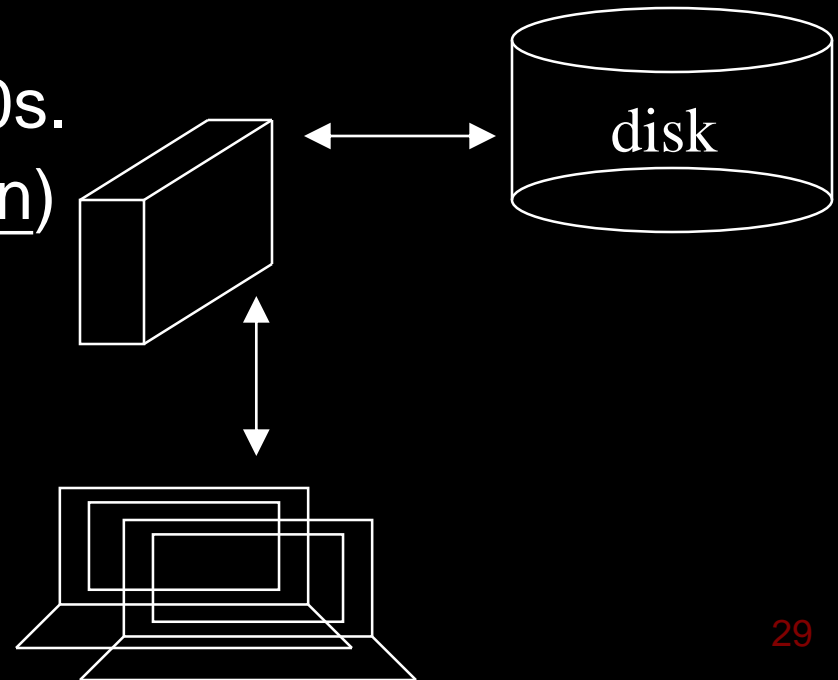
- Multiprogramming increases CPU utilization by organizing jobs so that the CPU always has one to execute – Early 1960
 - Job scheduling and CPU scheduling
 - Goal : efficient use of scarce resources



Operating-System Structure

- Time sharing (or multitasking) is a logical extension of multiprogramming!
 - Started in 1960s and become common in 1970s.
 - An interactive (or hand-on) computer system
 - Multics, IBM OS/360
- Virtual Memory
 - Physical Address

on-line file system
virtual memory
sophisticated CPU scheduling
job synchronization
protection & security
.....
and so on



Operating-System Operations

- An Interrupt-Driven Architecture for Modern OS's
 - Events are almost always signaled by the occurrence of an interrupt or a trap (or an exception).
- Protection of User Programs and OS
 - Multiprogramming
 - Sharing of Hardware and Software

Hardware Protection

- Goal:
 - Prevent errors and misuse!
 - E.g., input errors of a program in a simple batch operating system
 - E.g., the modifications of data and code segments of another process or OS
- Dual-Mode Operations – a mode bit
 - User-mode executions except those after a trap or an interrupt occurs.
 - Monitor-mode (system mode, privileged mode, supervisor mode)
 - Privileged instruction: Machine instructions that may cause harm

Hardware Protection

- More Modes:
 - One for the Virtual Machine Manager – It provides an interface that is identical to the underlying bare hardware.
 - More for different kernel components

virtual
user
mode
virtual
monitor
mode
monitor
mode

User
mode

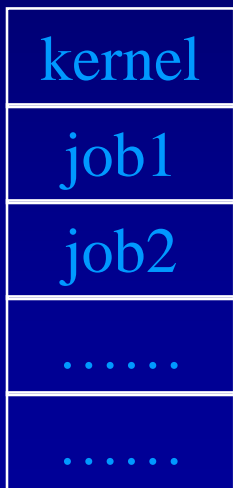
processes	processes	processes
kernel 1	kernel 2	kernel 3
virtual machine software		
hardware		

Hardware Protection

- System Calls – trap to OS for executing privileged instructions.
- Resources to protect
 - I/O devices, Memory, CPU
- I/O Protection (I/O devices are scare resources!)
 - I/O instructions are privileged.
 - User programs must issue I/O through OS
 - User programs can never gain control over the computer in the system mode.

Hardware Protection

- Memory Protection
 - Goal: Prevent a user program from modifying the code or data structures of either the OS or other users!
 - Instructions to modify the memory space for a process are privileged.



Base register

Limit register

⇔ Check for every
memory address by
hardware

Hardware Protection

- CPU Protection
 - Goal
 - Prevent user programs from sucking up CPU power!
 - Use a timer to implement time-sharing or to compute the current time.
 - Instructions that modify timers are privileged.
 - Computer control is turned over to OS for every time-slice of time!
 - Terms: time-sharing, context switch

System Components – Process Management

- Process Management
 - Process: An Active Entity
 - Physical and Logical Resources
 - Memory, I/O buffers, data, etc.
 - Data Structures Representing Current Activities:
 - Program Counter
 - Stack
 - Data Section
 - CPU Registers
 -
 - And More

Program
(code)

+

System Components – Process Management

- Services
 - Process creation and deletion
 - Process suspension and resumption
 - Process synchronization
 - Process communication
 - Deadlock handling

System Components – Memory Management

- Memory: a large array of words or bytes, where each has its own address
- OS must keep several programs in memory to improve CPU utilization and user response time
- Management algorithms depend on the hardware support
- Services
 - Memory usage and availability
 - Decision of memory assignment
 - Memory allocation and deallocation

System Components – File-System Management

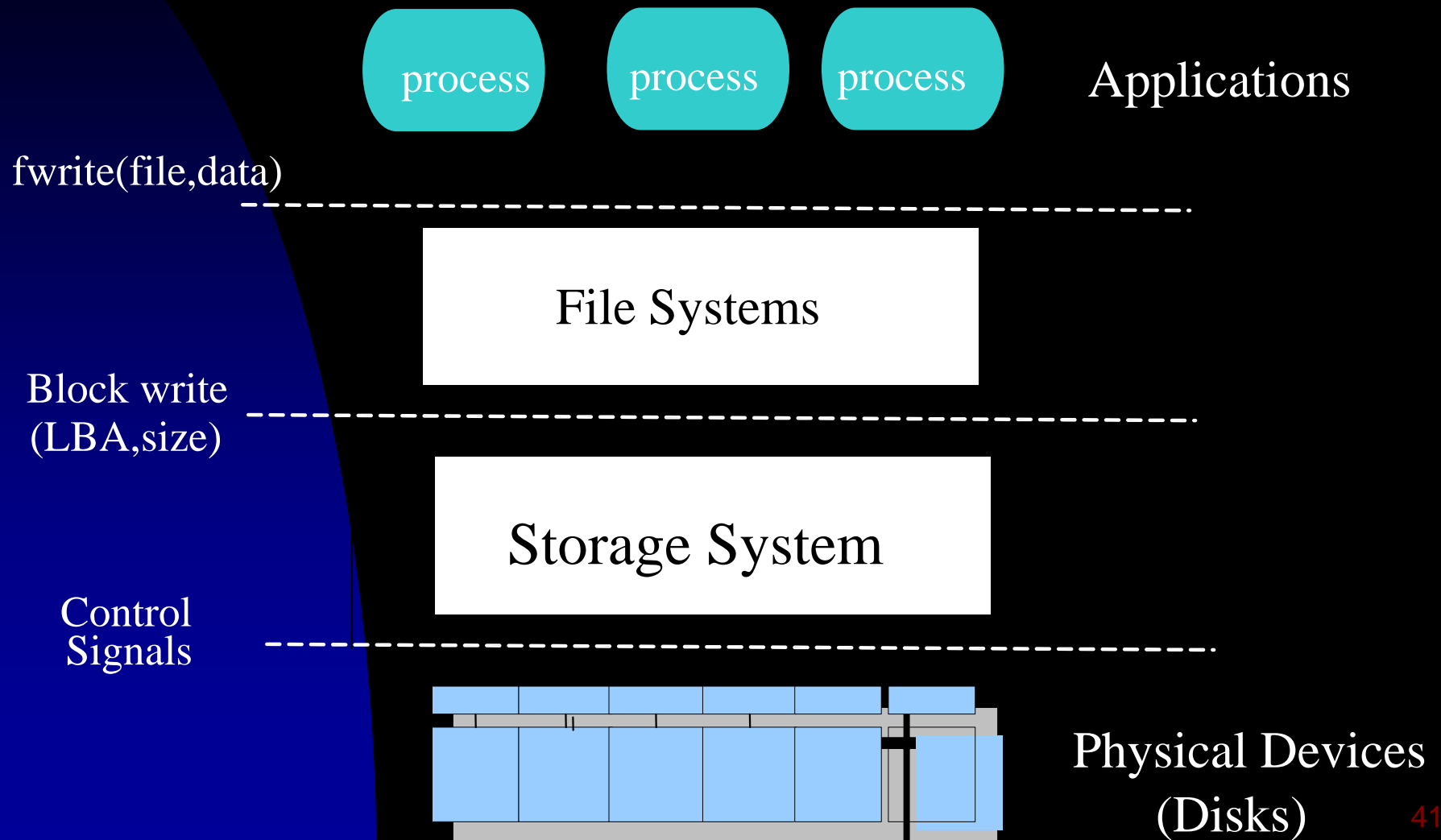
- Goal:
 - A uniform logical view of information storage
 - Each medium controlled by a device
 - Magnetic tapes, magnetic disks, optical disks, etc.
- OS provides a logical storage unit: File
 - Formats:
 - Free form or being formatted rigidly.
 - General Views:
 - A sequence of bits, bytes, lines, records

System Components – File-System Management

- Services
 - File creation and deletion
 - Directory creation and deletion
 - Primitives for file and directory manipulation
 - Mapping of files onto secondary storage
 - File Backup

* Privileges for file access control

System Components – File-System Management



System Components – Mass-Storage Management

- Goal:
 - On-line storage medium for programs & data
 - Backup of main memory
- Services for Disk Management
 - Free-space management
 - Storage allocation, e.g., continuous allocation
 - Disk scheduling, e.g., FCFS

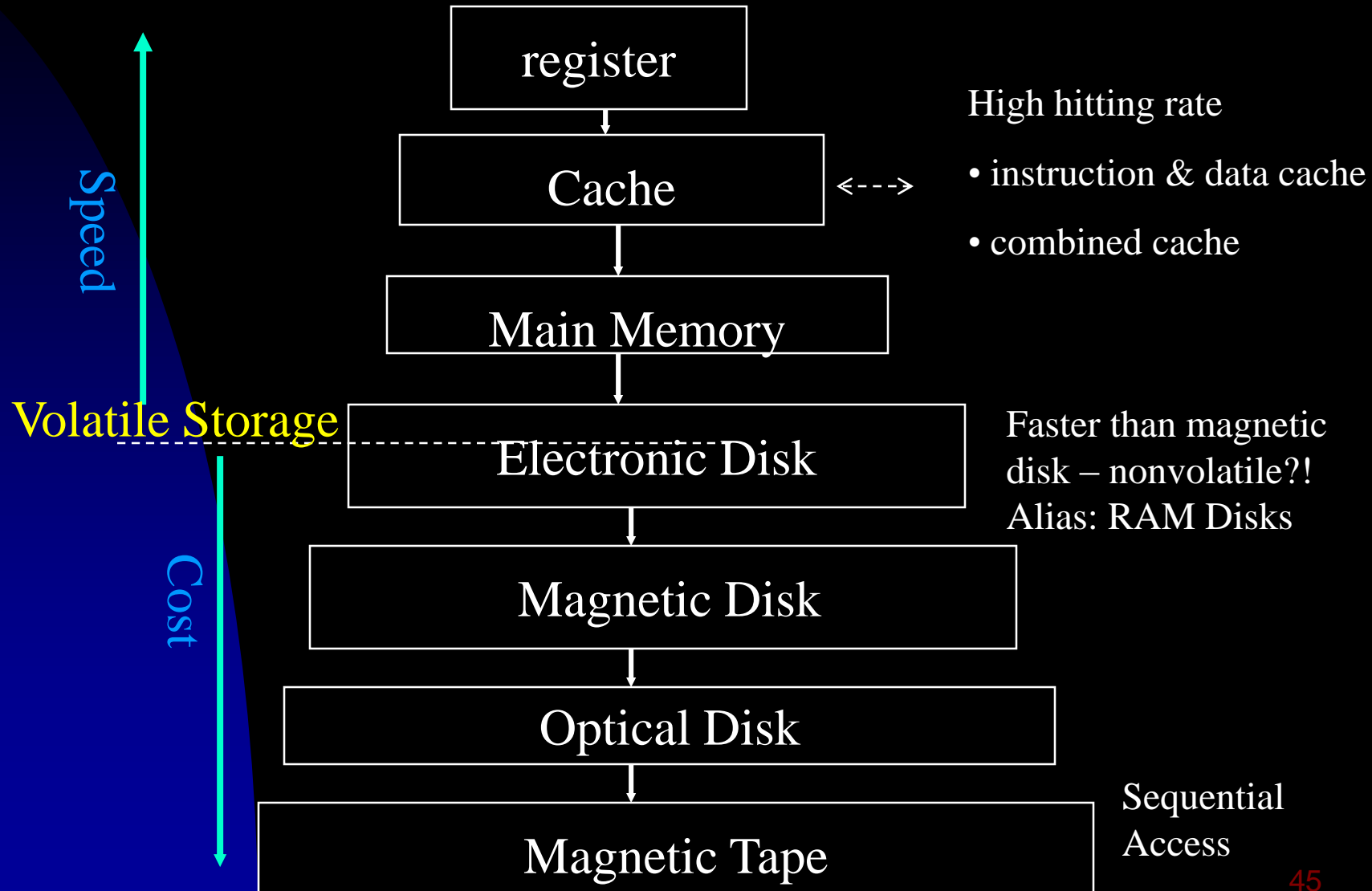
System Components –Tertiary Storage Devices

- Goals:
 - Backups of disk data, seldom-used data, and long-term archival storage
- Examples:
 - Magnetic tape drives and their tapes, CD & DVD drives and platters.
- Services – OS Supports or Applications' Duty
 - Device mounting and unmounting
 - Exclusive allocation and freeing
 - Data transfers from tertiary devices to secondary storage devices.

System Components – I/O System Management

- Goal:
 - Hide the peculiarities of specific hardware devices from users
- Components of an I/O System
 - A buffering, caching, and spooling system
 - A general device-driver interface
 - Drivers

Caching



Caching

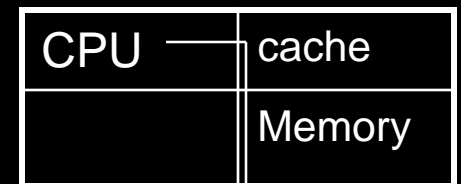
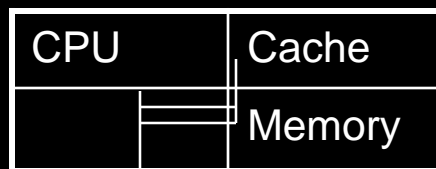
Level	1	2	3	4
Name	Registers	Cache	Memory	Disk
Typical Size	< 1KB	> 16MB	> 16GB	> 100GB
Implementation Strategy	Custom memory with multiple ports, CMOS	On-chip or off-chip CMOS SRAM	CMOS DRAM	Magnetic Disks
Access Time (ns)	0.25 – 0.5	0.5 – 2.5	80 – 250	5,000,000
Bandwidth (MB/s)	20,000 – 100,000	5000 – 10,000	1000 – 5000	20 – 150
Managed by	Compiler	Hardware	OS	OS
Backup by	Cache	Memory	Disk	CD/Tape

Caching

- Caching
 - Information is copied to a faster storage system on a temporary basis
 - Assumption: Data will be used again soon.
 - Programmable registers, instr. cache, etc.
- Cache Management
 - Cache Size and the Replacement Policy
- Movement of Information Between Hierarchy
 - Hardware Design & Controlling Operating Systems

Caching

- Coherency and Consistency
 - Among several storage levels (vertical)
 - Multitasking vs unitasking
 - Among units of the same storage level , (horizontal), e.g. cache coherency
 - Multiprocessor or distributed systems



Protection and Security

- Goal
 - Resources are only allowed to be accessed by authorized processes.
- Definitions:
 - Protection – any mechanism for controlling the access of processes or users to the resources defined by the computer system.
 - Security – Defense of a system from external and internal attacks, e.g., viruses, denial of services, etc.

Protection and Security

- Protected Resources
 - Files, CPU, memory space, etc.
- Protection Services
 - Detection & controlling mechanisms
 - Specification mechanisms
- Distinguishing of Users
 - User names and ID's
 - Group names and GID's
 - Privilege Escalating, e.g., Setuid in Unix
 - To gain extra permissions for an activity.
- Remark: Reliability!

Kernel Data Structures

- Frequently Used Data Structures
 - Array, List, Stack, Queue, Tree, Hash
 - Bitmaps – A string of n binary digits to represent the status of n items.
 - Advantage: Space Efficiency
 - An example is the availability status of disk blocks.

Computing Environments

- Evolving Environments
 - Transition from the period of scarce resources to the period of ubiquitous access!
 - In the past, portability is achieved by laptops!
 - Remote access is supported in a limited way. Mainframes are prevalent!
 - Now, PC's, mobile devices, and various equipments are connected!
 - High speed networks are available at home and office! Web-computing is popular (e.g., portals).

Computing Environments

- Mobile Computing
 - Trends: Computing on handheld smartphones and tablets now offers tremendous growth in the wide range of applications, such as email and GPS, augmented-reality applications, but with limitation on screen size, memory/storage capacity, and power/energy consumption.

Computing Environments

- Distributed/Loosely-Coupled Systems: Heterogeneous or homogeneous computer systems that are networked to provide access to various resources
 - Depend on networking for their functionality
 - Networks vary by the protocols used: TCP/IP, ATM, etc.
 - Be characterized by their node distances
 - Local-area network (LAN)
 - Wide-area network (WAN)
 - Metropolitan-area network (MAN)
 - Personal-area network – distance of few feet

Computing Environments

- Media – copper wires, fiber strands, satellite wireless transmission, infrared communication, etc.
- Network Operating Systems
 - Autonomous computers
 - A distributed operating system – a single OS controlling the network.

Computing Environments

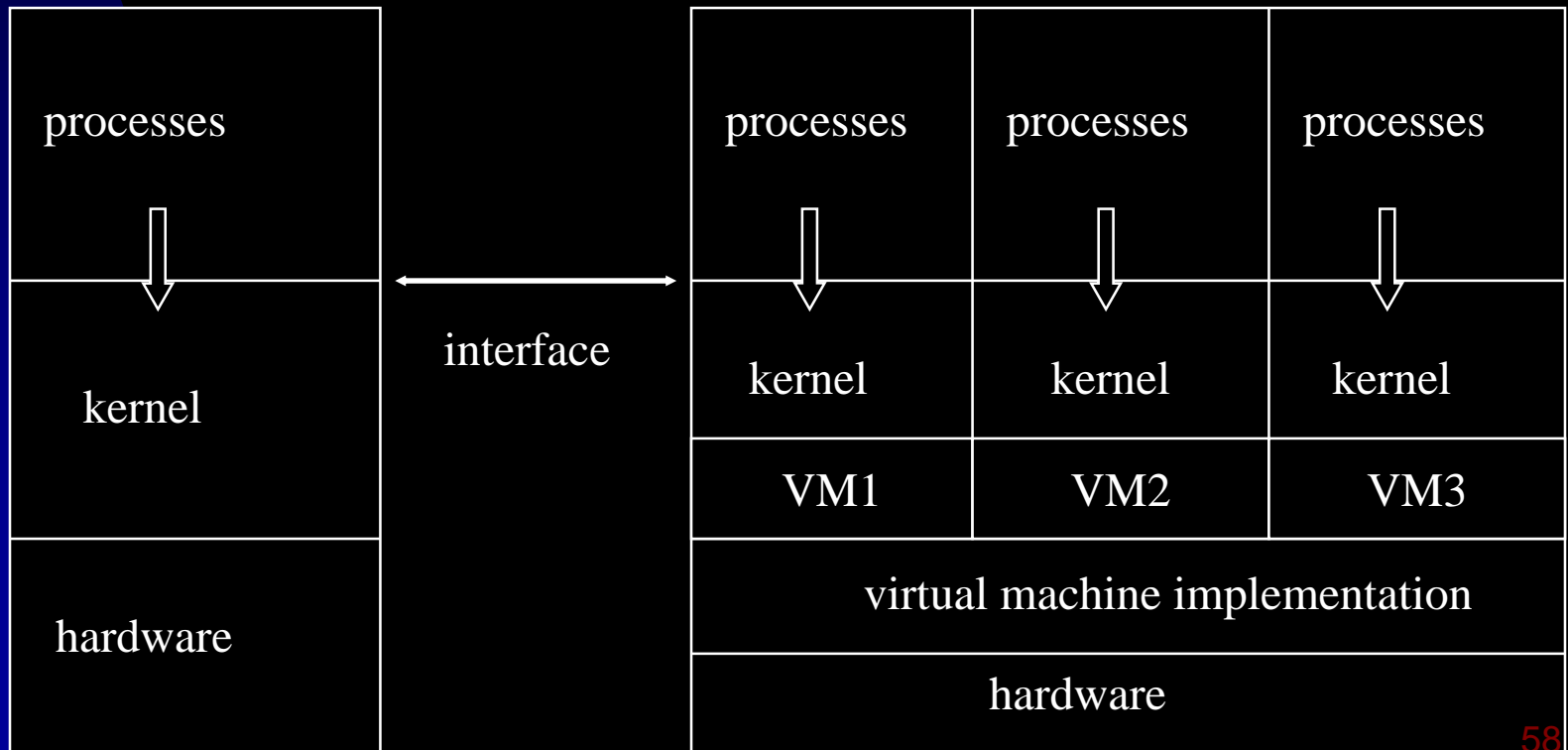
- Peer-to-Peer Systems
 - Characteristics: Client and server roles depend on who is requesting or providing a service.
 - Network connectivity is an essential component.
 - Service Availability and Discovery
 - Registration of services: a centralized lookup service or not
 - A discovery protocol
 - Issues:
 - Legal problems in exchanging files.

Computing Environments

- Client-Server Systems
 - Trend: The functionality of clients is improved in the past decades.
 - Categories:
 - Compute-server systems
 - File-server systems

Computing Environments

- Virtual Machines: provide an interface that is identical to the underlying bare hardware

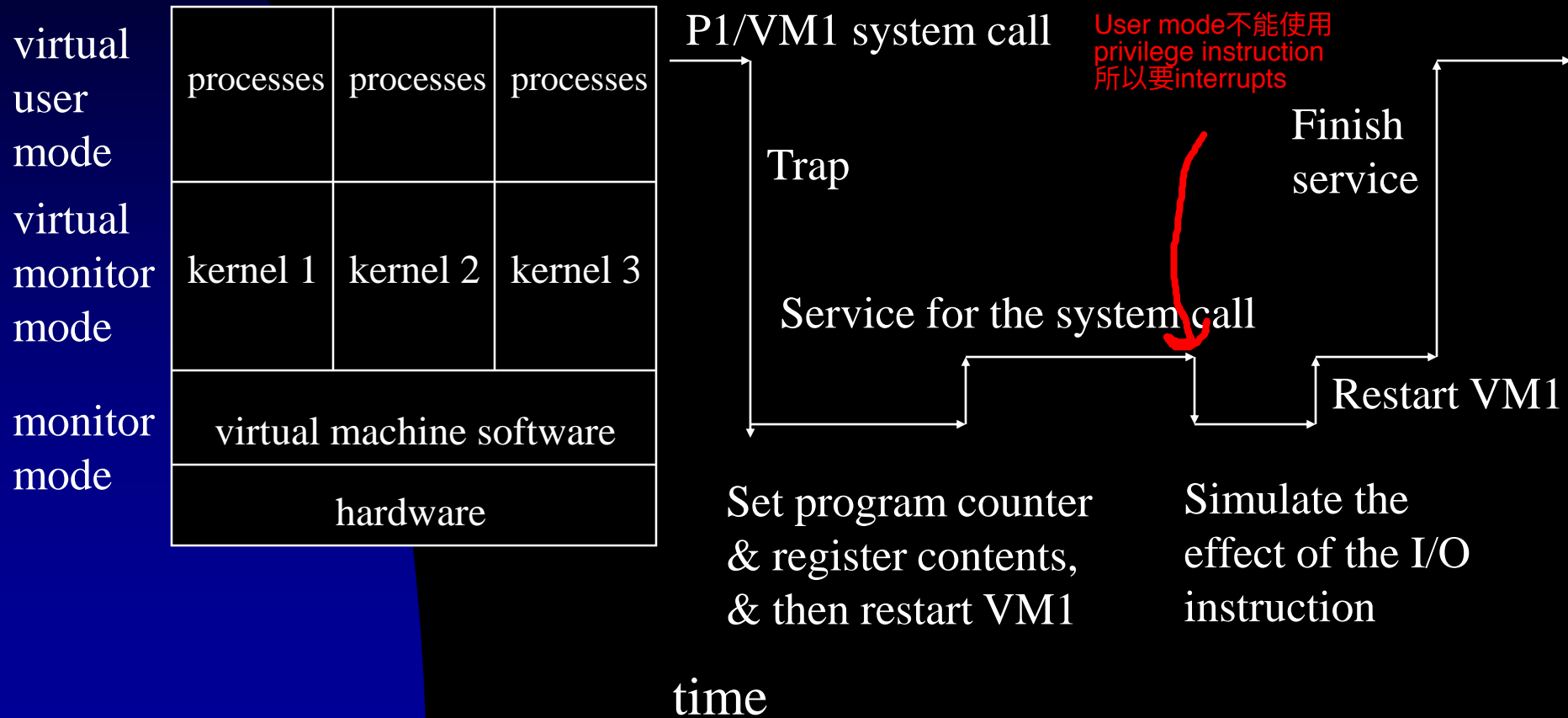


Computing Environments

- Implementation Issues of Virtual Machines:
 - Emulation of Physical Devices
 - E.g., Disk Systems
 - An IBM minidisk approach
 - User/Monitor Modes
 - (Physical) Monitor Mode
 - Virtual machine software
 - (Physical) User Mode
 - Virtual monitor mode & Virtual user mode

Computing Environments

■ How a Virtual Machine works:



Computing Environments

- Disadvantages of Virtual Machines:
 - Slow!
 - Execute most instructions directly on the hardware
 - Emulation is slow but is needed for obsolete hardware.
 - No direct sharing of resources
 - Physical devices and communications
- * I/O could be slow (interpreted) or fast (spooling)

Computing Environments

- Advantages of Virtual Machines:
 - Complete Protection – Complete Isolation !
 - OS Research & Development
 - System Development Time
 - Extensions to Multiple Personalities, such as Mach (software emulation)
 - Emulations of Machines and OS's, e.g., Windows over Linux
 - System Consolidation

* Simulation: Programs of a guest system are run on an emulator that translate each of the guest system instructions into the native instruction set of the host system.

Computing Environments

- Cloud Computing - Delivers computing, storage, and even applications as a service across a network
- Types
 - Public, Private and Hybrid Clouds
 - Software as a service (SaaS), e.g., Gmail.
 - Platform as a service (PaaS), e.g., database server.
 - Infrastructure as a service (IaaS), e.g., storage for backup.

Computing Environments

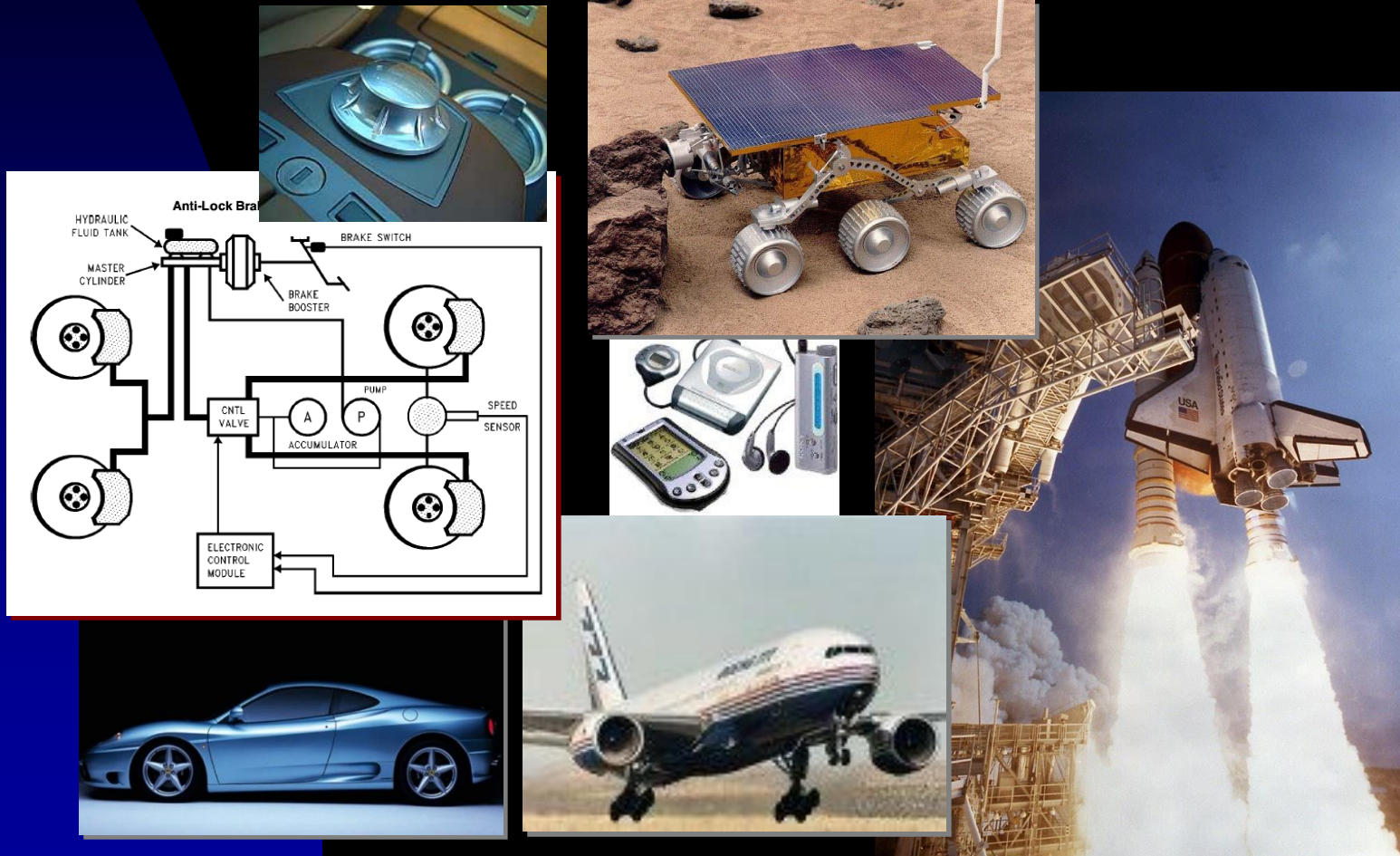
- Web-Based Computing
 - Web Technology
 - Portals, network computers, etc.
 - Network connectivity
 - New categories of devices
 - Load balancers
- Embedded Computing
 - Car engines, robots, VCR's, home automation
 - Embedded OS's often have limited features.

Computing Environments

- Embedded Computers – Most Prevalent Form of Computers
 - Have a wide variety ranged from car engines to VCR's.
 - General-purpose computers with standard OS's, HW devices with or without embedded OS's
 - Standalone units or members of networks and the Web
 - Tend to have specific tasks and almost always run real-time operating systems.

Computing Environments

- Real-Time Embedded Computers



Computing Environments

- Definition: A real-time system is a computer system where a timely response by the computer to external stimuli is vital!
- Hard real-time system: The system has failed if a timing constraint, e.g. deadline, is not met.
 - All delays in the system must be bounded.
 - Many advanced features are absent.

Computing Environments

- Soft real-time system: Missing a timing constraint is serious but does not necessarily result in a failure unless it is excessive!
 - A critical task has a higher priority.
 - Supported in most commercial OS.
- Real-time means on-time instead of fast

Open-Source Operating Systems

- Definitions: OS with available source code.
 - Closed-source OS, e.g., MS Windows, or hybrid OS, e.g., iOS.
 - Arguably issues on bugs, security, support, etc.
 - Examples: GNU/Linux, BSD UNIX, and Solaris (up to 2005 versions).