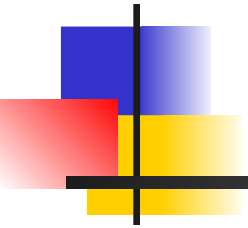
Operating System Principles

操作系统原理



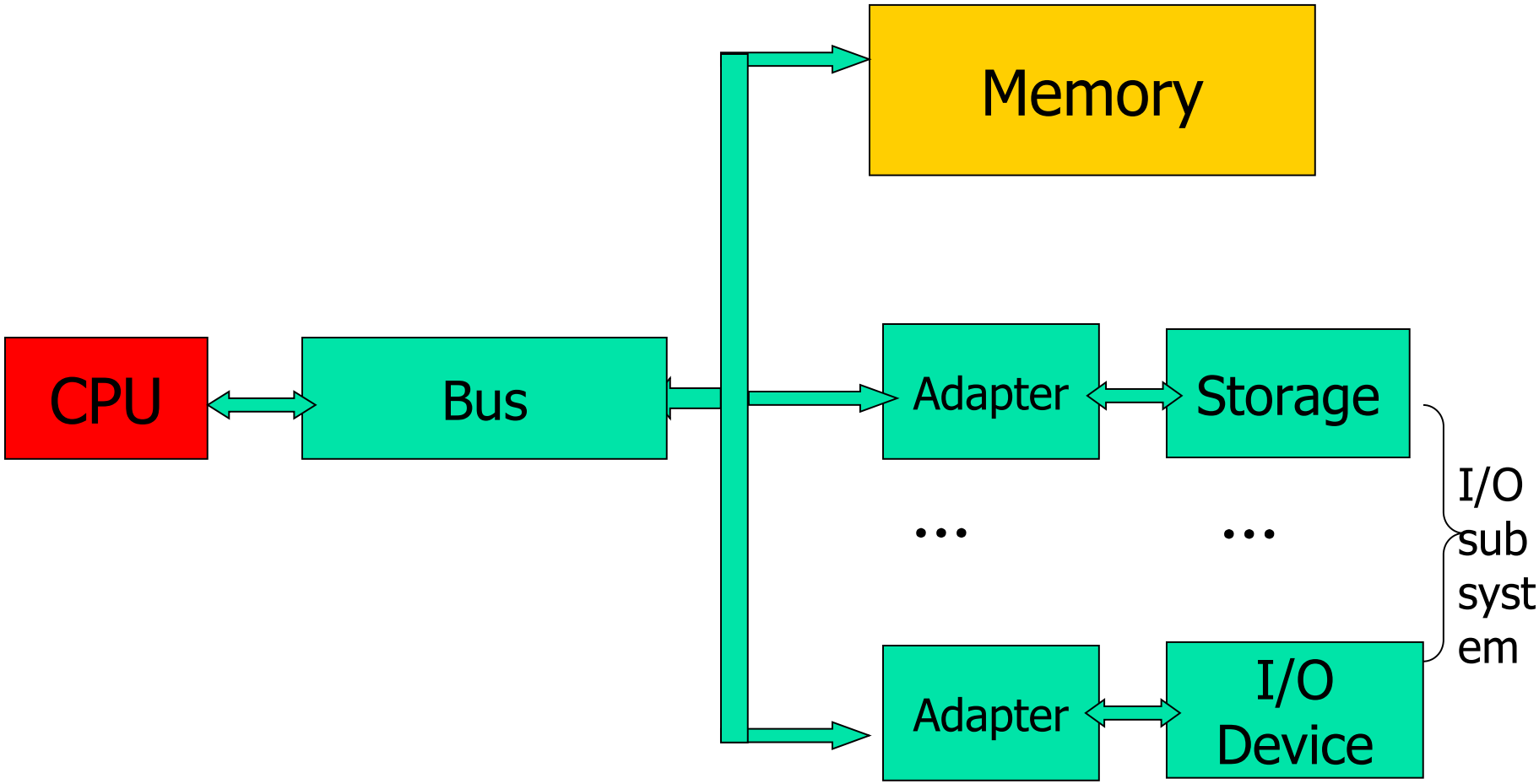
Input/Output

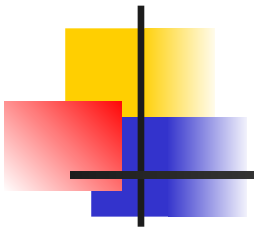
李旭东

leexudong@nankai.edu.cn

Nankai University

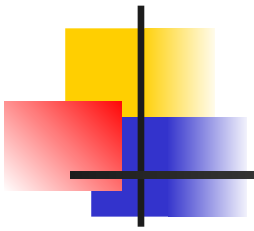
Computer System:Hardware





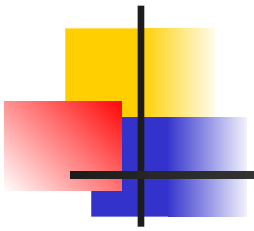
I/O System Target

- Basic
  - Issue commands to the device
  - catch interrupts
  - Handle errors
- Easy to use
- Extensibility
  - Device independence

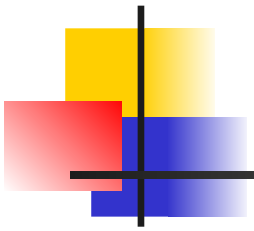


Objectives

- Principles of I/O Hardware
- Principles of I/O Software
- I/O Software Layers
- Disks

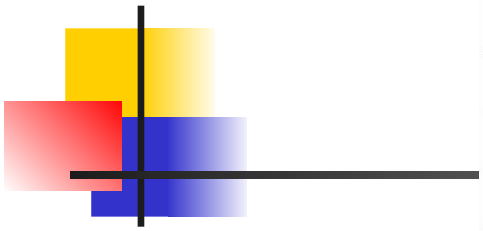


Principles of I/O Hardware



I/O Devices

- Block devices
  - Block addressable
- Character devices
  - A stream of characters
- Other devices
  - Clocks



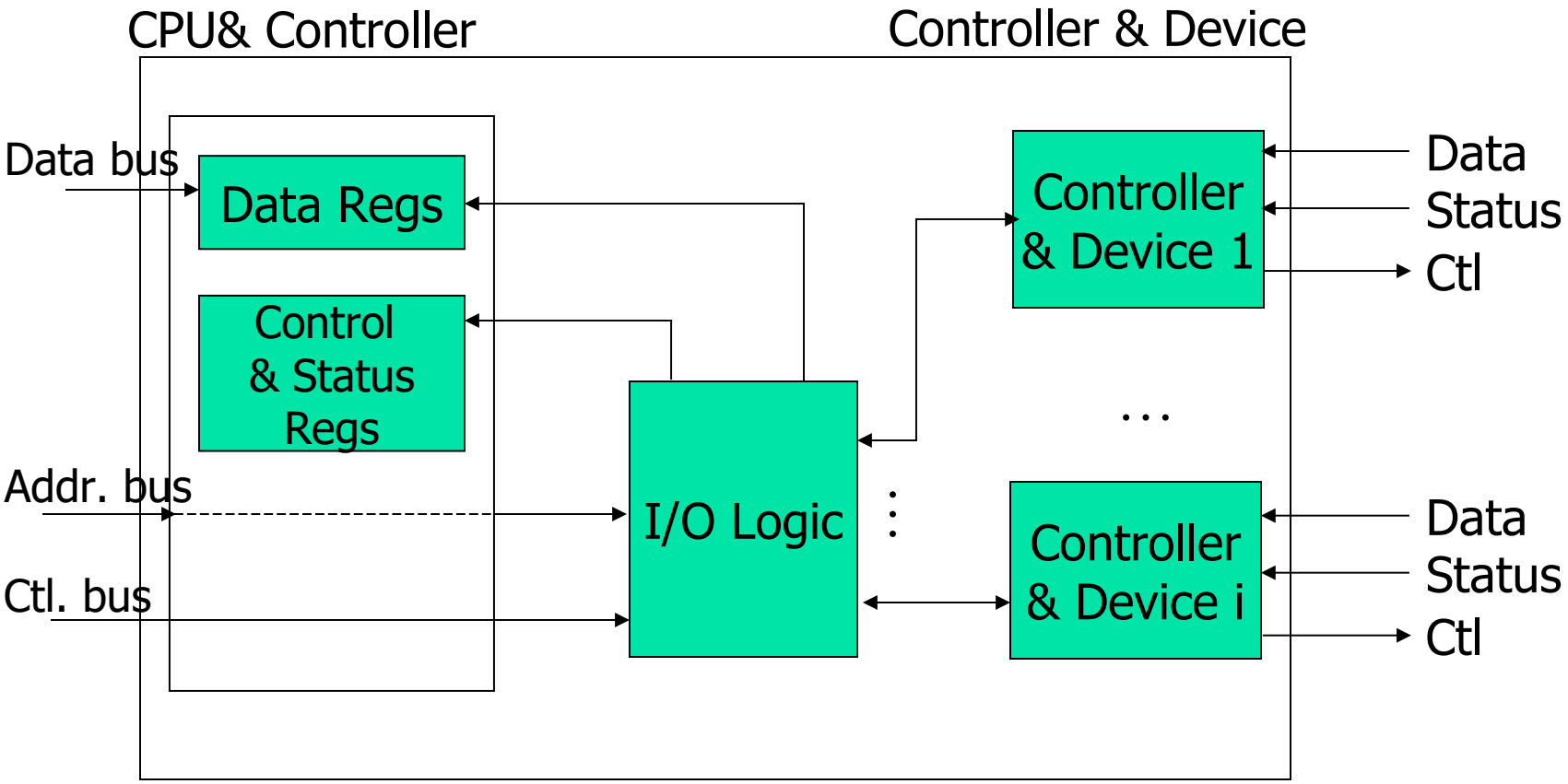
- USB2.0
  - 480Mbit/s
- USB3.0
  - 5Gbit/s
- WLAN
  - 1Gbit/s

Device	Data rate
Keyboard	10 bytes/sec
Mouse	100 bytes/sec
56K modem	7 KB/sec
Telephone channel	8 KB/sec
Dual ISDN lines	16 KB/sec
Laser printer	100 KB/sec
Scanner	400 KB/sec
Classic Ethernet	1.25 MB/sec
USB (Universal Serial Bus)	1.5 MB/sec
Digital camcorder	4 MB/sec
IDE disk	5 MB/sec
40x CD-ROM	6 MB/sec
Fast Ethernet	12.5 MB/sec
ISA bus	16.7 MB/sec
EIDE (ATA-2) disk	16.7 MB/sec
FireWire (IEEE 1394)	50 MB/sec
XGA Monitor	60 MB/sec
SONET OC-12 network	78 MB/sec
SCSI Ultra 2 disk	80 MB/sec
Gigabit Ethernet	125 MB/sec
Ultrium tape	320 MB/sec
PCI bus	528 MB/sec
Sun Gigaplane XB backplane	20 GB/sec

Device Controllers

- I/O Unit
  - A mechanical component
  - An elecronic component
    - Device controller: (i.e.) Adapter
    - Preamble
    - ECC: Error-Correcting Code
- Device Controller
  - Convert the serial bit stream into a block of bytes and perform any error correction necessary
  - Can handle one, two, four … identical devices
- Interface between the controller and device
  - ANSI, IEEE, ISO standard, A de facto standard
  - IDE, SCSI,SATA, USB, Firewire(IEEE 1394)

Device Controllers

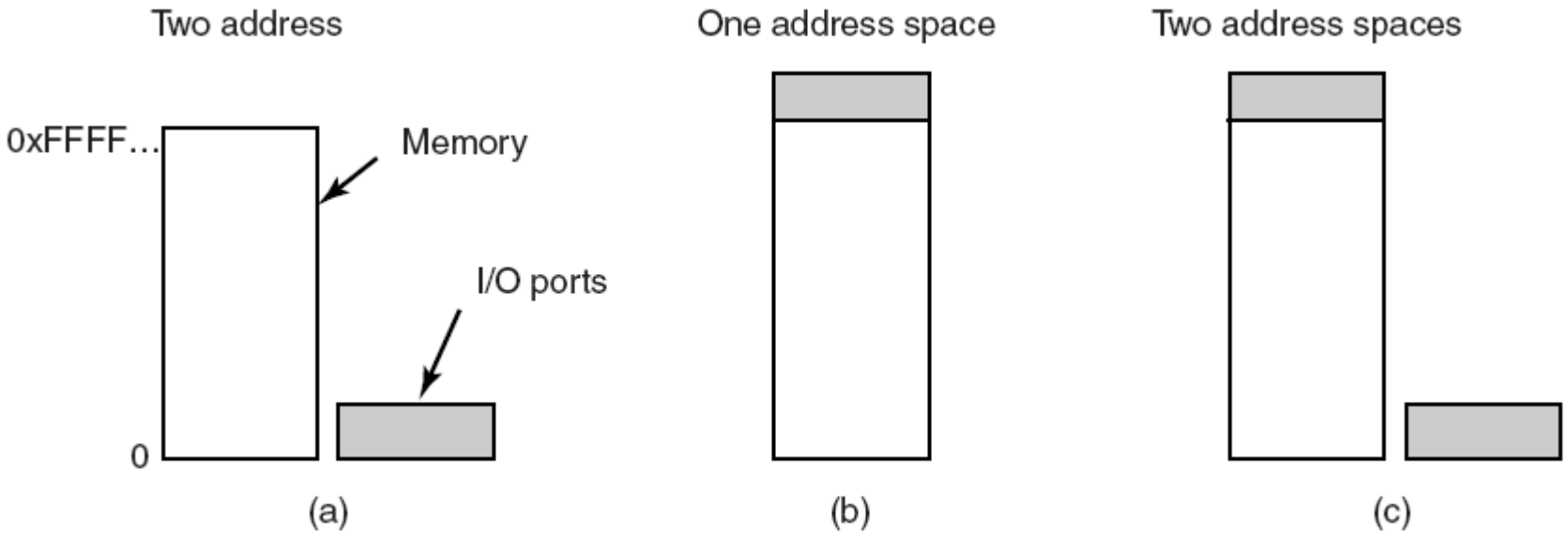


Device Controller Components

Memory-Mapped I/O

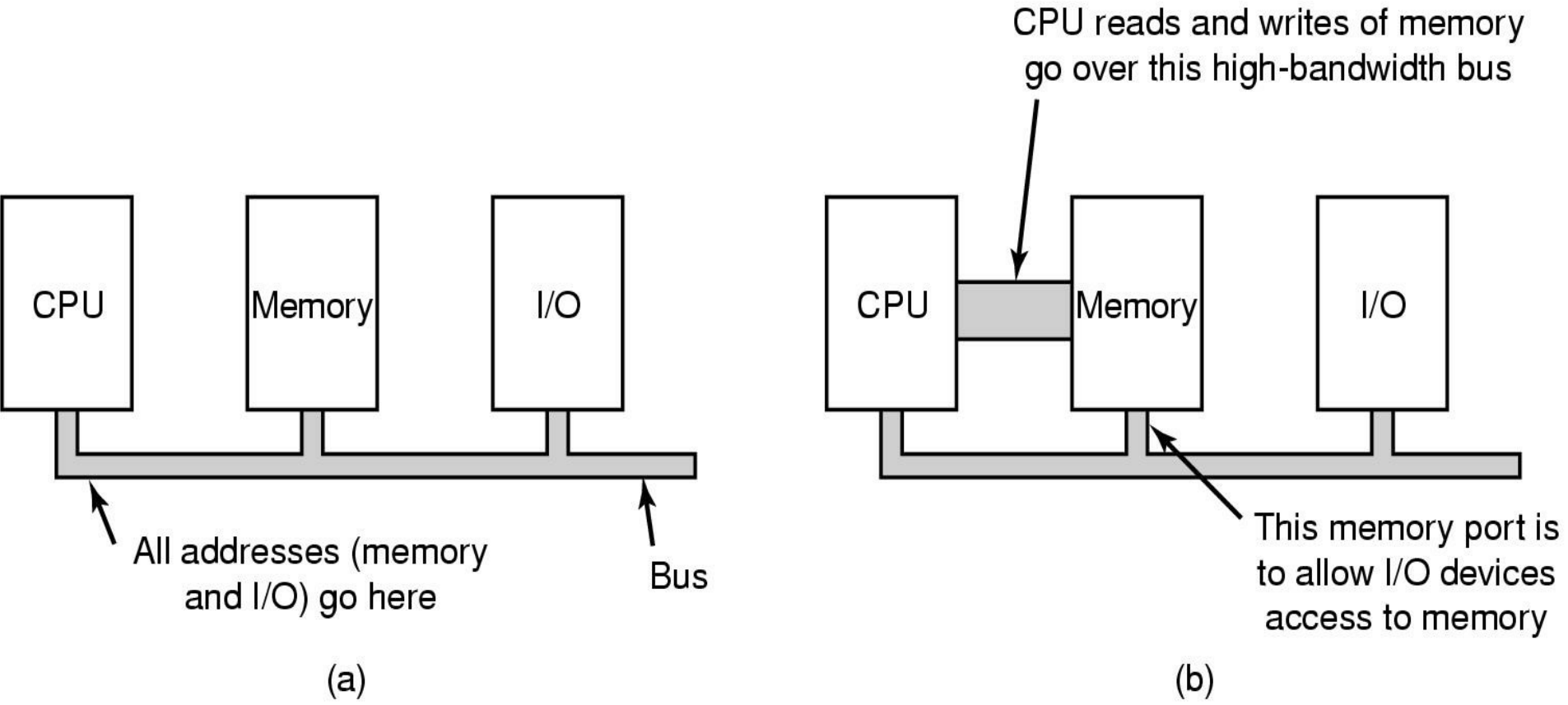
- Device controller
  - Control registers
  - A data buffer
- I/O port
- I/O port space: set of I/O ports
- Special I/O instruction
  - IN REG, PORT
  - OUT PORT, REG
- Memory-Mapped I/O
  - MOV R0, 4

Memory-Mapped I/O



a) Separate I/O and memory space
b) Memory-mapped I/O
c) Hybrid

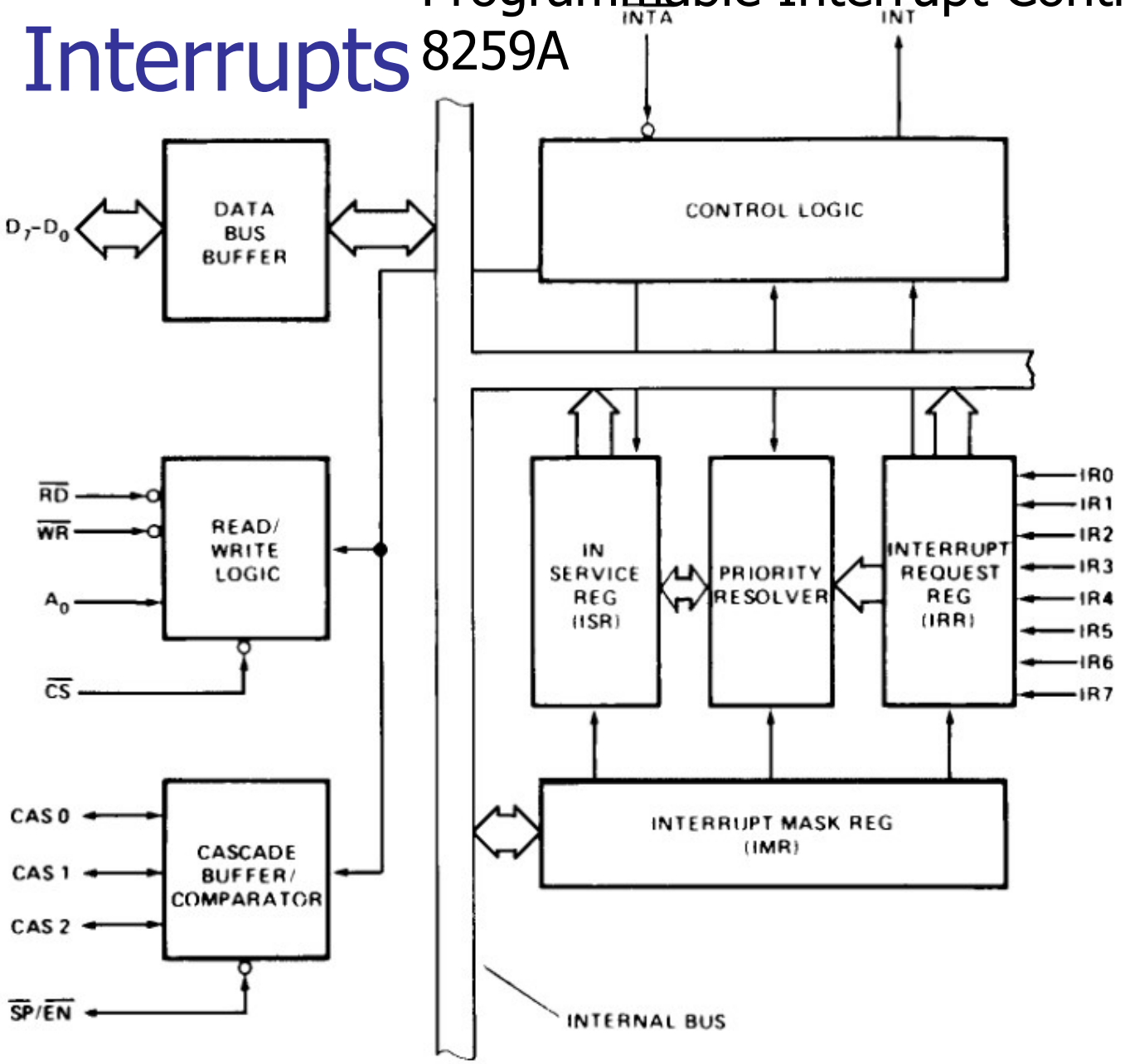
Memory-Mapped I/O



(a) A single-bus architecture
(b) A dual-bus memory architecture

Interrupts

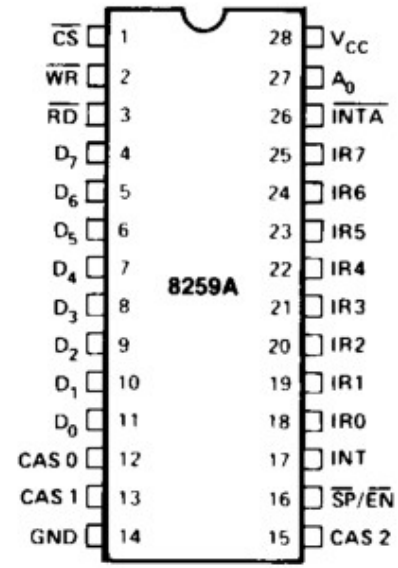
Programmable Interrupt Controller 8259A



231468–1

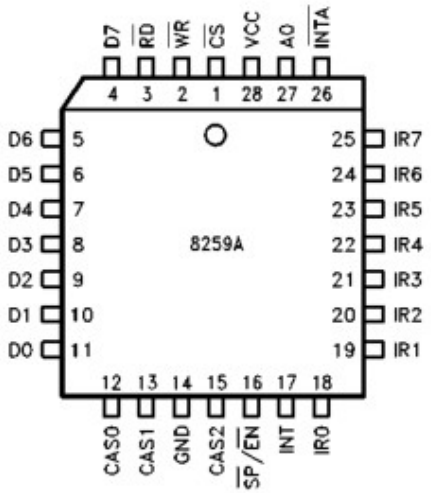
Figure 1. Block Diagram

DIP



231468–2

PLCC

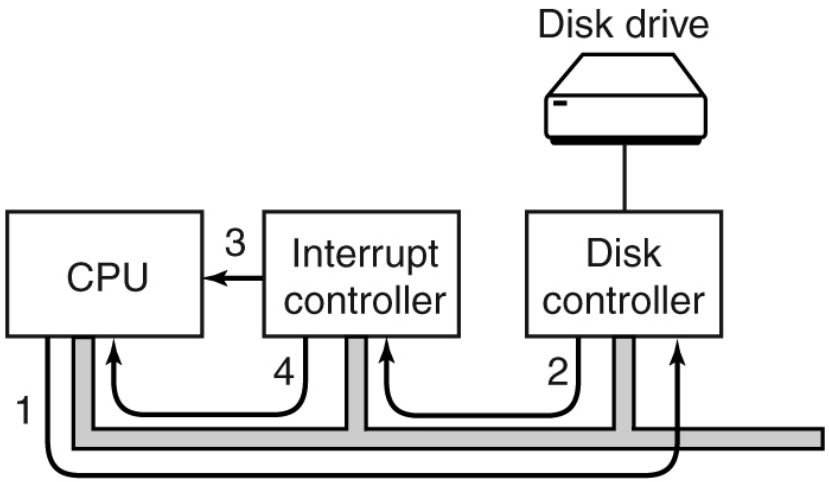


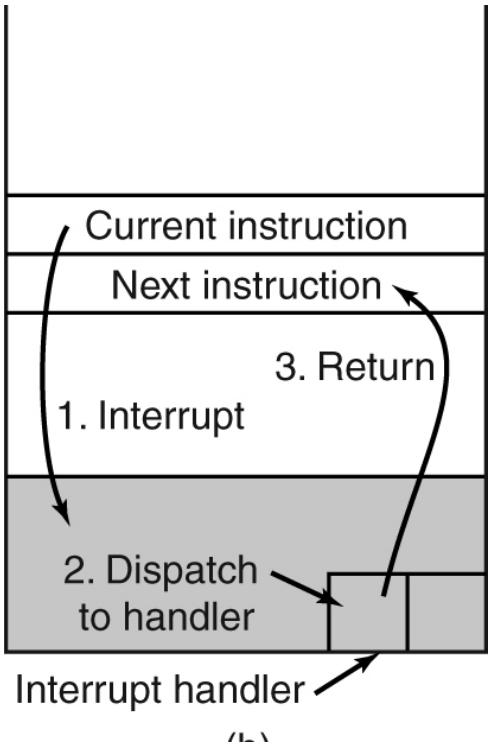
231468–31

Figure 2. Pin Configurations

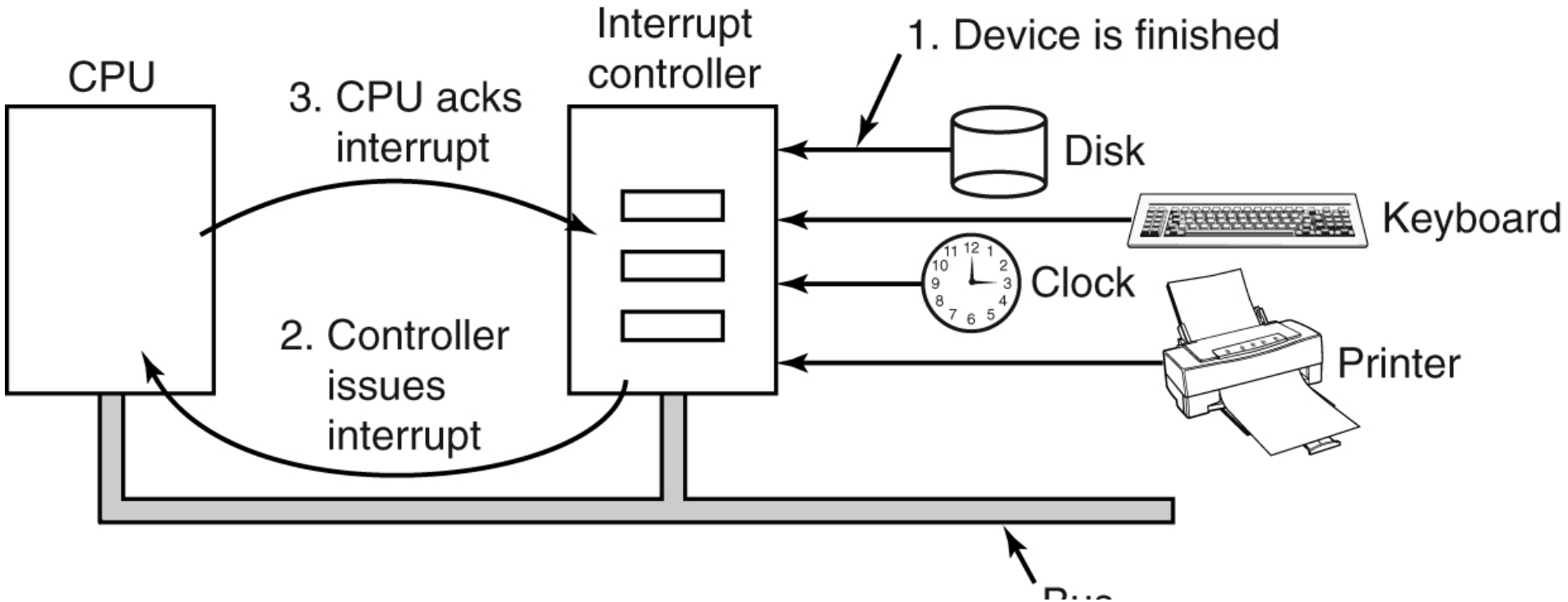
Interrupts

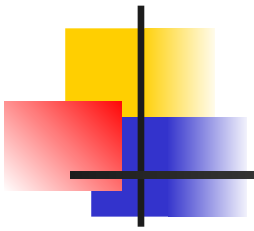
- Interrupt vector
  - 中断向量





Interrupts


CPU
3. CPU acks interrupt
Interrupt controller
1. Device is finished
Disk
Keyboard
Clock
Printer
2. Controller issues interrupt

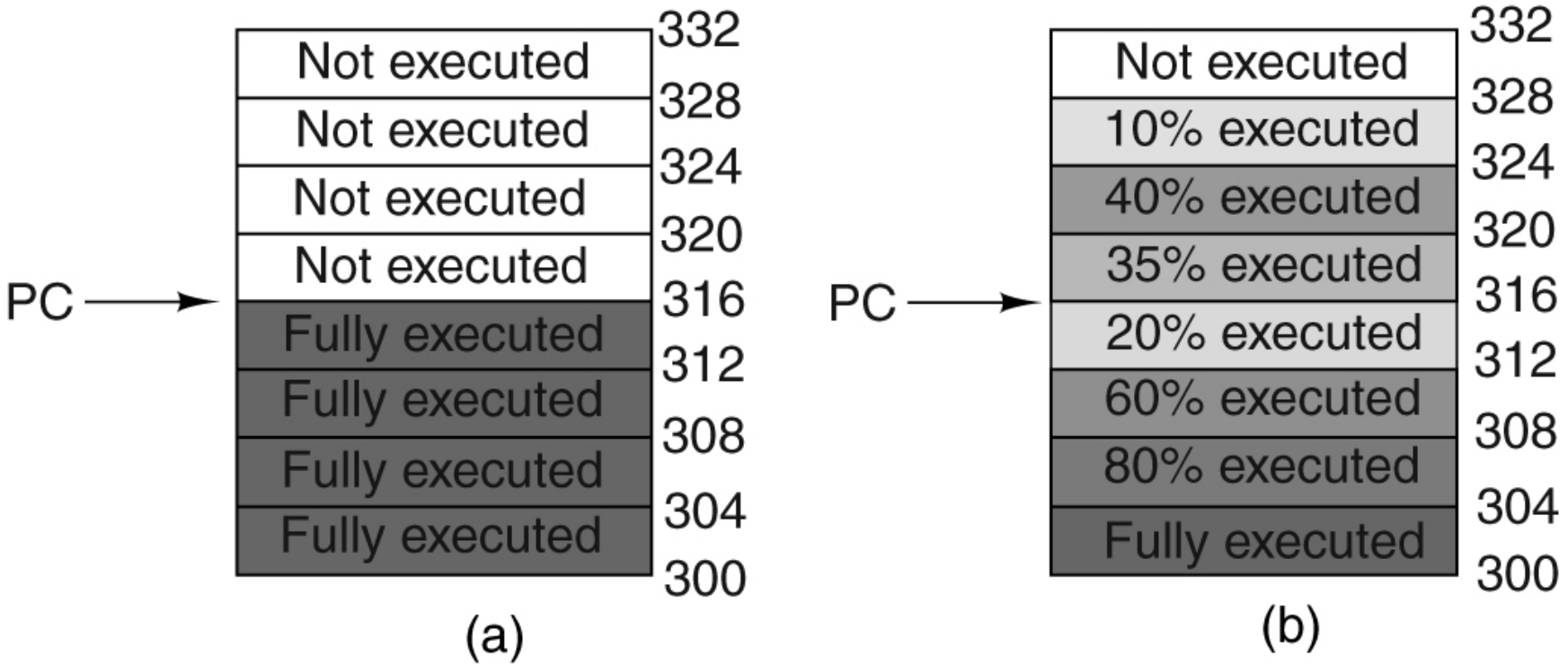


Interrupts

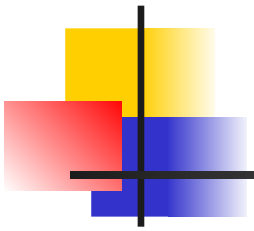
- Interrupts and traps 陷阱
  - Different interrupt source
    - Trap: current running process
  - Different interrupt handler's provider
  - Different act time
  - Different context

Interrupts

- Precise and Imprecise interrupts



a) a precise interrupt; b) an imprecise interrupt



Principles of I/O Software

Goals of I/O Software 1/2

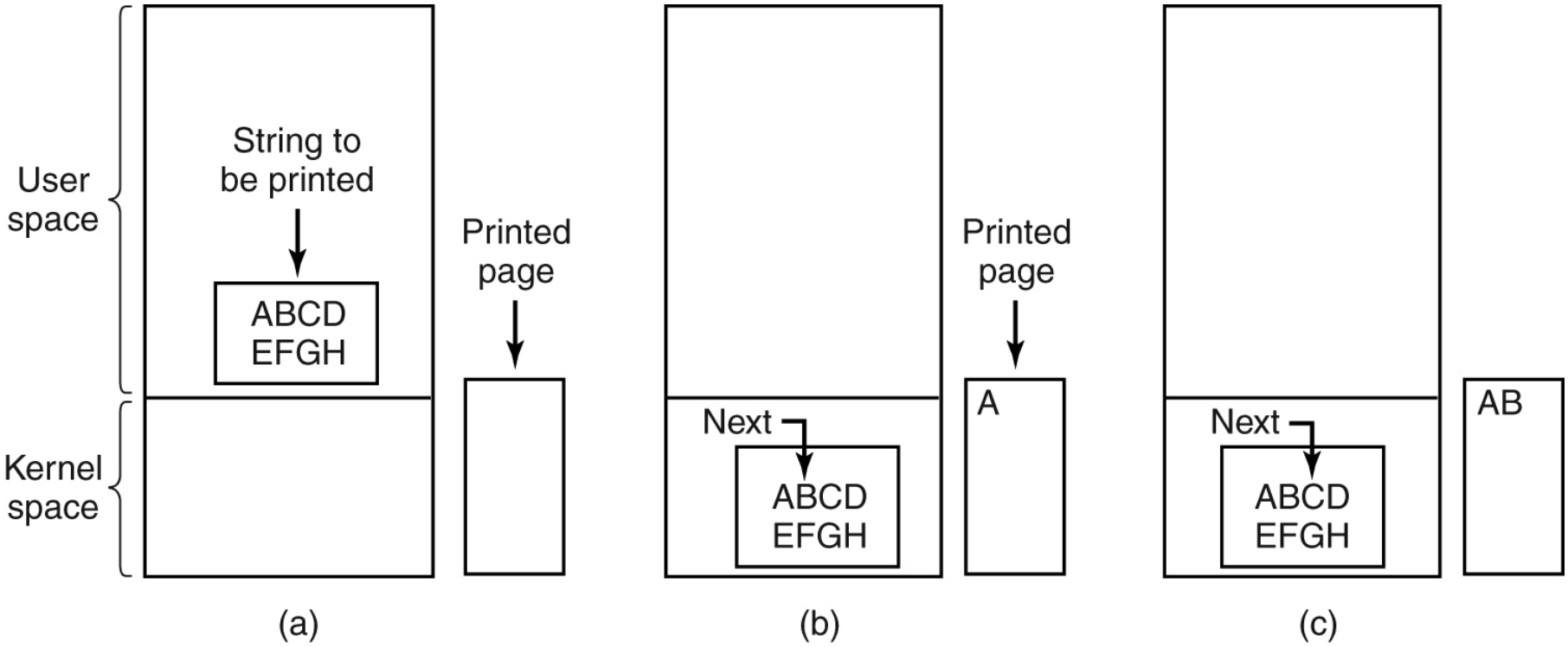
- device independence 设备独立性
  - programs can access any I/O device
  - without specifying device in advance
  - (floppy, hard drive, or CD-ROM)
- uniform naming 统一命名
  - name of a file or device a string or an integer
  - not depending on which machine
- error handling 错误处理
  - handle as close to the hardware as possible

Goals of I/O Software 2/2

- synchronous(同步) V.S. asynchronous(异步)
  - blocked transfers vs. interrupt-driven
- buffering 缓冲
  - data coming off a device cannot be stored in final destination
- Shareable vs. dedicated devices
  - disks are shareable
  - tape drives would not be

Programmed I/O

- Programmed I/O 程序控制 I/O
  - Busy waiting, polling



Steps in printing a string

Programmed I/O

- Busy waiting

```
copy_from_user(buffer, p, count);                    /* p is the kernel buffer */
for (i = 0; i < count; i++) {                        /* loop on every character */
        while (*printer_status_reg != READY) ;       /* loop until ready */
        *printer_data_register = p[i];               /* output one character */
}
return_to_user( );
```

Interrupt-Driven I/O

- 中断驱动式 I/O

```
copy_from_user(buffer, p, count);
enable_interrupts( );
while (*printer_status_reg != READY) ;
*printer_data_register = p[0];
scheduler( );
```

(a)

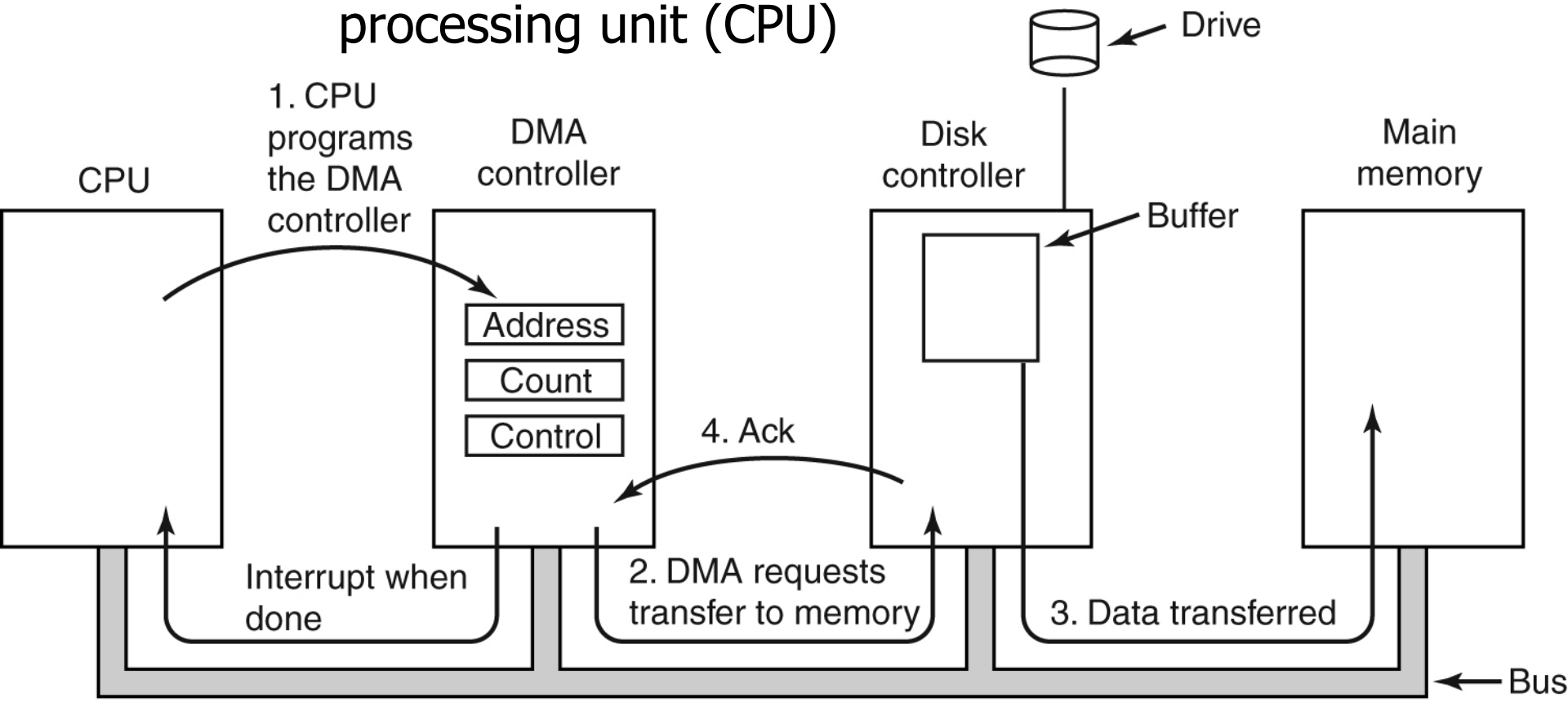
```
if (count == 0) {
    unblock_user( );
} else {
    *printer_data_register = p[i];
    count = count – 1;
     i = i + 1;
}
acknowledge_interrupt( );
return_from_interrupt( );
```

(b)

Writing a string to the printer using interrupt-driven I/O
a)Code executed at the time the print system call is made
b) Interrupt service procedure for the printer

I/O Using DMA

- Direct Memory Access, DMA
  - a feature of computerized systems that allows certain hardware subsystems to access main system memory independently of the central processing unit (CPU)



I/O Using DMA

- 使用 DMA 的 I/O

```
copy_from_user(buffer, p, count);
set_up_DMA_controller( );
scheduler( );
```

(a)

```
acknowledge_interrupt( );
unblock_user( );
return_from_interrupt( );
```

(b)

Printing a string using DMA.
(a) Code executed when the print system call is made.
(b) Interrupt service procedure.

DMA

- Bus modes
  - Word-at-a-time mode
  - Block mode
- DMA modes
  - Burst mode: 突发模式
    - DMA controller requests for the transfer of one word and gets it
    - Cycle stealing mode:block the CPU
  - Fly-by mode: 飞越模式
    - DMA controller tell the device controller to transfer the data directly to main memory

DMA

- Physical memory addresses
- Virtual memory addresses
  - DMA controller must use the MMU to have the virtual-to-physical translation done
- Disk ↔ Disk Controller buffer ↔ mem

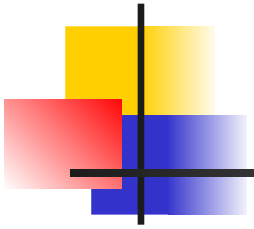
I/O Using Channel

- Channel 通道
- A high-performance input/output (I/O) architecture that is implemented in various forms on a number of computer architectures, especially on mainframe computers
- Channel architecture uses a separate, independent, low-cost processor
- Channel processors are simple, but self-contained, with minimal logic and sufficient on-board scratchpad memory (working storage) to handle I/O tasks
- Each channel may support one or more controllers and/or devices, but each channel program may only be directed at one of those connected devices

Channel I/O

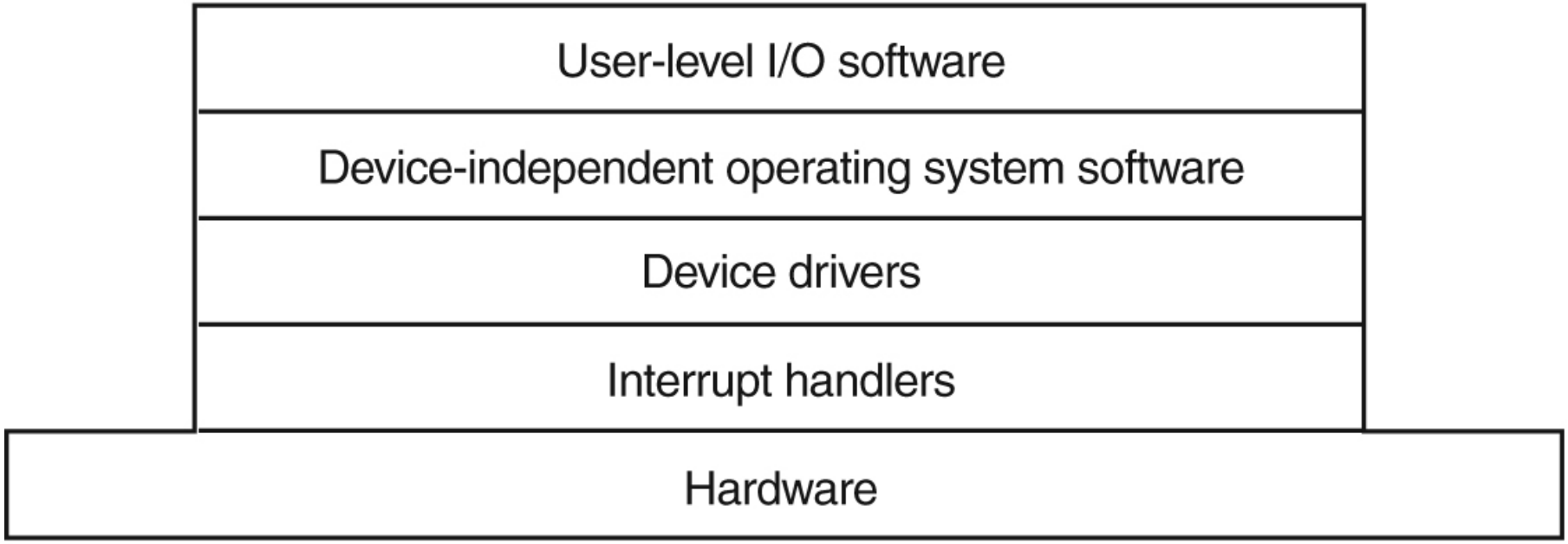
- Channel program
  - a sequence of channel command words (CCWs) which are executed by the I/O channel subsystem.

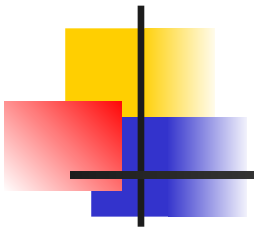
OP	P	R	Bytes	Mem Addr.
WRITE	0	0	80	813
WRITE	0	0	140	1034
WRITE	0	1	60	5830
WRITE	0	1	300	2000
WRITE	0	0	250	1850
WRITE	1	1	250	720



I/O Software Layers

I/O Software Layers





Interrupt Handlers

1.Save registers not already been saved by interrupt hardware.

2.Set up a context for the interrupt service procedure.

3.Set up a stack for the interrupt service procedure.

4.Acknowledge the interrupt controller. If there is no centralized interrupt controller, reenable interrupts.

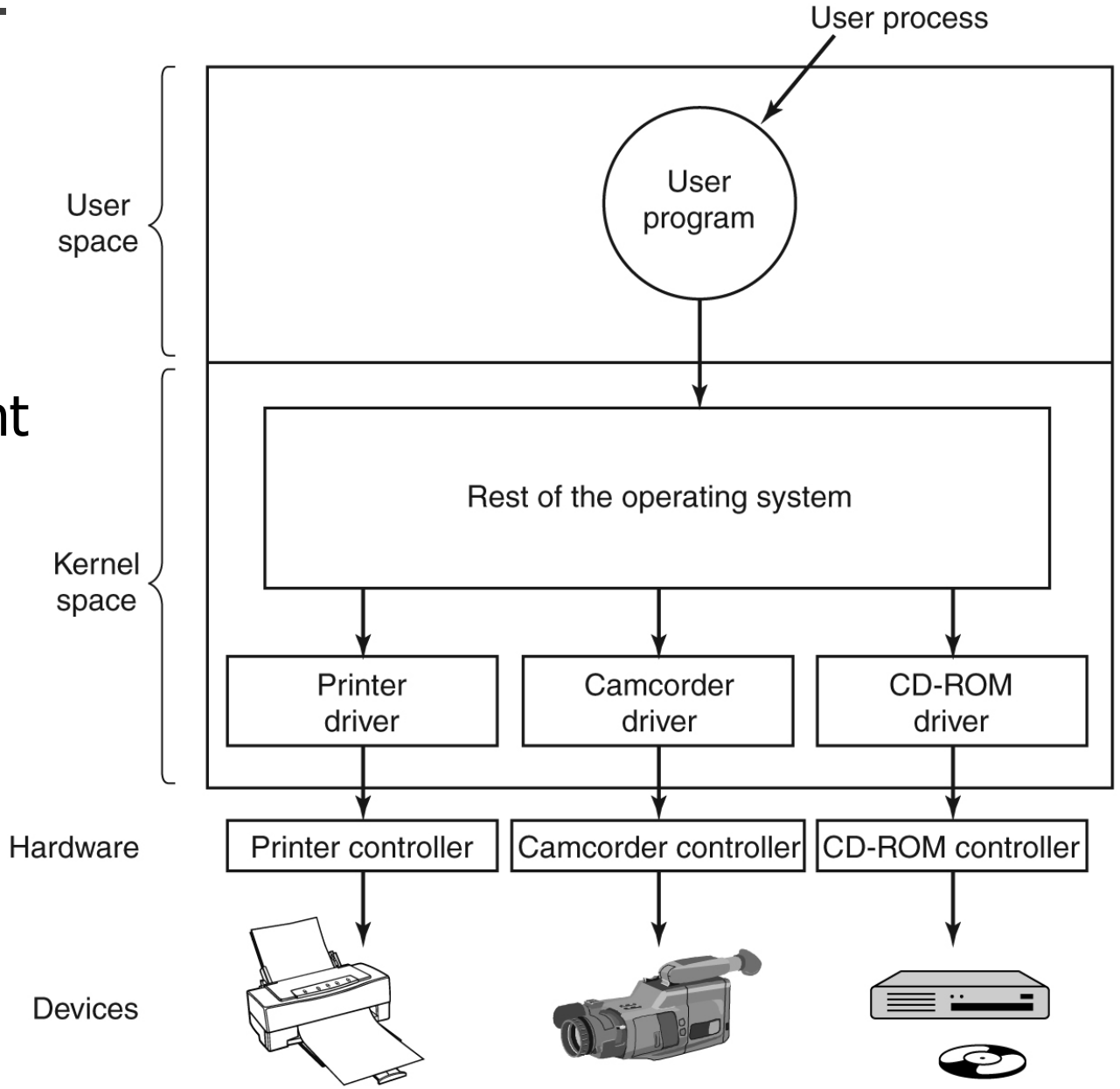
5.Copy the registers from where they were saved to the process table.

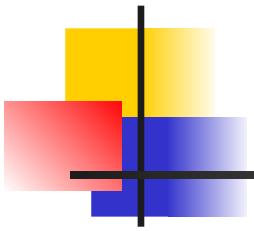
Interrupt Handlers

6. Run the interrupt service procedure.
7. Choose which process to run next.
8. Set up the MMU context for the process to run next.
9. Load the new process' registers, including its PSW.
10. Start running the new process.

Device Drivers

- Reentrant
- Hot plug





Device Drivers

- Device driver
  - Each I/O device attached to a computer needs some device-specific code for controlling it
  - Each device driver normally handles one device type, or at most, one class of closely related devices
  - In order to access the device's hardware, meaning the controller's registers, the device driver normally has to be part of the os kernel

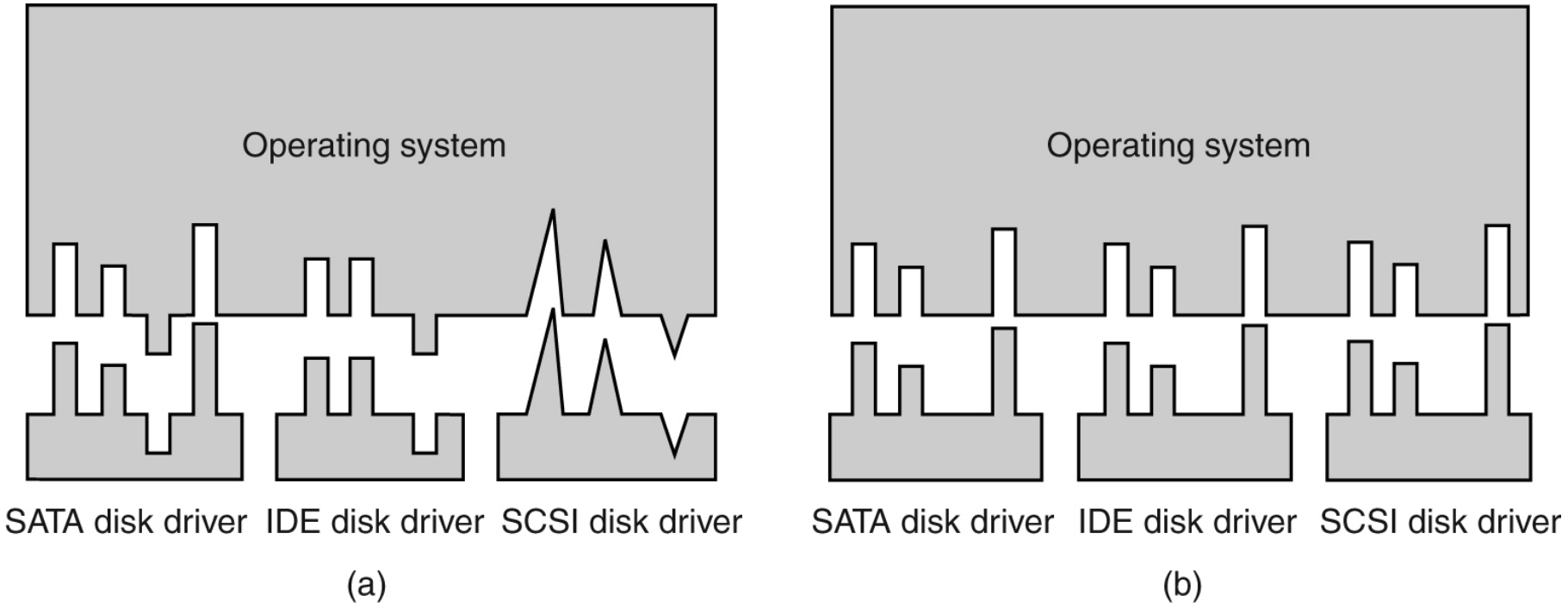
Device-Independent I/O Software

Uniform interfacing for device drivers
Buffering
Error reporting
Allocating and releasing dedicated devices
Providing a device-independent block size

Functions of the device-independent I/O software

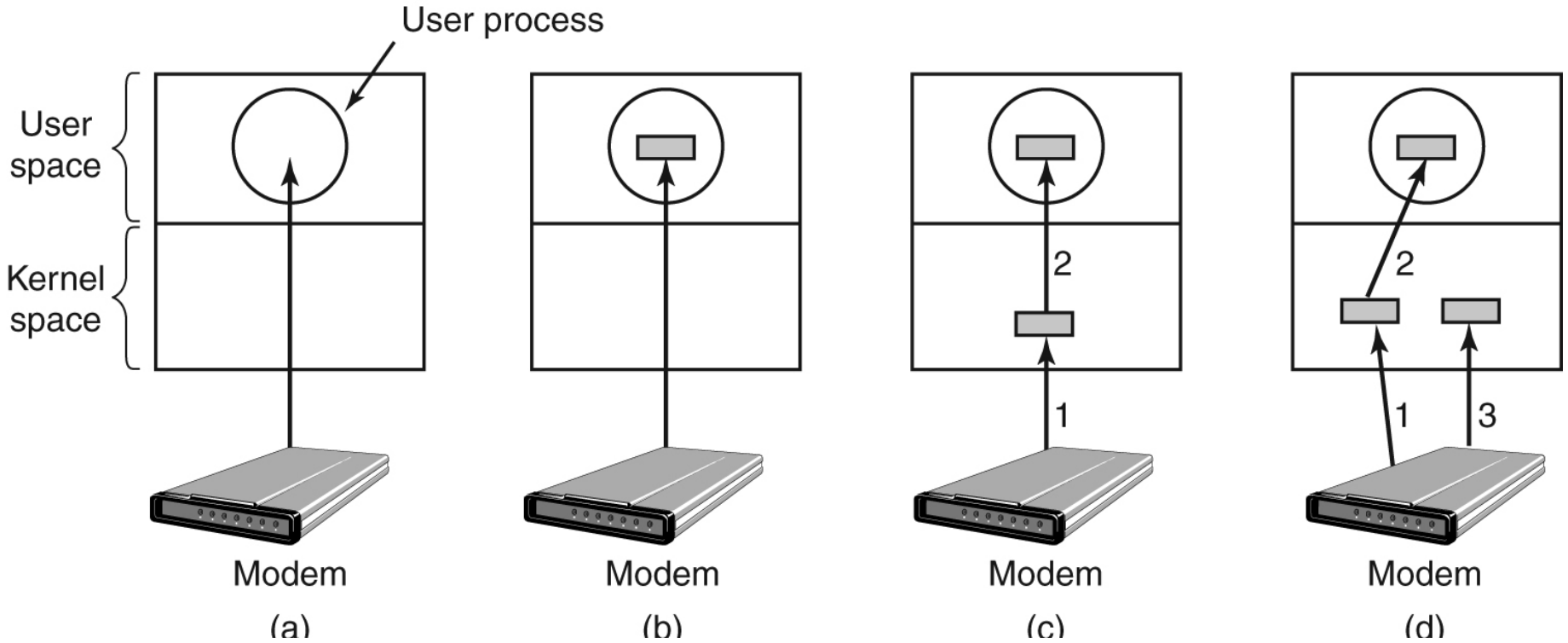
Uniform Interfacing for Device Drivers

- Major device number, minor device number

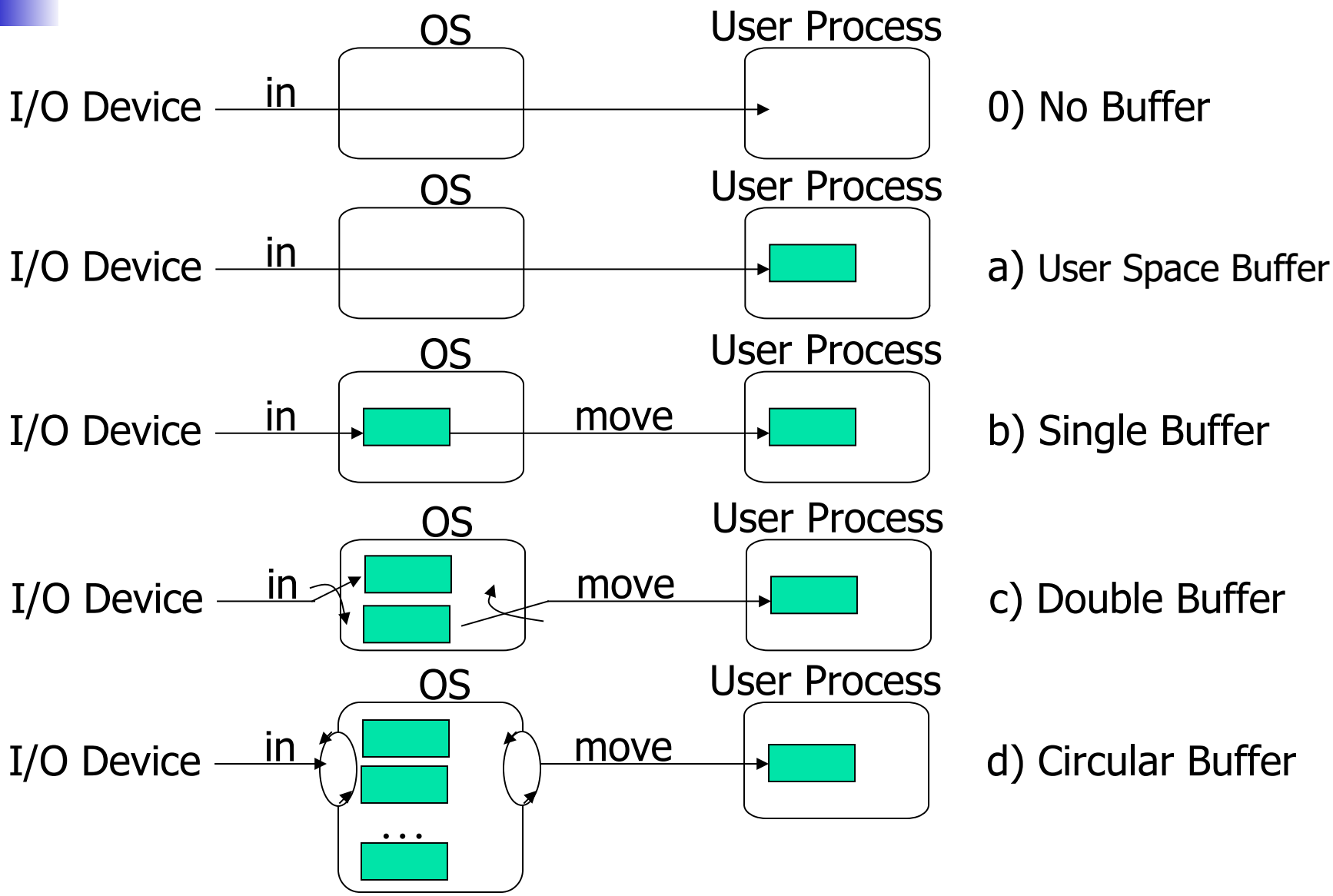


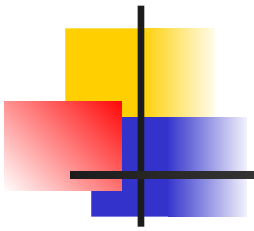
Buffering

- Buffers can increase application **performance**
  - by allowing synchronous operations such as file reads or writes to complete quickly instead of blocking while waiting for hardware interrupts to access a physical disk subsystem



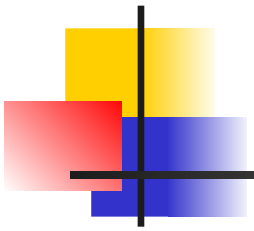
Buffering


OS
User Process
I/O Device
in
0) No Buffer
OS
User Process
I/O Device
in
a) User Space Buffer
OS
User Process
I/O Device
in
move
b) Single Buffer
OS
User Process
I/O Device
in
move
c) Double Buffer
OS
User Process
I/O Device
in
move
d) Circular Buffer



Error Reporting

- Errors are far more common in the context of I/O than in other contexts
- Classes of I/O errors
  - Programming errors
  - Actual I/O errors
- How to handle I/O errors
  - …

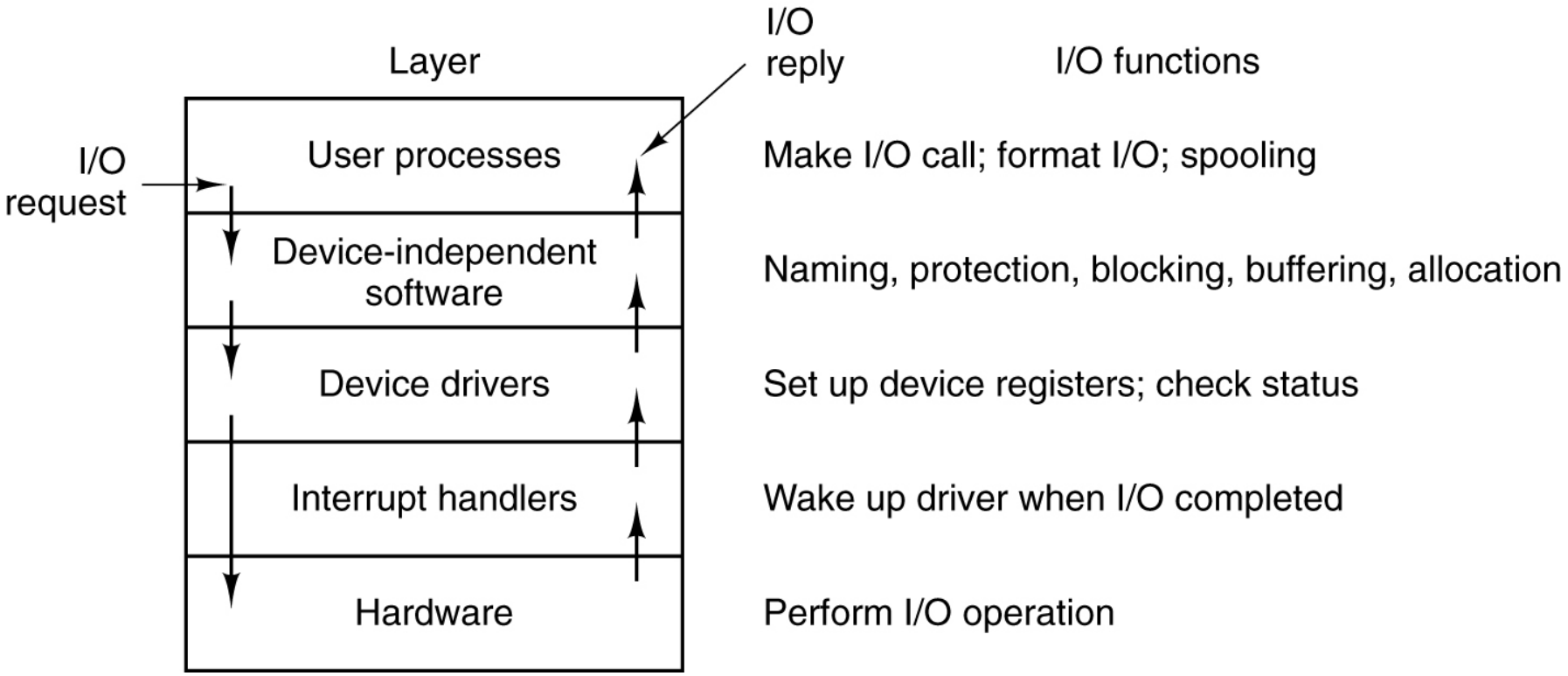


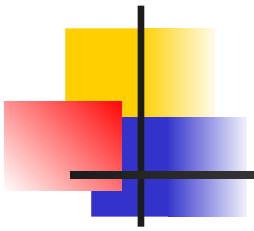
Device-Independent Block Size

- Different disks may have different sector sizes
- The device-independent software hides this fact and provides a uniform block size to higher layers

User-Space I/O Software

- Applications
  - Open, Read,Write, …, Close





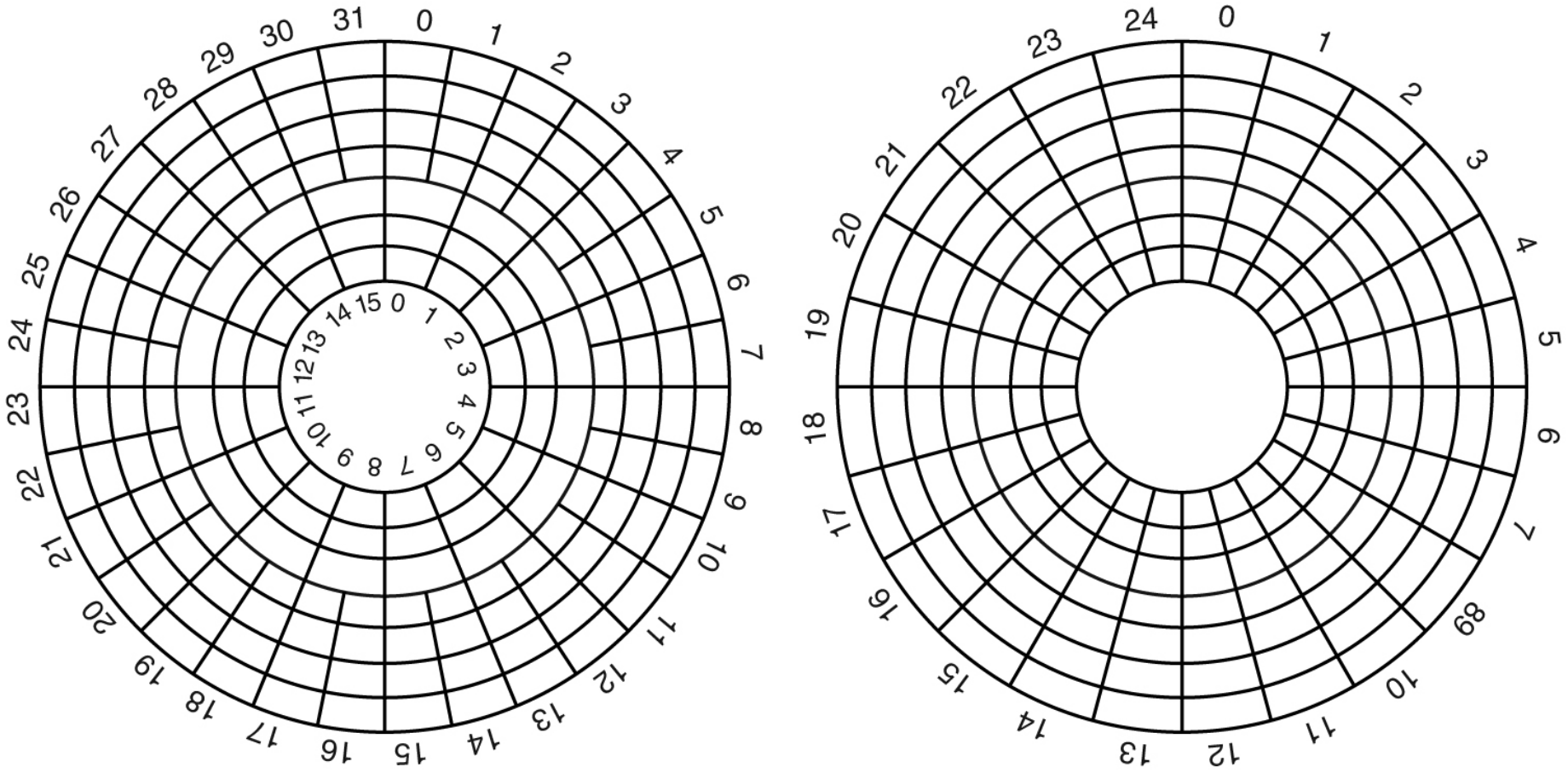
Disks

- Magnetic Disks
  - IDE: Integrated Drive Electronics
  - SATA: Serial ATA
- overlapped seeks
  - A controller can do seeks on two or more drivers at the same time
- Logical block addressing
  - X Cylinders, Y heads, Z sectors
  - (x, y, z)
  - IBM PC: (65536, 16, 63)

Disks

Parameter	IBM 360-KB floppy disk	WD 18300 hard disk
Number of cylinders	40	10601
Tracks per cylinder	2	12
Sectors per track	9	281 (avg)
Sectors per disk	720	35742000
Bytes per sector	512	512
Disk capacity	360 KB	18.3 GB
Seek time (adjacent cylinders)	6 msec	0.8 msec
Seek time (average case)	77 msec	6.9 msec
Rotation time	200 msec	8.33 msec
Motor stop/start time	250 msec	20 sec
Time to transfer 1 sector	22 msec	17 μsec

Disks



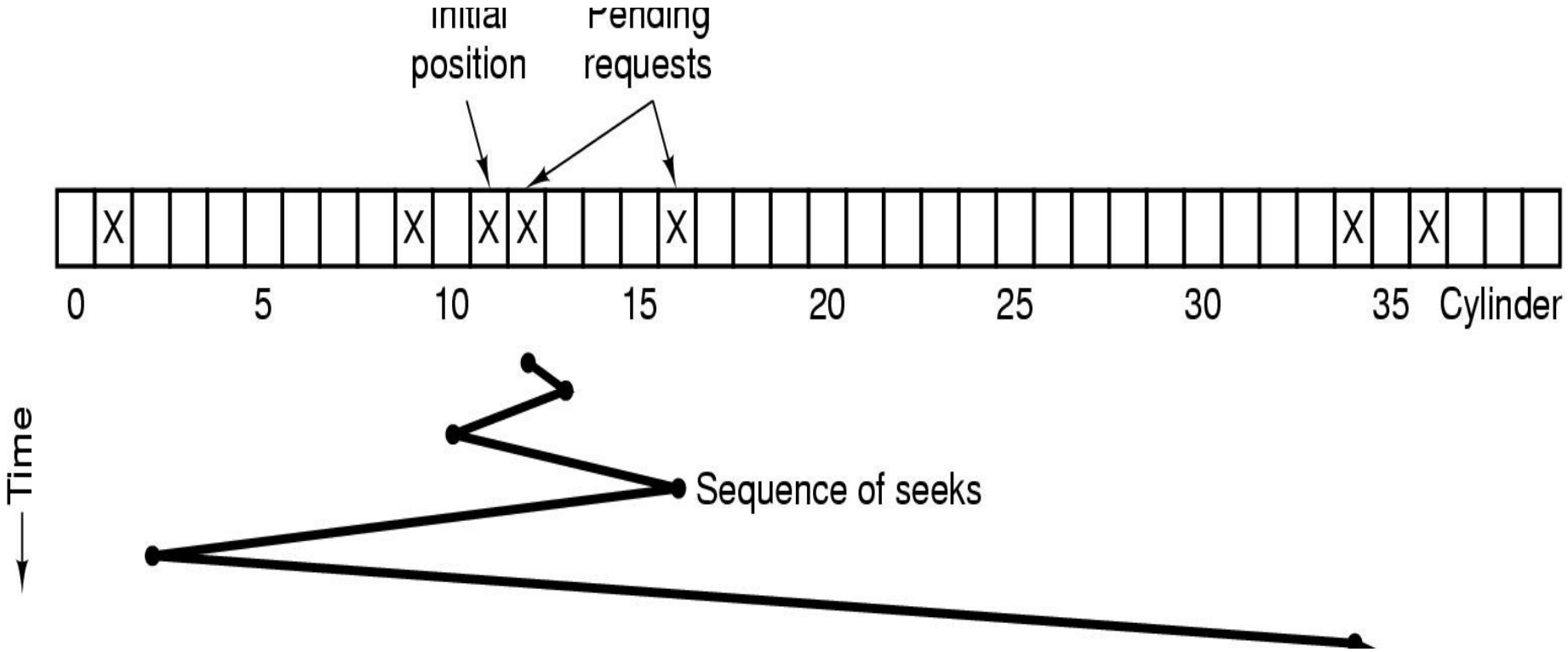
a) Physical geometry of a disk with two zones
b)A possible virtual geometry for this disk

Disk Arm Scheduling Algorithms

- Time required to read or write a disk block determined by 3 factors
  - Seek time
  - Rotational delay
  - Actual transfer time
- **Seek time dominates**
- Error checking is done by controllers
- Scheduling Algorithms
  - FCFS、 SSF、 Elevator
  - Example:11,1,36,16,34,9,12
    - Moved 111 cylinders

SSF disk scheduling algorithm

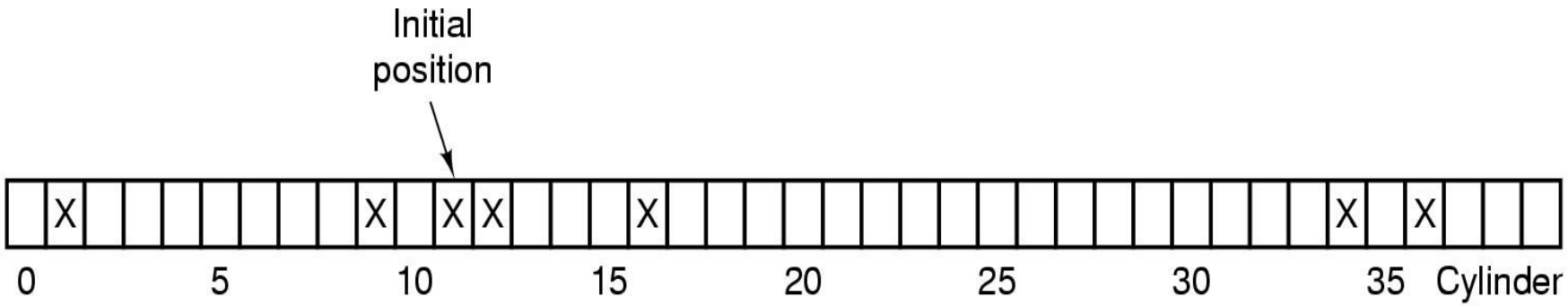
- Shortest Seek First (SSF) disk scheduling algorithm

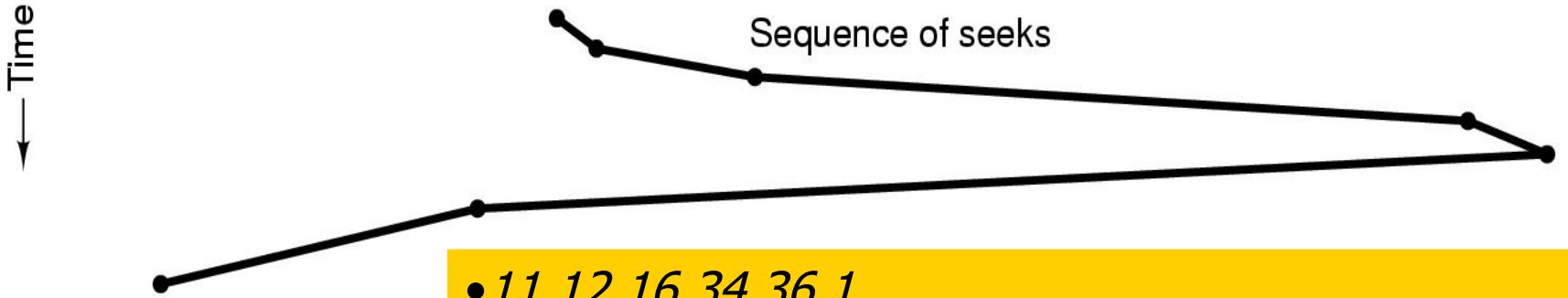


- *11,12,9,16,1,34,36*
- *61 Cylinders*

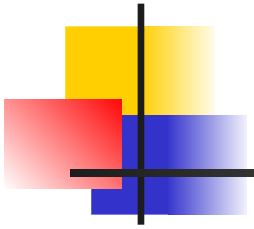
Elevator disk scheduling algorithm

- Elevator(电梯) disk scheduling algorithm
  - SCAN algorithm(扫瞄)





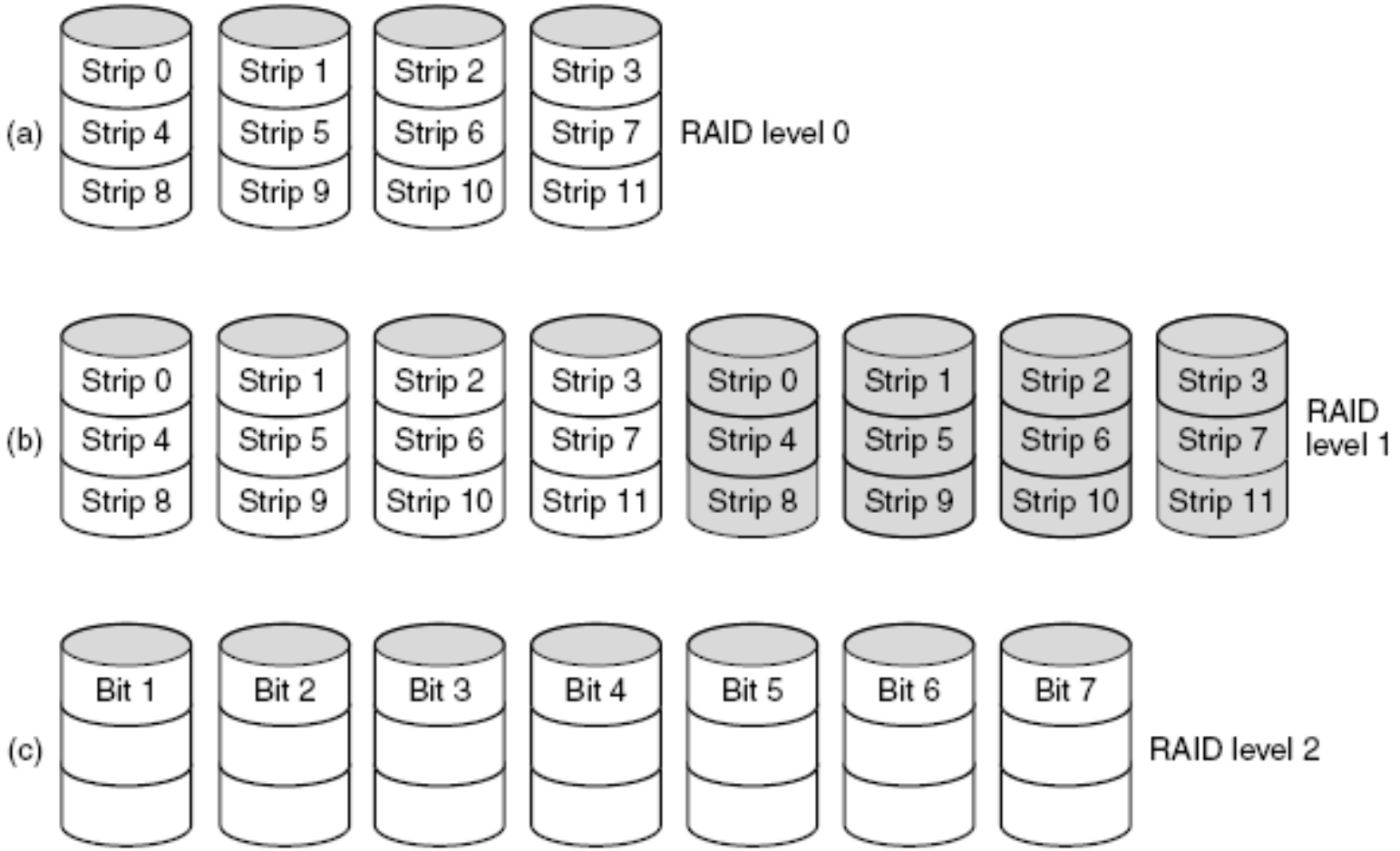
- *11,12,16,34,36,1*
- *60 Cylinders*



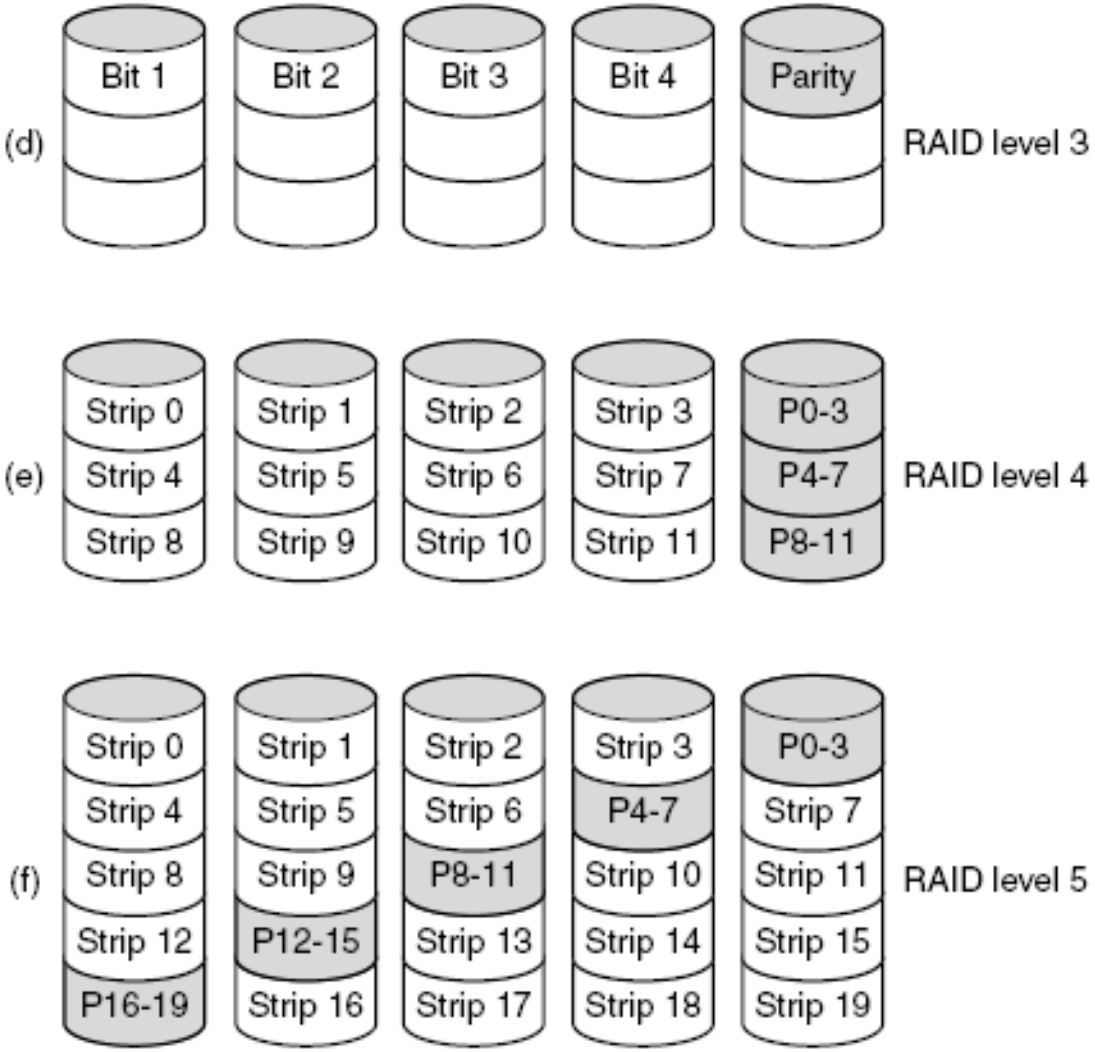
RAID

- RAID
  - Redundant Array of Inexpensive Disks
  - Redundant Array of **Independent** Disks
- Goals of RAID
  - Improve disk performance
  - Improve disk storage safe

RAID


(a)
Strip 0
Strip 4
Strip 8
Strip 1
Strip 5
Strip 9
Strip 2
Strip 6
Strip 10
Strip 3
Strip 7
Strip 11
RAID level 0
(b)
Strip 0
Strip 4
Strip 8
Strip 1
Strip 5
Strip 9
Strip 2
Strip 6
Strip 10
Strip 3
Strip 7
Strip 11
Strip 0
Strip 4
Strip 8
Strip 1
Strip 5
Strip 9
Strip 2
Strip 6
Strip 10
Strip 3
Strip 7
Strip 11
RAID level 1
(c)
Bit 1
Bit 2
Bit 3
Bit 4
Bit 5
Bit 6
Bit 7
RAID level 2

RAID



Strip: 条带

RAID

- ? Which one is better?

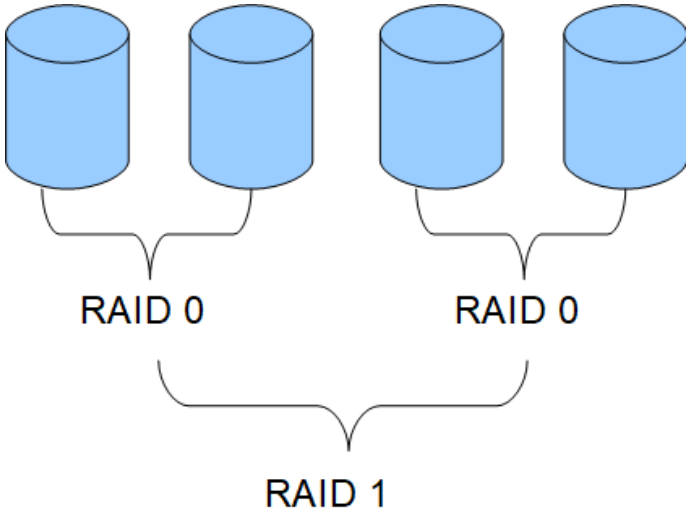


Fig. RAID 0+1

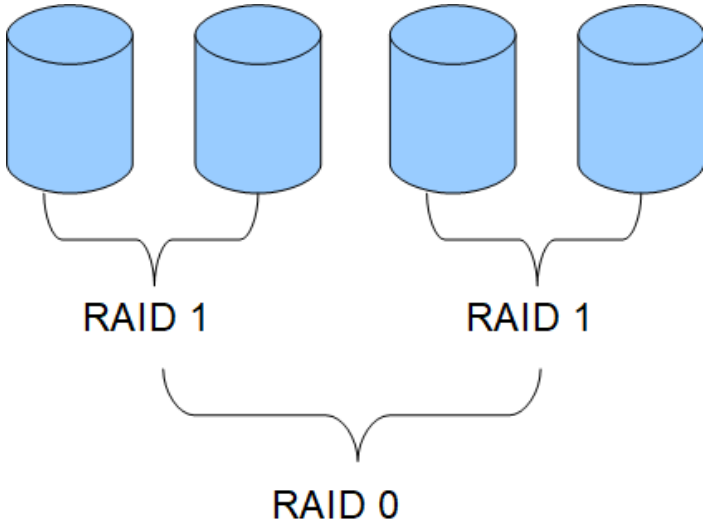
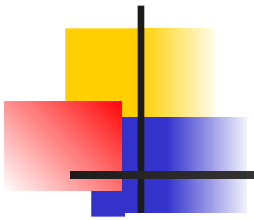


Fig. RAID 1+0

Others Storage Devices

- CD-ROM:
  - Compact Disc – Read Only Memory
- CD-Recordables
- CD-Rewritables
- DVD
  - Digital Video Disk
- …

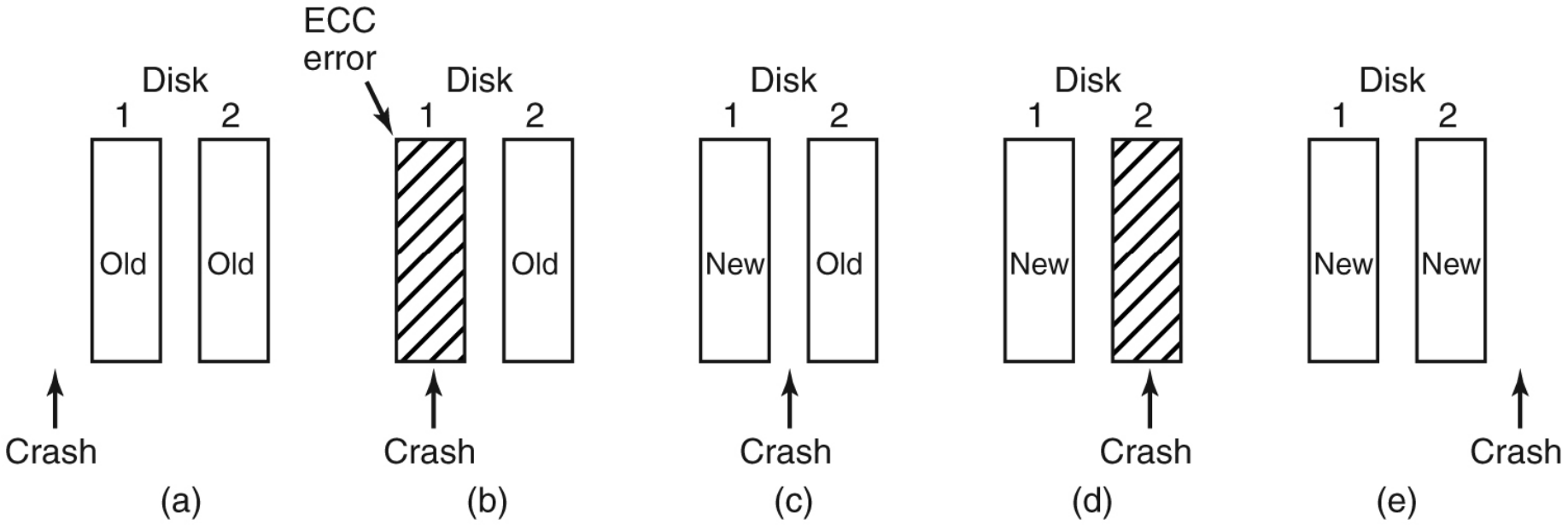


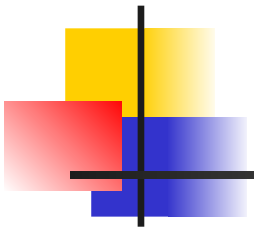
Stable Storage

- Stable Storage
  - Different from RAID
  - Logical Error: keep the disk consistent
    - crashes during writes corrupting the original data without replacing them by newer data
- ECC
  - Error-correcting code
  - 16 bytes: ecc(512 bytes)
- Stable Storage
  - Stable Writes
  - Stable Reads
  - ...

Stable Storage

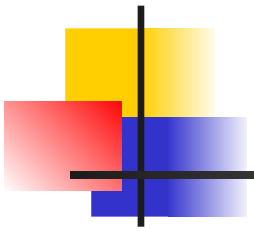
- Stable Storage
  - Crash Recovery
    - CPU crash :five cases





Summary

- Principles of I/O Hardware
- Principles of I/O Software
- I/O Software Layers
- Disks



Any Questions?