0117401: Operating System
计算机原理与设计

Chapter 1-2: CS Structure

陈香兰
xlanchen@ustc.edu.cn
http://staff.ustc.edu.cn/~xlanchen

Computer Application Laboratory, CS, USTC @ Hefei
Embedded System Laboratory, CS, USTC @ Suzhou

March 9, 2016

温馨提示：

为了您和他人的工作学习，
请在课堂上关机或静音。

不要在课堂上接打电话。

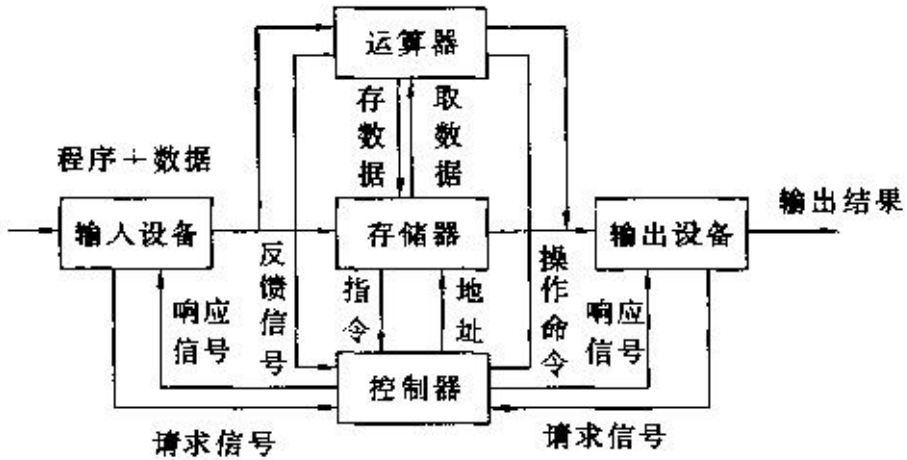
outline

CS & Von Neumann architecture

- 计算机
  1. 不可编程的：强定制，高效
  2. 可编程的：灵活
     - 提供指令集，程序就是一个指令序列

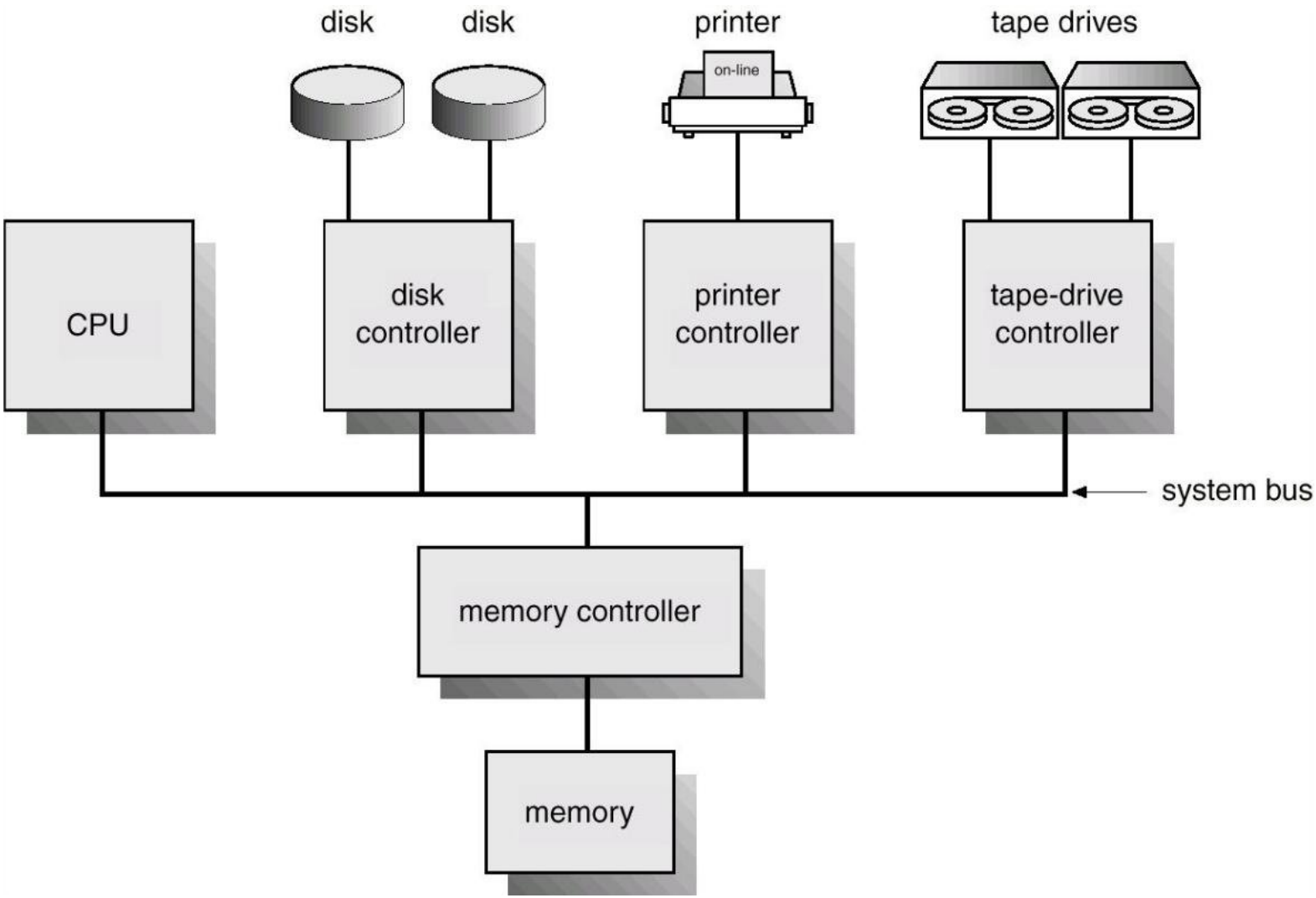
冯·诺伊曼体系结构

- 五大部件：运算器、控制器、存储器、I/O设备
- 存储器与CPU相分离
- 指令存储与数据存储共享存储器

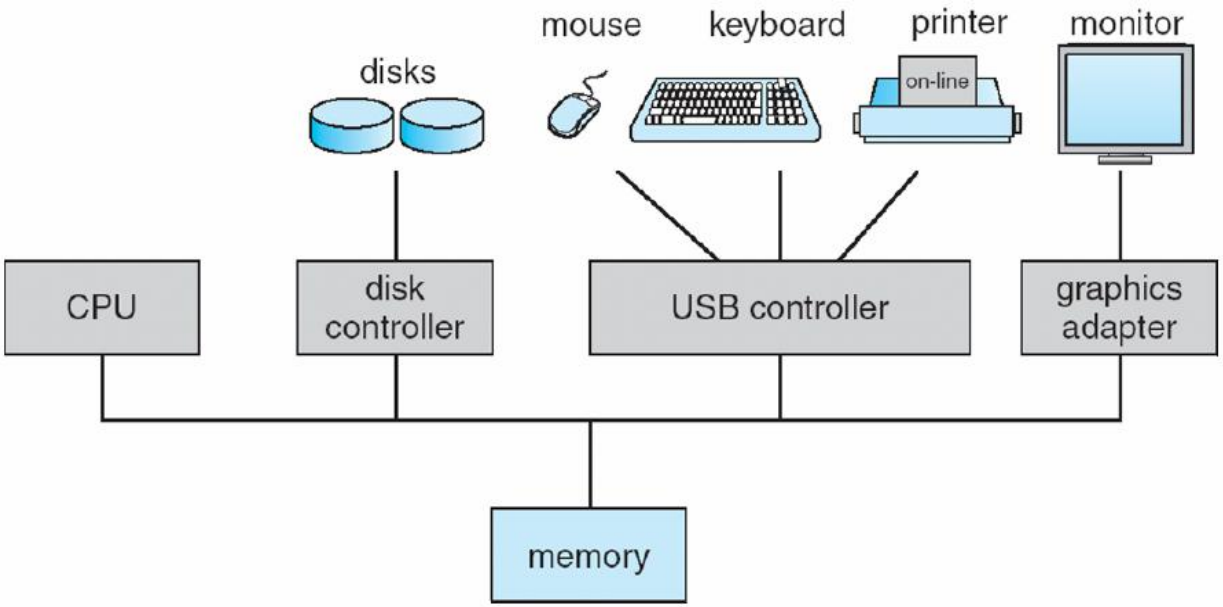


Outline

A modern computer system I



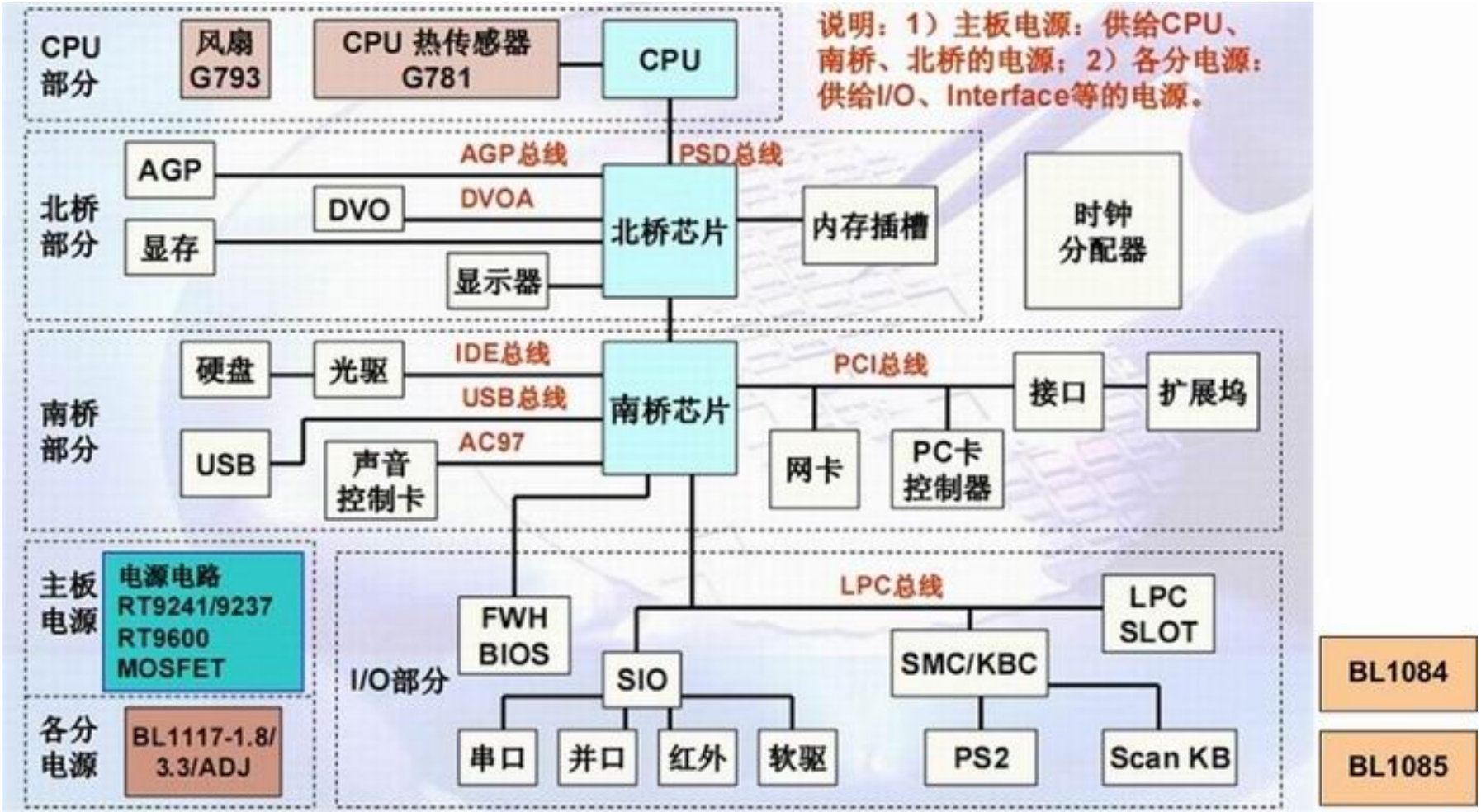
A modern computer system II



参考：三款core i5 CPU芯片外观比较

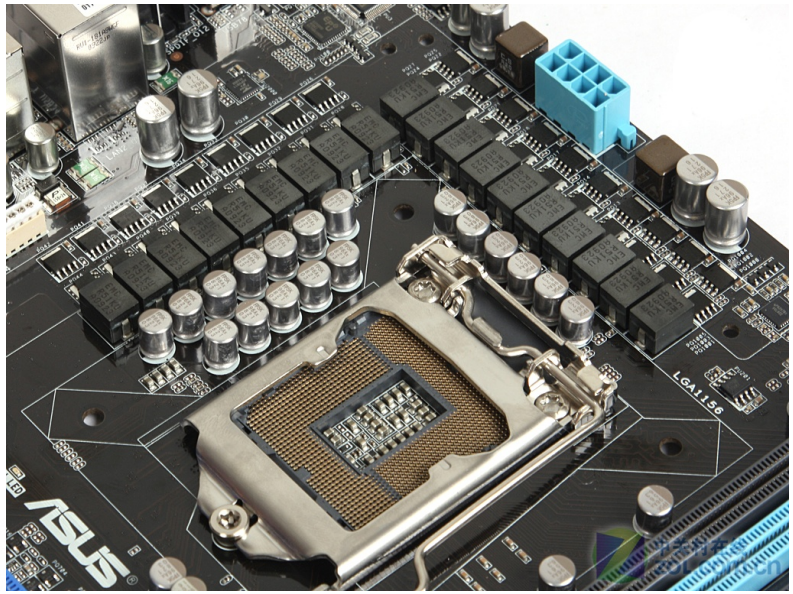
From：VB先睹爲快！Intel三代Core i5搶先評测

参考：一个电脑主板芯片应用方案



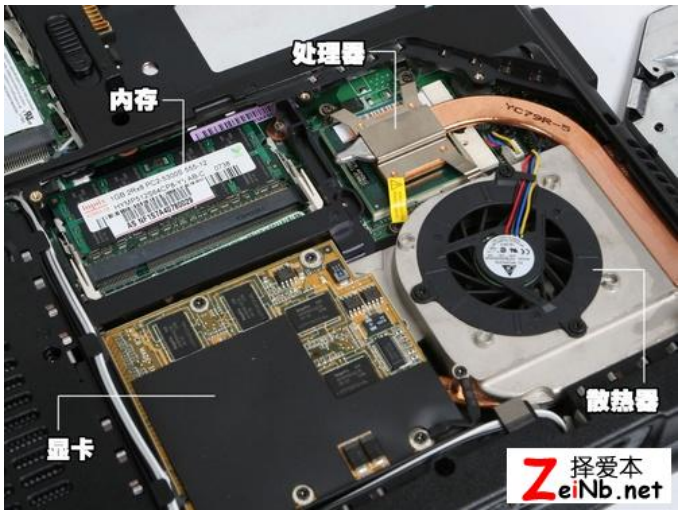
仅用作参考示意。From：http://www.chinesechip.com/news_4/ec3c0dbbed7f458cb7d06c012c86cc44.html1

参考：华硕的一款主板



From：中关村在线 华硕P7P55D Deluxe

参考：华硕F8H笔记本拆解



From：华硕F8H系列笔记本评测

Outline

Start a computer system

- Bootstrap program(启动引导程序), a initial program
  - Loaded at power-up or reboot
  - Typically stored in ROM or EPROM, generally known as firmware(固件)
  - initializes hardware
    - CPU registers, device controllers, memory content
  - Load at least a part of the OS into main memory & start executing it
- Platform dependent(平台相关/体系结构相关)

Example: Linux system startup

typical operating sytems startup course

Power-on→Bootstrap: BIOS→BootLoader: GRUB→OS: Linux

Linux (Intel i386)

Refer to appendix A of 《Understanding Linux Kernel》

- →RESET pin of the CPU
- cs:ip= 0xFFFF FFF0
- ROM BIOS（基本输入输出系统）

Example: Linux system startup (cont.)

BIOS（基本输入输出系统）

Basic I/O System (BIOS) : A set of programs stored in ROM, including

- Several interrupt-driven low-level procedures
- A bootstrap procedure, who
  - POST (Power On Self-Test)
  - Initializes hardware device
  - Searches for an OS to boot
    - Master Boot Record(MBR) on Hard drive, Boot Sector on floppy disk, network
  - Copies the first sector of the OS into RAM 0x0000 7C00, and jumps & executes

Example: Linux system startup (cont.)

Master Boot Record, MBR, 主引导记录

- the first sector on a hard drive, a special type of boot sector
- MBR = MBR code (also called boot loader) + partition table
  - MBR code: code necessary to startup the OS
  - typical boot loader: GRUB

Example: Linux system startup (cont.)

Master Boot Record, MBR, 主引导记录

Structure of a classical generic MBR

Address		Description		Size in bytes
Hex	Dec			
+000h	+0	Bootstrap code area		446
+1BEh	+446	Partition entry #1	Partition table (for primary partitions)	16
+1CEh	+462	Partition entry #2		16
+1DEh	+478	Partition entry #3		16
+1EEh	+494	Partition entry #4		16
+1FEh	+510	55h	Boot signature	2
+1FFh	+511	AAh		
Total size: 446 + 4*6 + 2				512

??? After starts up

- Executes prearranged process, or

- Waits for interrupt

Modern OSs are interrupt-driven（中断驱动的）.

Outline

Interrupt I

Interrupt represents an event to be handled

For hardware: Device interrupt

- The completion of an I/O operation
- a key stroke or a mouse move
- timer
- ...

For error (also hardware): exception

1. Trap for debug
2. Fault
   - example: page fault, division by zero, invalid memory access
3. Abort, a serious error

Interrupt II

For software: System call

- To request for some operating-system service
  - Linux: INT 0x80
  - MS/DOS, windows: INT 0x21

Modern OSs are interrupt-driven（中断驱动的）

Interrupt handling I

When the CPU is interrupted

1. Stops what it is doing
2. Incoming interrupts are disabled to prevent a lost interrupt
3. Transfers control to the ISR (Interrupt Service Routine, 中断服务例程)
   - ISR: A generic routine in fixed location and then call the interrupt-specific handler
   - interrupt vector table (中断向量表)

Interrupt handling II

When the ISR completed, Back to interrupted program

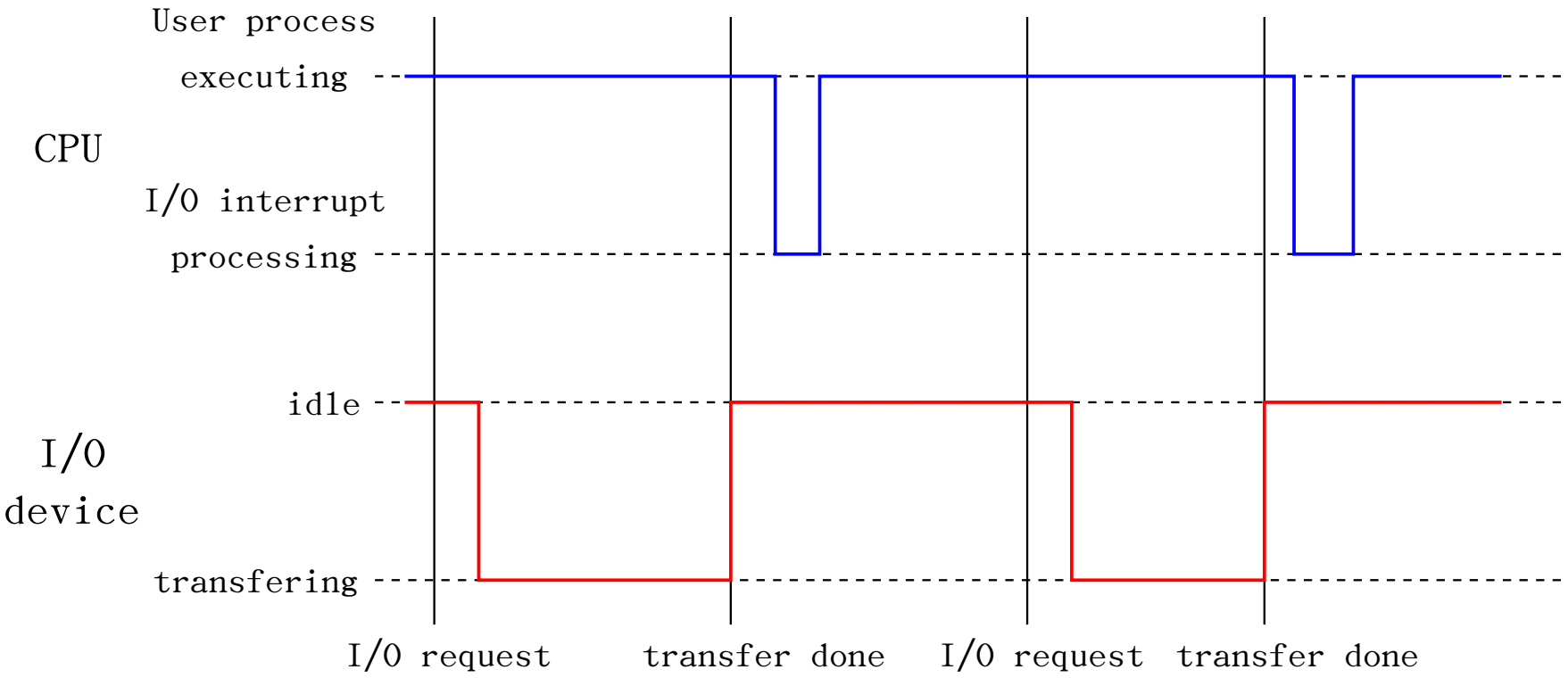
- HOW ?

  —— OS preserves the state of the CPU by storing registers and the program counter.

  also called context（上下文，硬件上下文）.

  - Old: Fixed location, or a location indexed by the device number
  - Recent: system stack（Linux：内核态栈）

Interrupt time line for a single process doing output

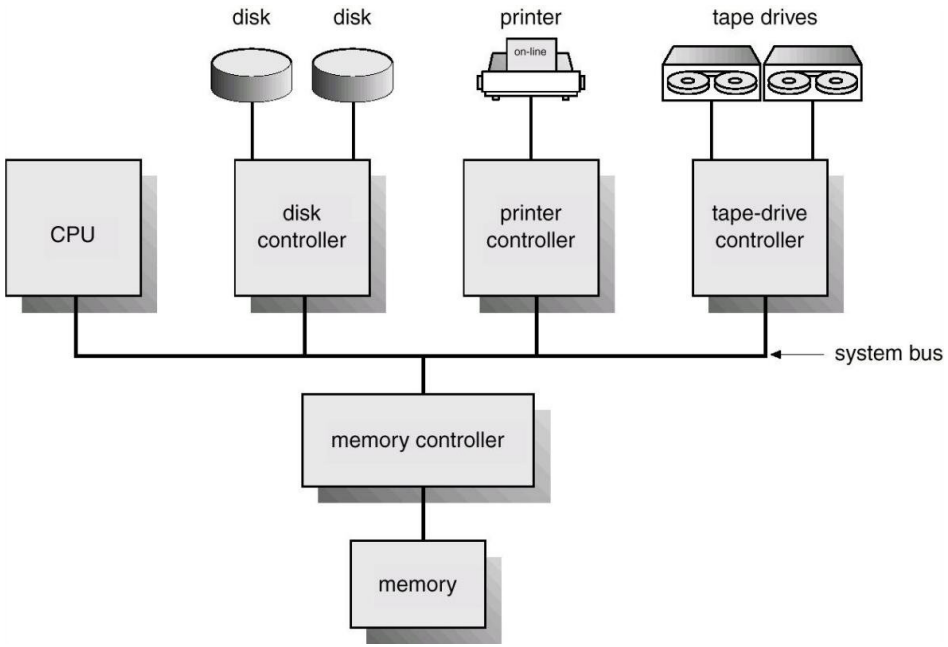


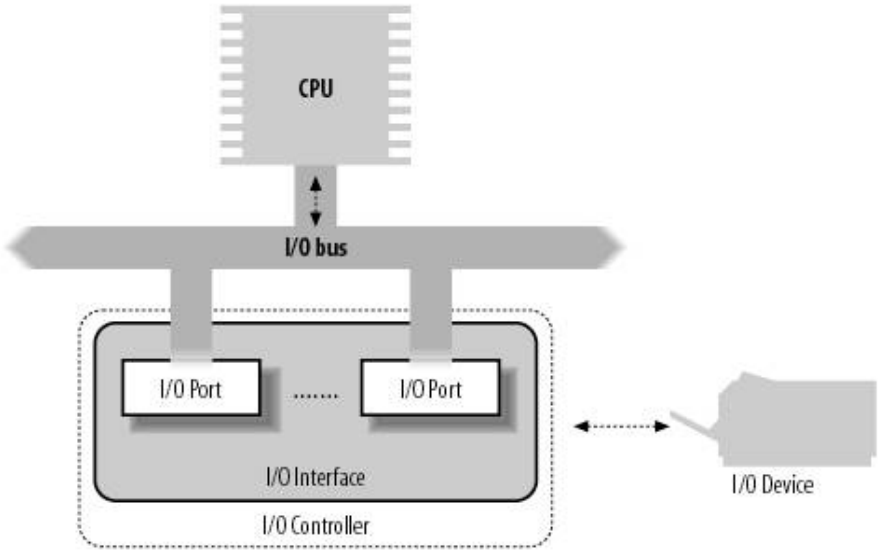
Example: interrupts in I386

- protect mode （保护模式）
  - IDT （Interrupt Descriptor Table,中断描述符表）
  - OS填写IDT表，包括每个中断处理例程的入口地址等信息
  - 中断发生的时候，CPU根据从中断控制器获得的中断向量号在IDT表中索引到对应的中断处理例程（ISR）入口地址，并跳转过去运行
    - 保存上下文
    - 处理中断
    - 恢复上下文

Outline

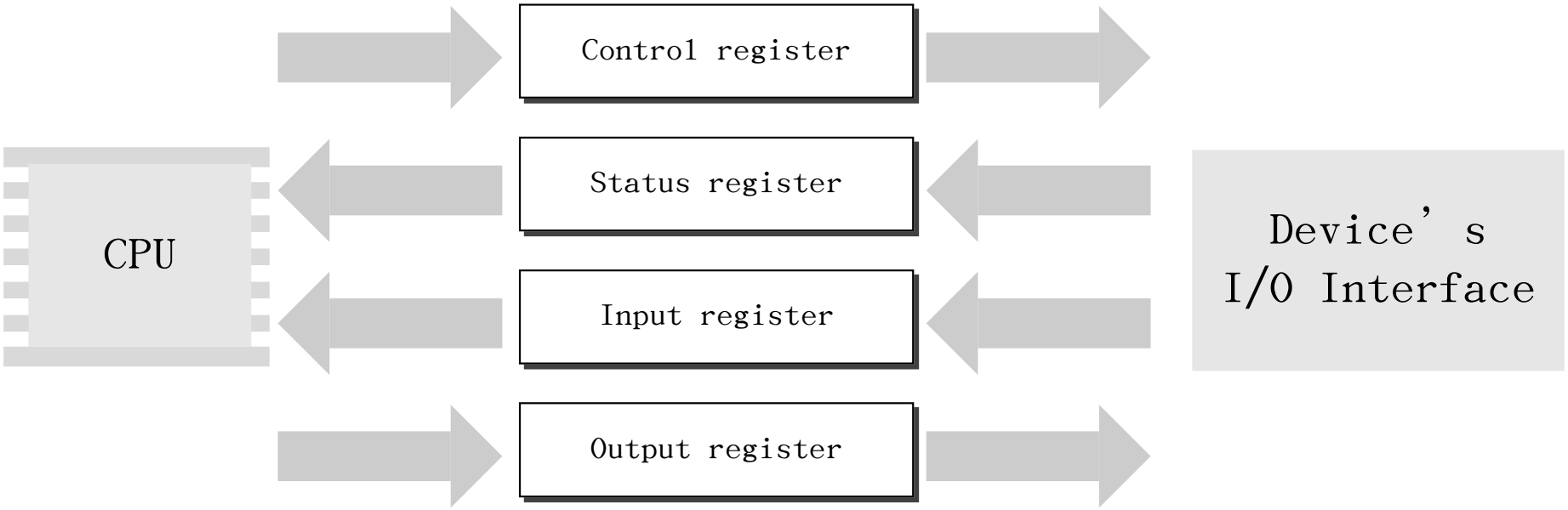
I/O structure





I/O structure

- Each device controller is in charge of a particular device type
- Each device controller has
  - a local buffer & a set of special-purpose registers
- Data transfer, two phrase
  - Main memory ←(CPU)→ local buffer of controller
  - device ←(device controller)→ local buffer
- I/O devices & CPU can execute concurrently（并发地）
  - Share/compete memory cycle
  - Memory controller


Control register
Status register
Input register
Output register
CPU
Device's
I/O Interface

Outline

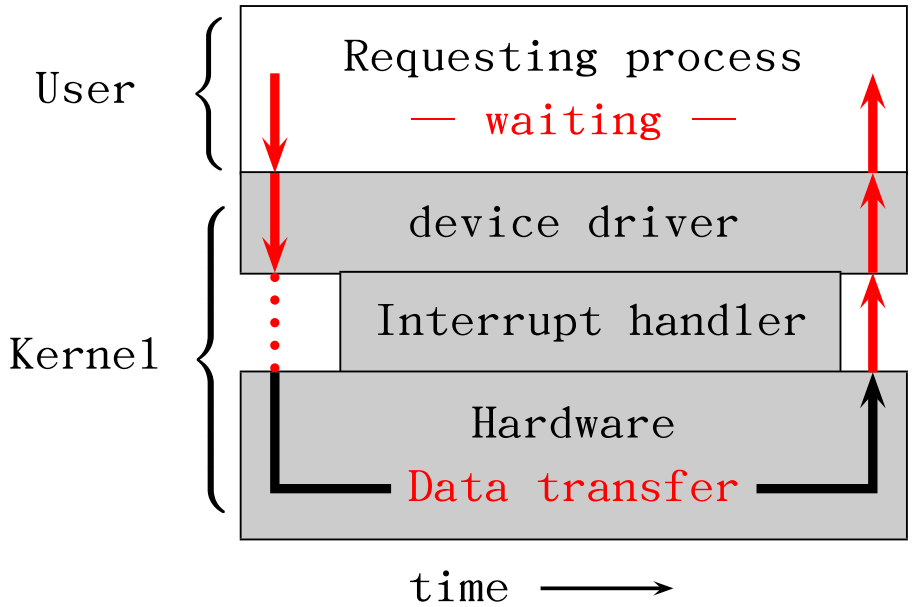
I/O operation

- CPU start an I/O operation by
  - Loading the appropriate registers within the device controller
  - When complete, device controller informs CPU by
    - Triggering an interrupt, or
    - Simply set a flag in one of their registers
- Two I/O methods
  - synchronous VS. asynchronous

1. Synchronous(同步)

- Waiting
  - Wait instruction
  - Dead loop like

    Loop: jmp Loop

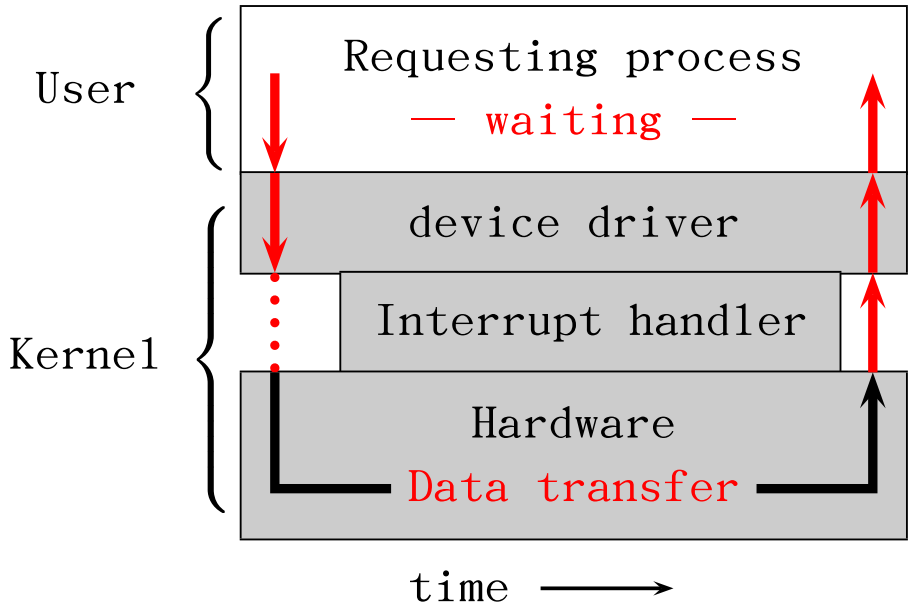


- At most one I/O request is outstanding at a time
  - Advantage: always knows exactly which device is interrupting
  - Disadvantage: excludes concurrent I/O operations & the possibility of overlapping useful computation with I/O

1. Synchronous(同步)

- Waiting
  - Wait instruction
  - Dead loop like

    Loop: jmp Loop



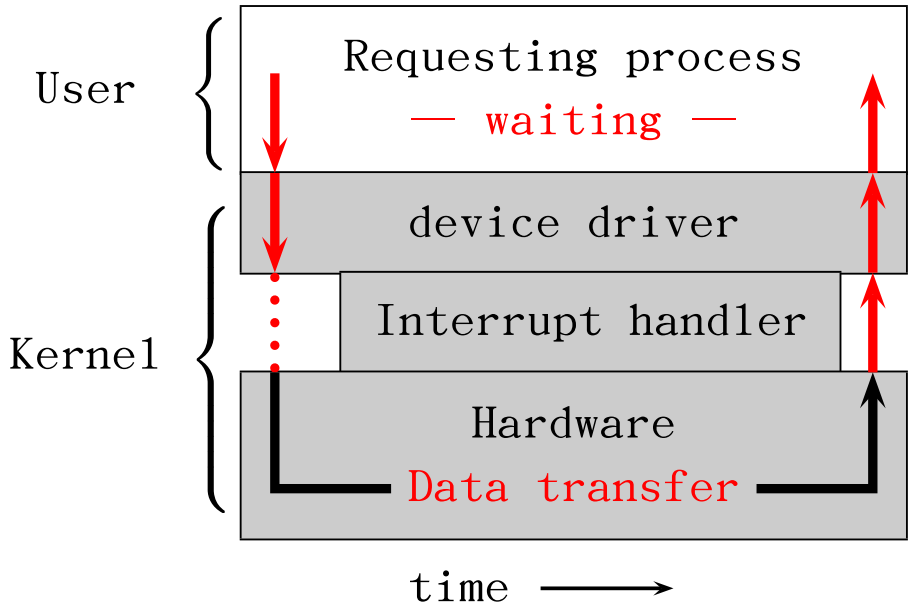
- At most one I/O request is outstanding at a time
  - Advantage: always knows exactly which device is interrupting
  - Disadvantage: excludes concurrent I/O operations & the possibility of overlapping useful computation with I/O

I/O method —— analysis

1. Synchronous(同步)

- Waiting
  - Wait instruction
  - Dead loop like

    Loop: jmp Loop

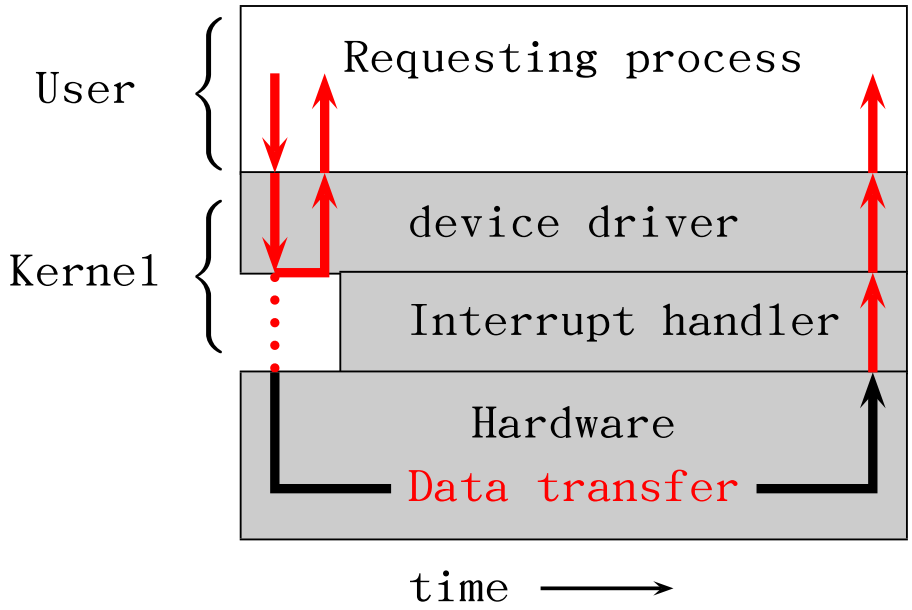


- At most one I/O request is outstanding at a time
  - Advantage: always knows exactly which device is interrupting
  - Disadvantage: excludes concurrent I/O operations & the possibility of overlapping useful computation with I/O

I/O method —— analysis (cont.)

2. Asynchronous(异步)

- Start & cont.
  - with a wait system call
  - os execute other programs, or, if no other program, idle

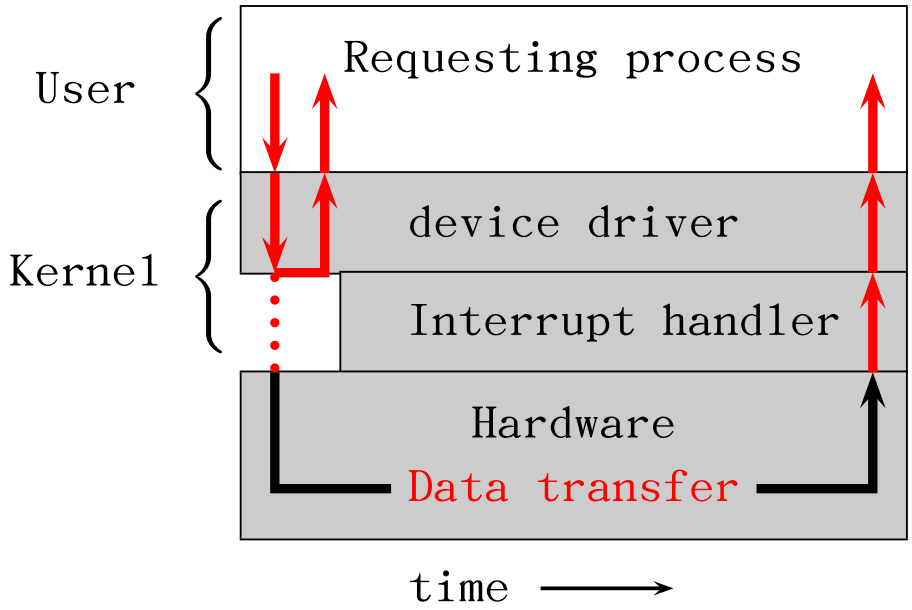


- Need to keep track of many I/O request
  1. Device-status table, 设备状态表
  2. A wait queue for each device
  3. When an interrupt occurs, OS indexes into I/O device table to determine device status and to modify table entry to reflect the occurrence of interrupt
- Main advantage: system efficiency

I/O method —— analysis (cont.)

2. Asynchronous(异步)

- Start & cont.
  - with a wait system call
  - os execute other programs, or, if no other program, idle

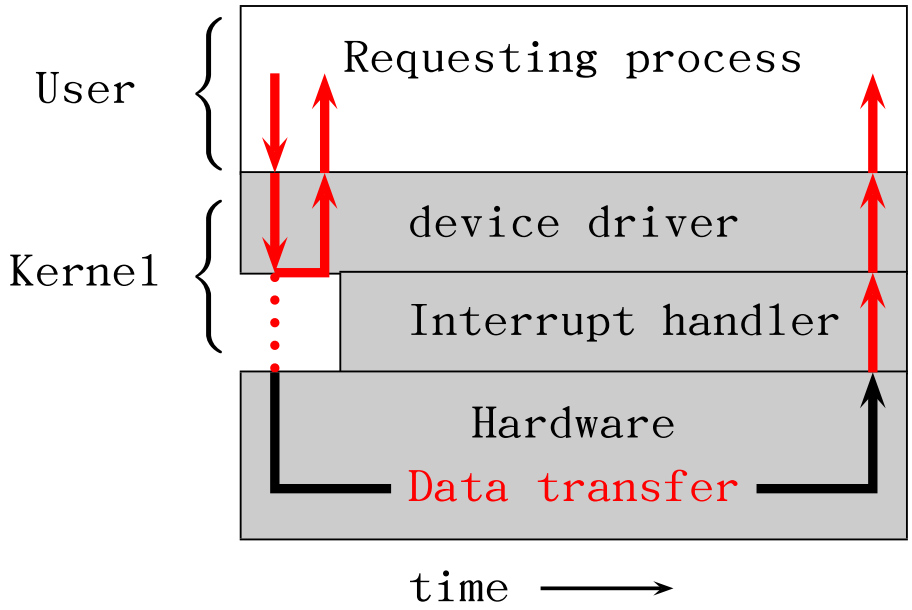


- Need to keep track of many I/O request
  1. Device-status table, 设备状态表
  2. A wait queue for each device
  3. When an interrupt occurs, OS indexes into I/O device table to determine device status and to modify table entry to reflect the occurrence of interrupt
- Main advantage: system efficiency

I/O method —— analysis (cont.)

2. Asynchronous(异步)

- Start & cont.
  - with a wait system call
  - os execute other programs, or, if no other program, idle



- Need to keep track of many I/O request, HOW?
  1. Device-status table, 设备状态表
  2. A wait queue for each device
  3. When an interrupt occurs, OS indexes into I/O device table to determine device status and to modify table entry to reflect the occurrence of interrupt
- Main advantage: system efficiency↑

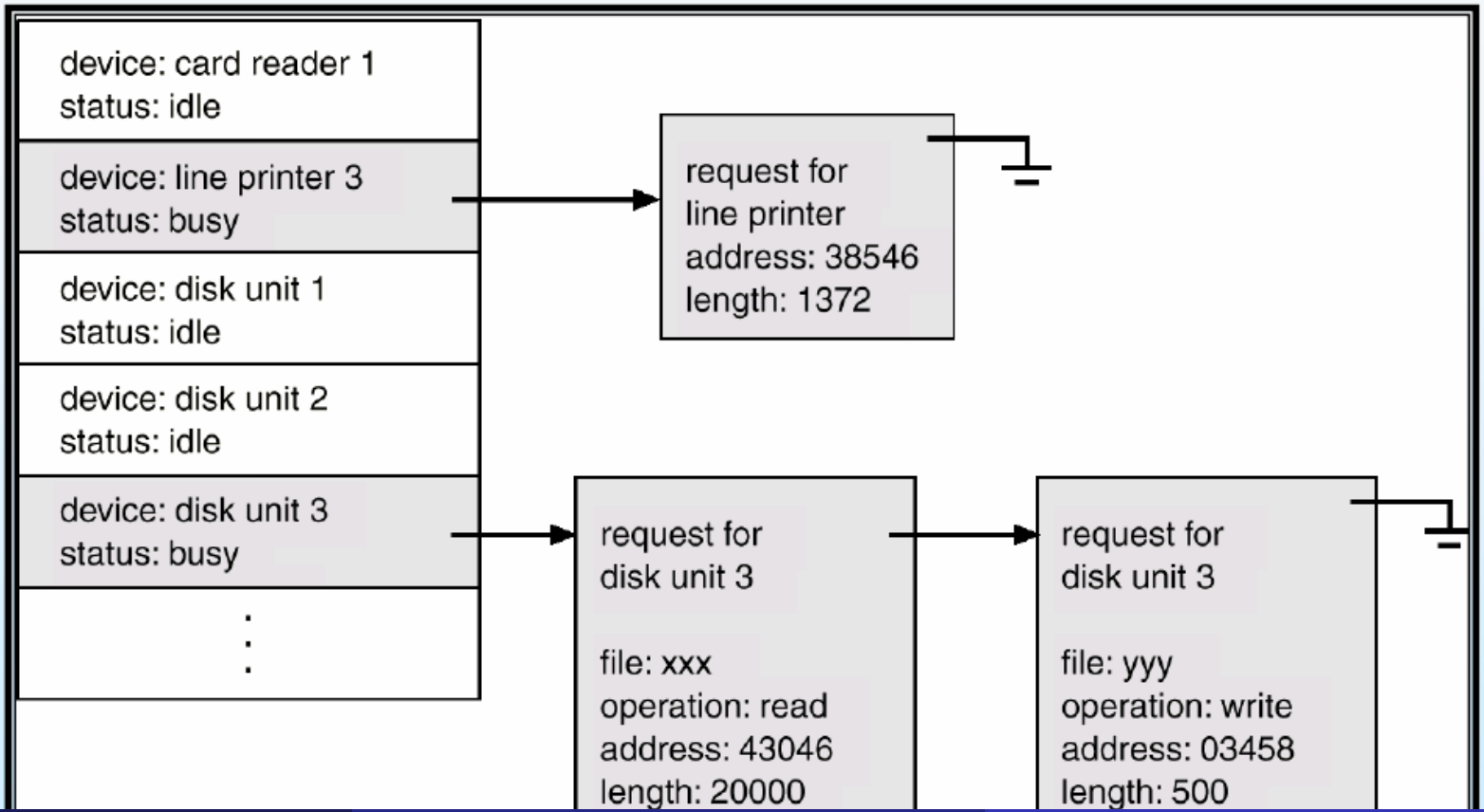
I/O method —— analysis (cont.)

2. Asynchronous(异步)

- Need to keep track of many I/O request, HOW?
  1. Device-status table, 设备状态表
     - Each device: an device entry;
     - Each entry: Device type, address, state(not work, idle/valid, or busy)
  2. A wait queue for each device
  3. When an interrupt occurs, OS indexes into I/O device table to determine device status and to modify table entry to reflect the occurrence of interrupt
- Main advantage: system efficiency↑

2. Asynchronous(异步)

- Need to keep track of many I/O request, HOW?
  1. Device-status table, 设备状态表



I/O method —— analysis (cont.)

2. Asynchronous(异步)

- Need to keep track of many I/O request, HOW?
  1. Device-status table, 设备状态表
  2. A wait queue for each device
  3. When an interrupt occurs, OS indexes into I/O device table to determine device status and to modify table entry to reflect the occurrence of interrupt
- Main advantage: system efficiency↑

I/O method —— analysis (cont.)

2. Asynchronous(异步)

- Need to keep track of many I/O request, HOW?
  1. Device-status table, 设备状态表
  2. A wait queue for each device
  3. When an interrupt occurs, OS indexes into I/O device table to determine device status and to modify table entry to reflect the occurrence of interrupt
- Main advantage: system efficiency↑

Outline

Direct Memory Access (DMA)

Example1: 9600-baud terminal

- 2us(ISR) per 1000us
- It's ok!

Example2: hard disk

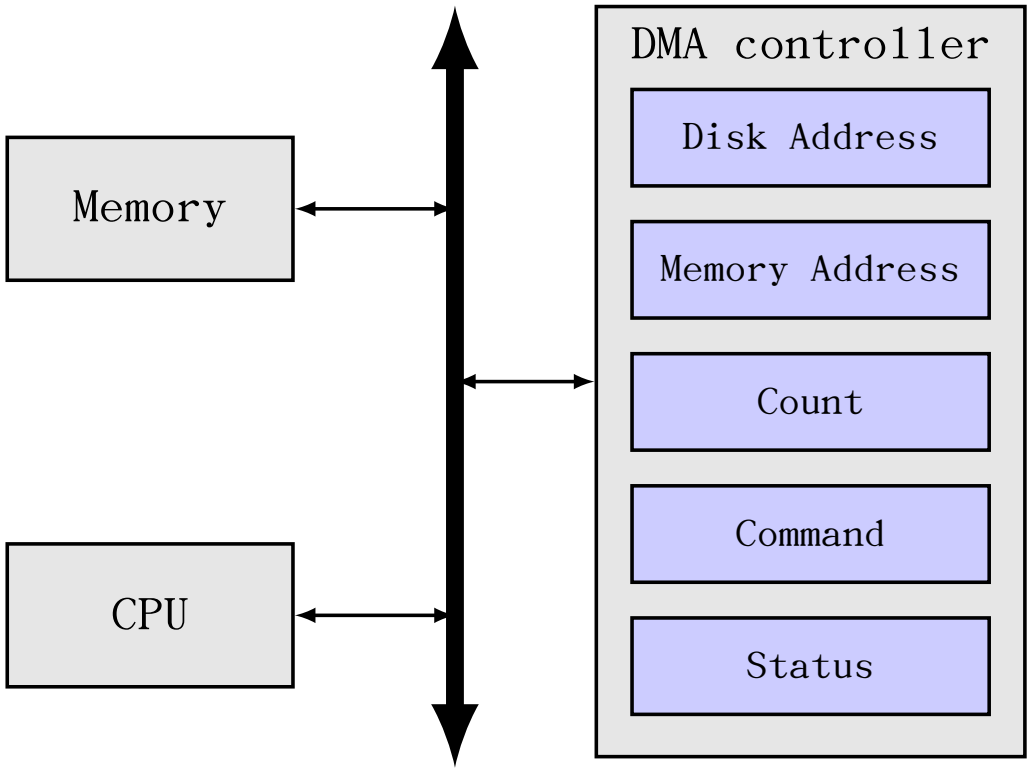
- 2us(ISR) per 4us
- The overhead (per byte) is relatively costly!

DMA (Direct Memory Access, 直接内存访问)

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

DMA structure

One interrupt / block of data



CPU:

- fetch instruction
- decode ←
- fetch operand
- operate ←

Device controller

- transfers between buffer and main memory directly, without CPU intervention.
- Memory cycle stealing

Outline

Storage structure

- Von Neumann architecture VS. Harvard architecture
  - Separated data & code in different memory???
- Main memory (RAM) is the only large storage media that the CPU can access directly
  - Small, Volatile
- Secondary storage is an extension of main memory that provides large nonvolatile storage capacity
  - Magnetic disk, 磁盘
  - Optical disk, 光盘
  - Magnetic tape, 磁带

Memory vs. registers

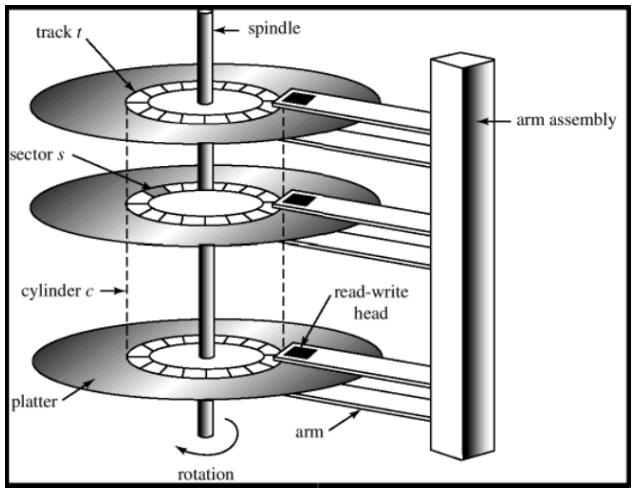
Memory VS. registers

- Same: Access directly for CPU
  - Register name
  - Memory address
- Different: access speed
  - Register, one cycle of the CPU clock
  - Memory, Many cycles (2 or more)
- Disadvantage:
  - CPU needs to stall frequently & this is intolerable
- Remedy : cache, 高速缓存

Magnetic disks

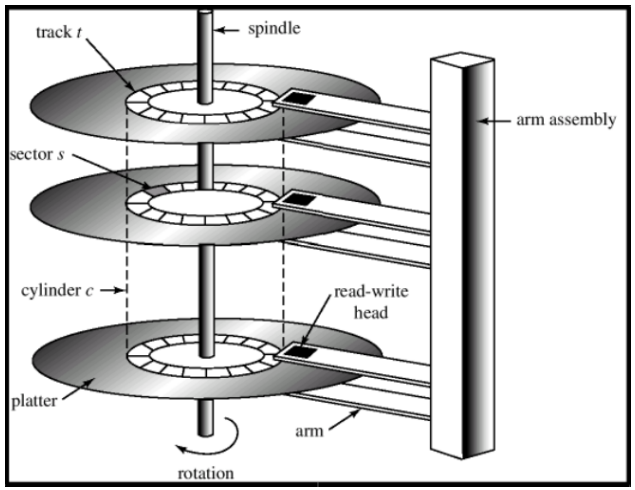
- Magnetic disks — rigid metal or glass platters covered with magnetic recording material
  - Disk surface is logically divided into tracks(磁道), which are subdivided into sectors(扇区).
  - The disk controller determines the logical interaction between the device and the computer.

- Position(定位) time T_p
- Transfer(传输) time T_T
- T_T VS. T_p
  - Please Store data closely



Magnetic disks

- Magnetic disks — rigid metal or glass platters covered with magnetic recording material
  - Disk surface is logically divided into tracks(磁道), which are subdivided into sectors(扇区).
  - The disk controller determines the logical interaction between the device and the computer.

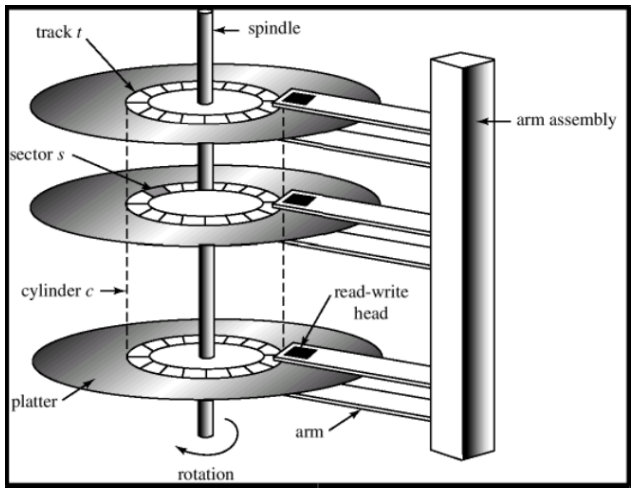


- Position(定位) time T_p
  - $T_p \approx T_s + T_R \approx$ m ms
  - Seek time T_s
  - Rotational latency T_R
- Transfer(传输) time T_T
- T_T VS. T_p
  - Please Store data closely

Magnetic disks

- Magnetic disks — rigid metal or glass platters covered with magnetic recording material
  - Disk surface is logically divided into tracks(磁道), which are subdivided into sectors(扇区).
  - The disk controller determines the logical interaction between the device and the computer.

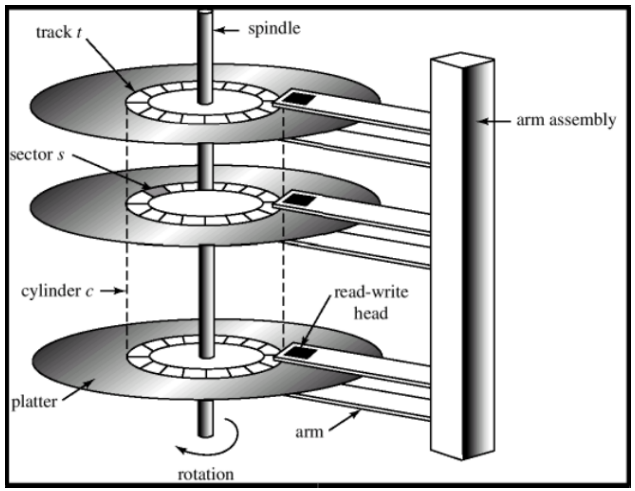
- Position(定位) time T_p
- Transfer(传输) time T_T
  - T_T
    $\approx$ data size $\times$ Transfer rate
  - Transfer rate $\approx (\text{nM/s})^{-1}$
    $\approx (\text{n Byte/us})^{-1}$
    $\approx 1/\text{n us/Byte}$
- T_T VS. T_p



Magnetic disks

- Magnetic disks — rigid metal or glass platters covered with magnetic recording material
  - Disk surface is logically divided into tracks(磁道), which are subdivided into sectors(扇区).
  - The disk controller determines the logical interaction between the device and the computer.

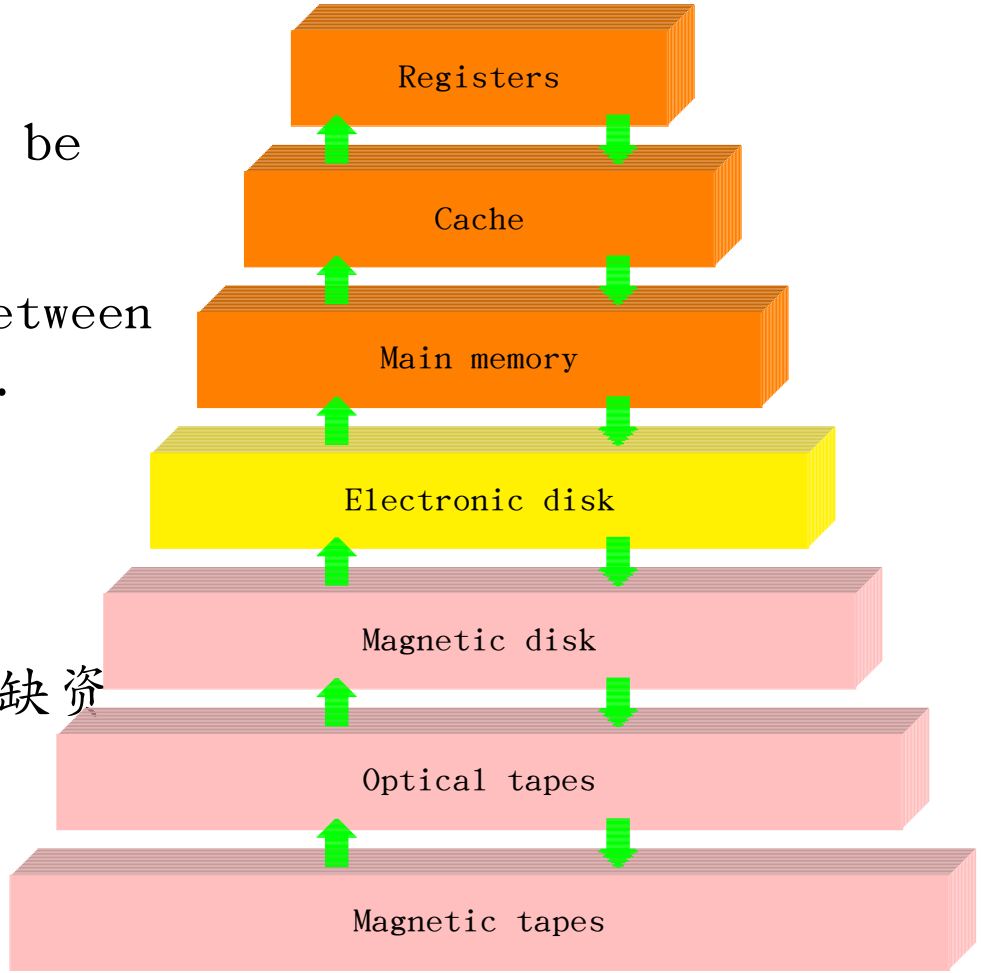
- Position(定位) time T_p
- Transfer(传输) time T_T
- T_T VS. T_p
  - Please Store data closely



Outline

Storage hierarchy，存储的层次

- Storage systems in a CS can be organized in a hierarchy.
  1. The contradiction(矛盾) between COST, SPEED, and CAPACITY.
  2. COST per bit.
  3. Volatility (易失性) VS. persistence (持久性).
- MM is a scarce resource (稀缺资源).



Caching

- Caching（高速缓存技术）
  - Copying information into faster storage system
  - When accessing, first check in the cache,
    - if In: use it directly
    - Not in: get from upper storage system, and leave a copy in the cache
- Using of caching
  - Registers provide a high-speed cache for main memory
  - Instruction cache & data cache
  - Main memory can be viewed as a fast cache for secondary storage
  - ...

Cache management

- Design problem
  - Hardware or software?
  - Cache size & Replacement policy is important
  - Hit rate $\approx$ 80%~99% is OK!

Memory Wall

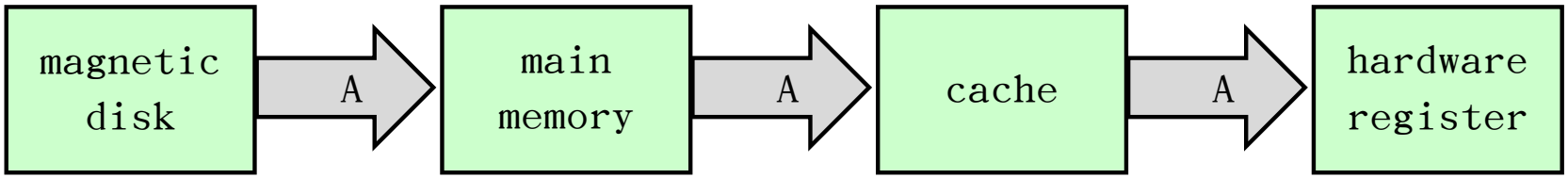
Memory Wall, 内存墙

- the growing disparity of speed between CPU and memory outside the CPU chip[a].
  - From 1986 to 2000, CPU speed improved at an annual rate of 55% while memory speed only improved at 10%.
  - Trend: memory latency would become an overwhelming bottleneck in computer performance

[a] From Wikipedia: Random-access memory

Coherency and consistency

- Multitasking environments must be careful to use most recent value, no matter where it is stored in the storage hierarchy
- Migration of Integer A from Disk to Register



- The same data may appear in different level of the storage system
- When
  - Simple batch system, no problem
  - Multitasking, always obtain the most recently updated value
  - Multiprocessor, cache coherency (always implicit to OS)
  - Distributed system?

Performance of Various Levels of Storage

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

Level	1	2	3	4
Name	registers	cache	main memory	disk storage
Typical size	<1KB	>16MB	>16GB	>100GB
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	OS	OS
Backed by	cache	main memory	disk	CD or tape

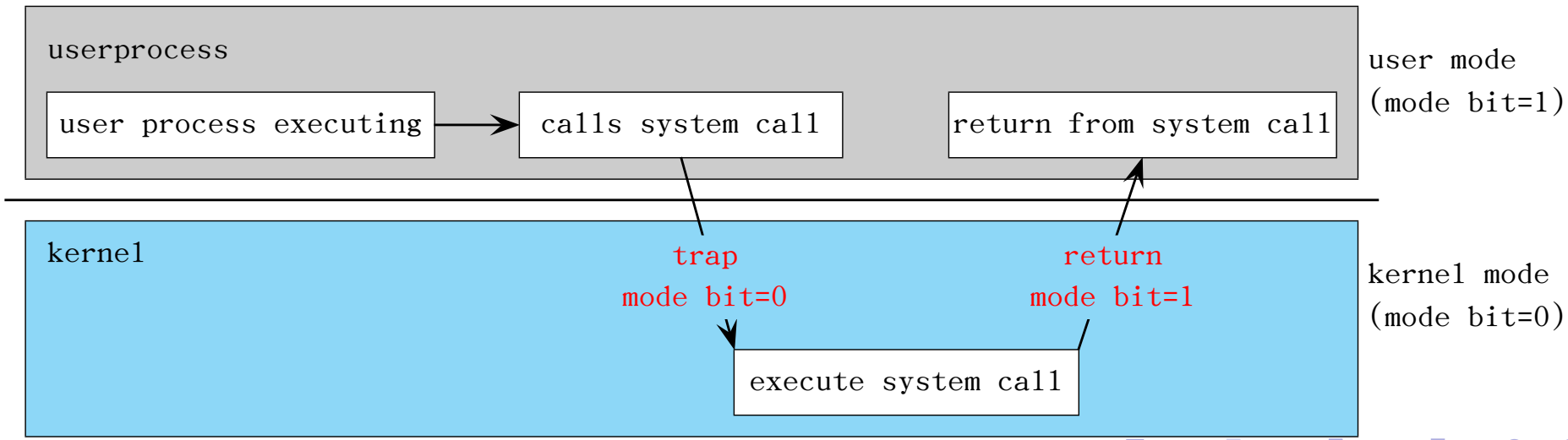
Outline

Hardware protection

- A properly designed OS must ensure that an incorrect (or malicious) program cannot cause other programs to execute incorrectly.
  1. When in dead loop
  2. When sharing recourses
  3. When one erroneous program might modify the program or data of another program, or even the OS
- Hardware must provide protection
  1. Dual-Mode Operation
  2. I/O protection
  3. Memory protection
  4. CPU protection

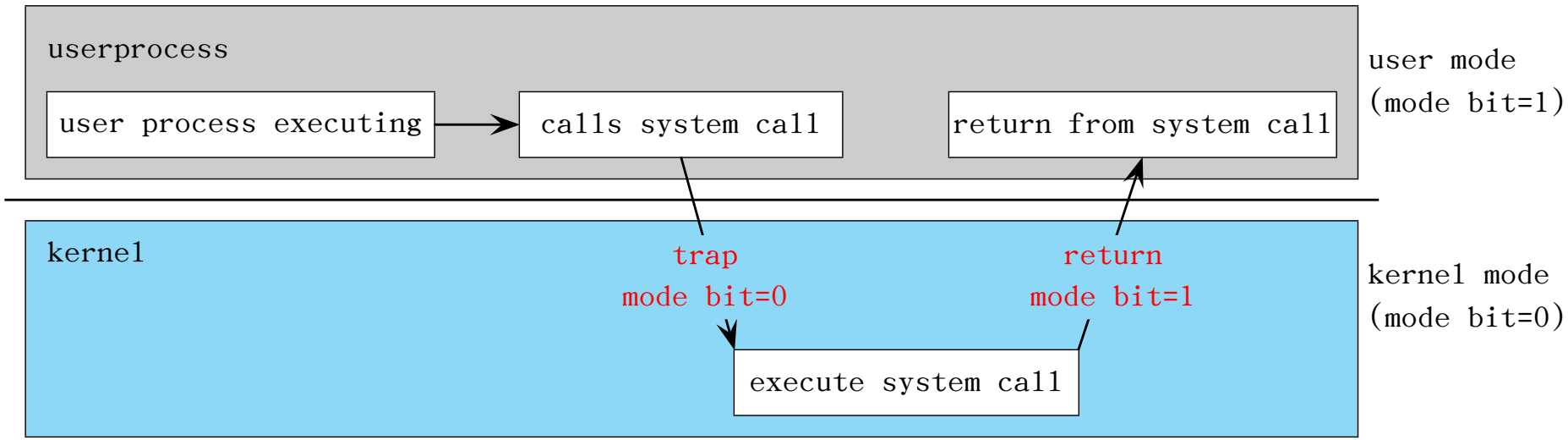
Hardware protection 1: Dual-Mode Operation（双操作模式）

- Using mode bit to provide different modes of execution
  - mode bit=1≡User mode（用户模式）:
    execution done on behalf of user
  - mode bit=0≡privileged mode（特权模式）,
    also called monitor mode（监督程序模式）/supervisor mode（管理模式）/system mode（系统模式）:
    execution done on behalf of OS
    - Privileged instructions

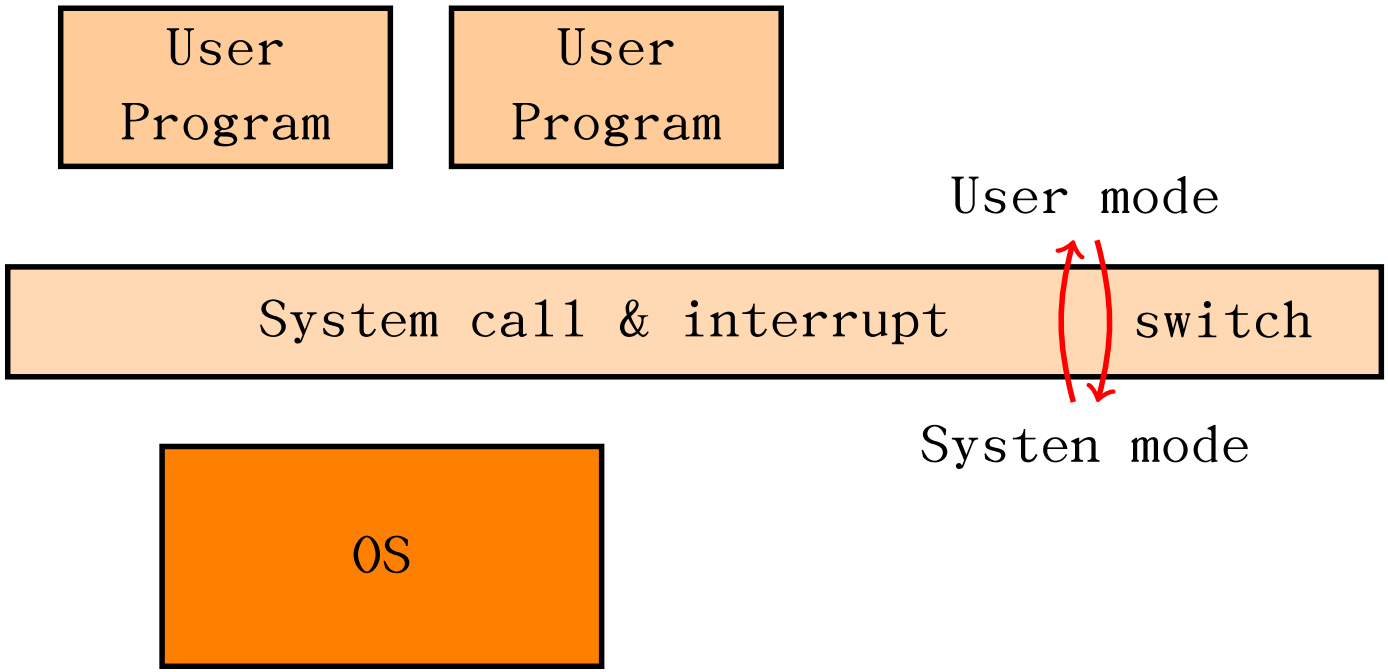


Hardware protection 1: Dual-Mode Operation（双操作模式）

- User program VS. OS (or Kernel)
  - Switch between user mode (1) and privileged mode(0)
    - Boot: from privileged mode.
    - User program: user mode.
    - Interrupt (include system call): switch to privileged mode.
    - OS: privileged mode



- Example：i386
  - 4 modes (2 mode bits)
  - Linux uses 2 mode (00b & 11b)

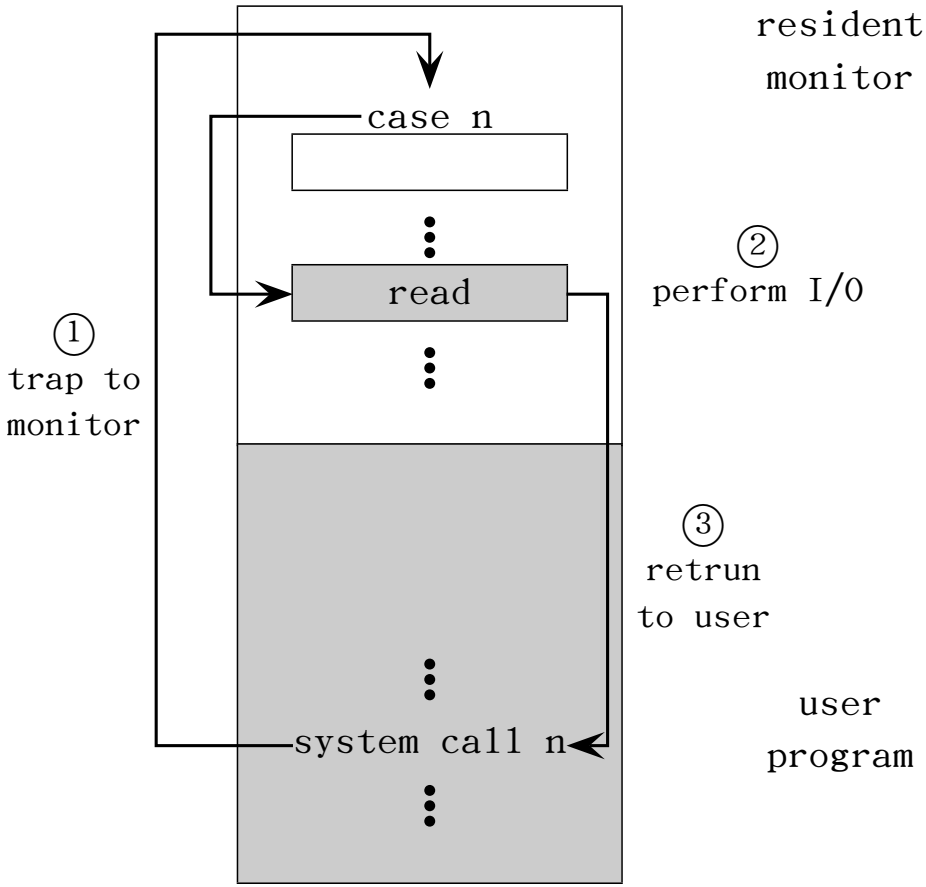


Figure： Linux uses two modes

Hardware protection 2: I/O protection

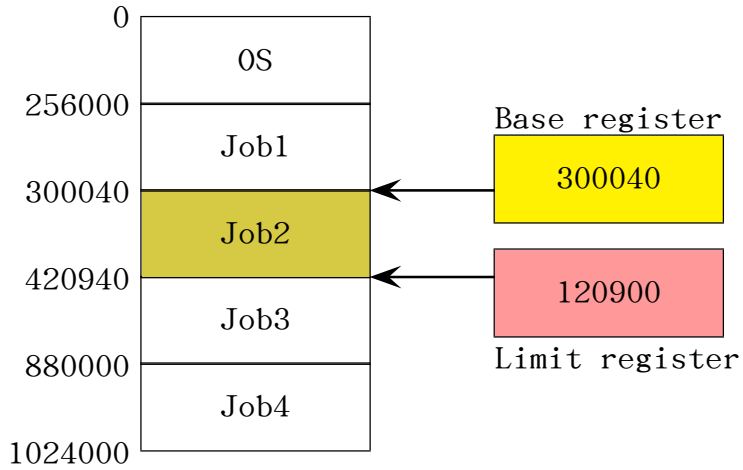
- Preventing the users from issuing illegal I/O instructions
- All I/O instructions are privileged instructions
  - instead of performing I/O operation directly, user program must make a system call
  - OS, executing in monitor mode, checks validity of request and does the I/O
  - input is returned to the program by the OS
- Smart hacker may…
  - Stores in the interrupt vector a new address, which points to a malicious routine
  - The I/O protection is compromised
  - We need some more protection…

Use of a system all to perform I/O



Hardware protection 3: Memory protection

- At least for interrupt vector and the ISR
- Base register protection scheme
  - Base register+Limit register
  - Memory outside is protected
  - OS has unrestricted access to both monitor and user's memory
  - Load instructions for the base/limit registers are privileged



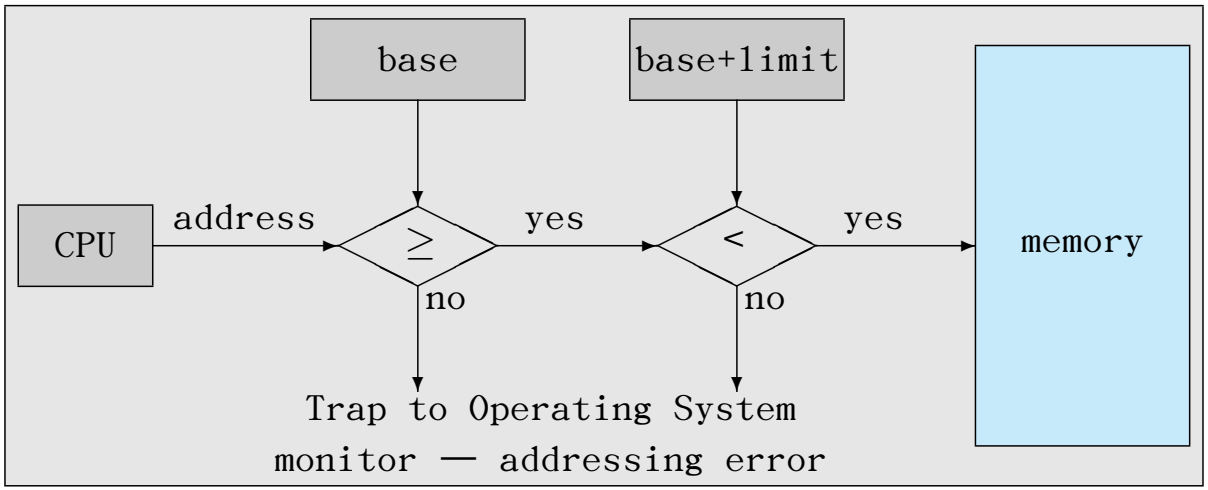


Figure: Hardware address protection with base and limit registers

Hardware protection 4: CPU protection

- OS should be always take control of everything
  - What if a user program is in dead loop?
- Timer
  - Interrupts computer after specified period
  - Periodically or one-shot
  - Load-timer is also a privileged instruction
- Usage
  - Time sharing
  - Compute current time
  - Alarm or timer

Timer to prevent infinite loop / process hogging resources

- Set interrupt after specific period
- Operating system decrements counter
- When counter zero generate an interrupt
- Set up before scheduling process to regain control or terminate program that exceeds allotted time

Outline

General system architecture

- multiprogramming
- time sharing
- OS: in kernel (privileged) mode
  - control hardware & software resource
  - execute privileged instruction
  - system call

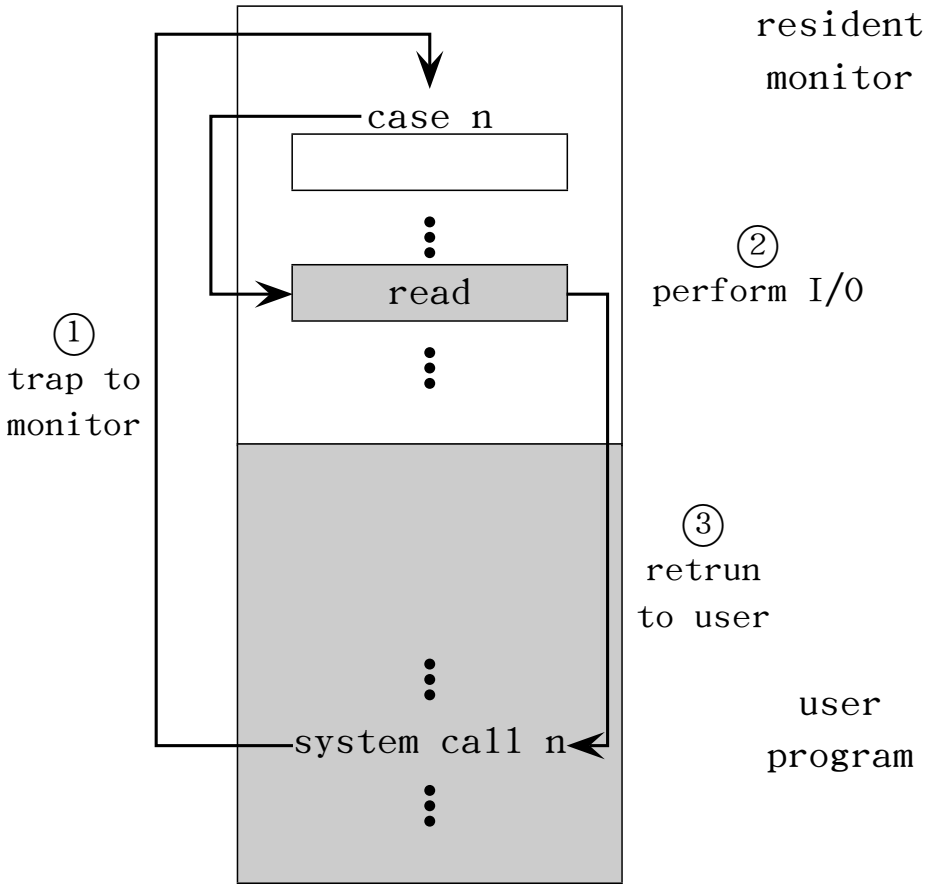
Outline

system call

System call—like a common function call, but totally different!

- Trap to a specific location in interrupt vector
  - int (i386)
  - trap (SUN SPARC)
  - syscall (MIPS R2000)
- Control passes to a service routine in the OS, and the mode bit is set to monitor mode
- The kernel
  - Verifies that the parameters are correct and legal
  - Executes the request
  - Returns control to the instruction following the system call

Use of a system all to perform I/O

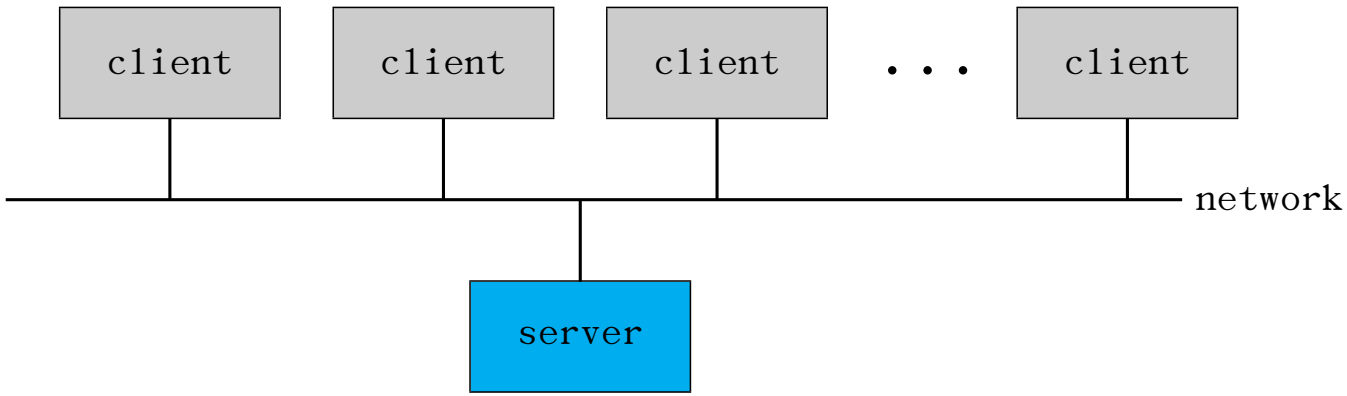


Computing Environments

- Traditional computer
  - 随计算机的发展而变化
  - Office environment
    - PCs connected to a network, terminals attached to mainframe or minicomputers providing batch and timesharing
    - Now portals allowing networked and remote systems access to same resources
  - Home networks
    - Used to be single system, then modems
    - Now firewalled, networked

Computing Environments

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



Computing Environments

- 其他
  - Peer-to-Peer Computing
  - Web-Based Computing
  - Grid Computing
  - Cloud Computing
  - 普适计算Pervasive/Ubiquitous Computing

小结

作业

- 请给出冯.诺依曼体系结构的系统上，一个典型的指令执行周期的执行过程。
- 作为一个基本的系统保护（安全）形式，系统模式和用户模式之间有什么不同？
- 1.10 What is the purpose of interrupts? What are the differences between a trap and an interrupt? Can traps be generated intentionally by a user program? If so, for what purpose?
- 1.13 Give two reasons why caches are useful. What problems do the solve? What problems do they cause? If a cache can be made as large as the device for which it is caching (for instance, a cache as large as a disk), why not make it that large and eliminate the device?
- 1.8
  Which of the following instructions should be privileged?
  - a. Set value of timer.
  - b. Read the clock.
  - c. Clear memory.
  - d. Issue a trap instruction.
  - e. Turn off interrupts.
  - f. Modify entries in device-status table.
  - g. Switch from user to kernel mode.
  - h. Access I/O device.
- 1.11 Direct memory access is used for high-speed I/O devices in order to avoid increasing the CPU's execution load.
  - a. How does the CPU interface with the device to coordinate the transfer?
  - b. How does the CPU know when the memory operations are complete?
  - c. The CPU is allowed to execute other programs while the DMA controller is transfering data. Does this process interfere with the execution of the user programs? If so, describe what forms of interference are caused.

视频作业（可选）

1. 介绍一款主板，要求
   1. 首先给出整体介绍，然后给出局部介绍。
2. 介绍完整的Linux的启动过程，要求：
   1. 进入BIOS界面
   2. 说明启动介质（硬盘还是网络）
   3. 有Linux启动菜单选择界面
   4. 有启动完成后的Linux桌面
3. 介绍完整的Windows操作系统启动过程，要求类似2。
4. 介绍其他操作系统的启动过程也可以。

谢谢！