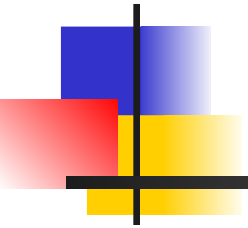
Operating System Principles

操作系统原理



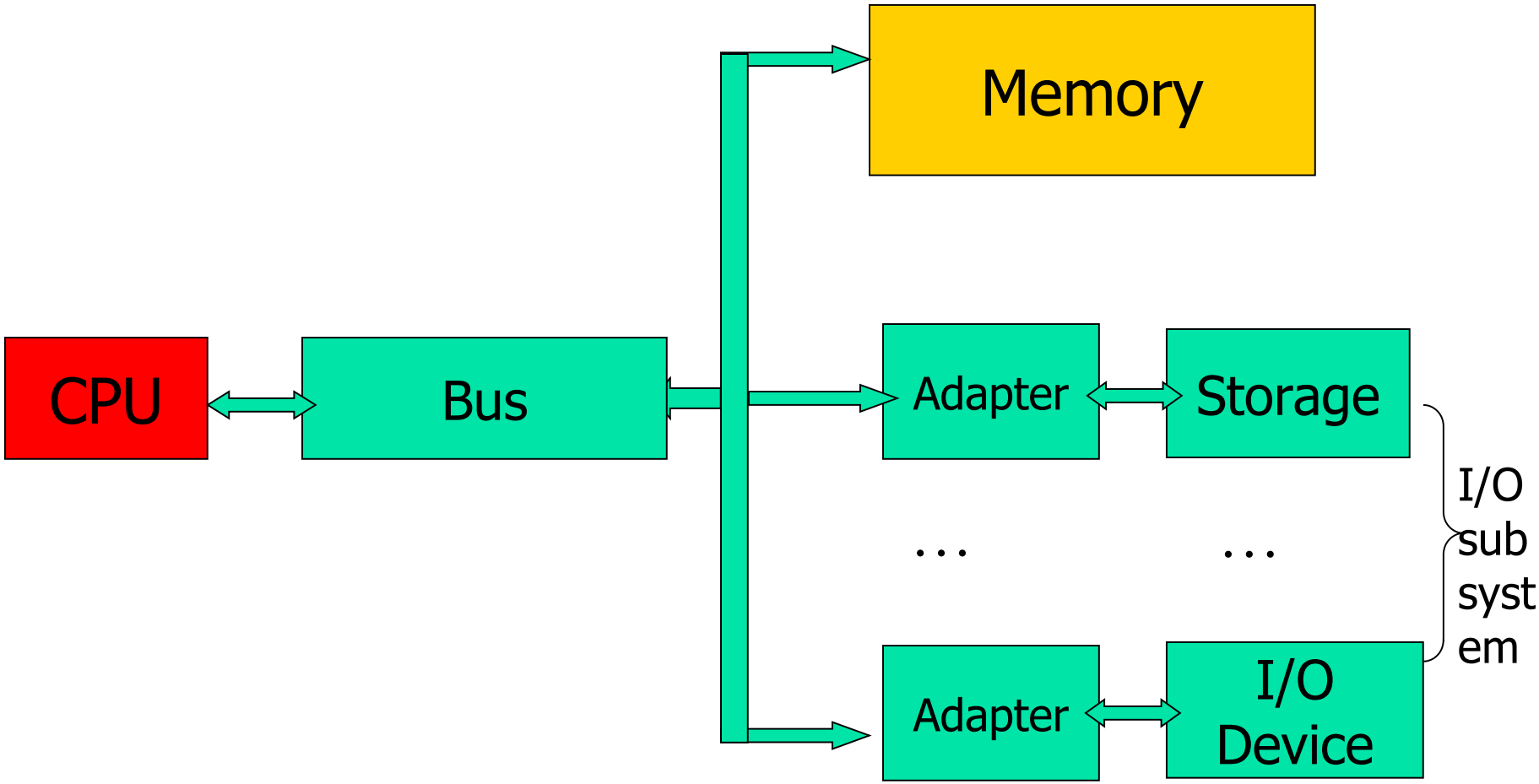
Input/Output

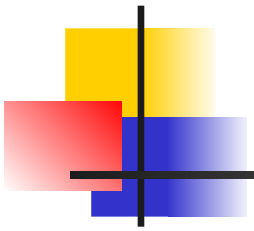
李旭东

leexudong@nankai.edu.cn

Nankai University

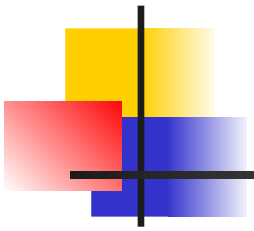
Computer System:Hardware





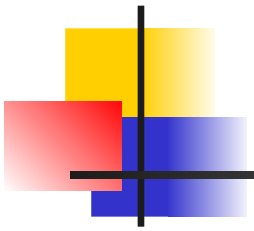
I/O System Target

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

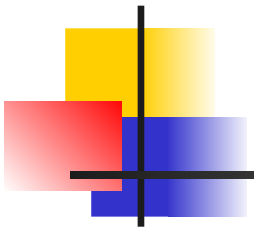


Objectives

- Principles of I/O Hardware
- Principles of I/O Software
- I/O Software Layers
- Disks
- Clocks
- User Interfaces
- Power Management

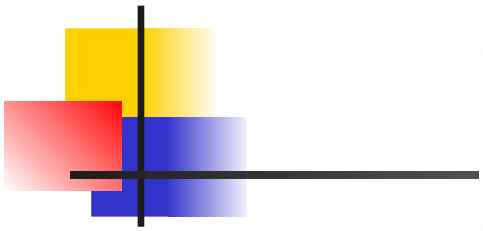


Principles of I/O Hardware



I/O Devices

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



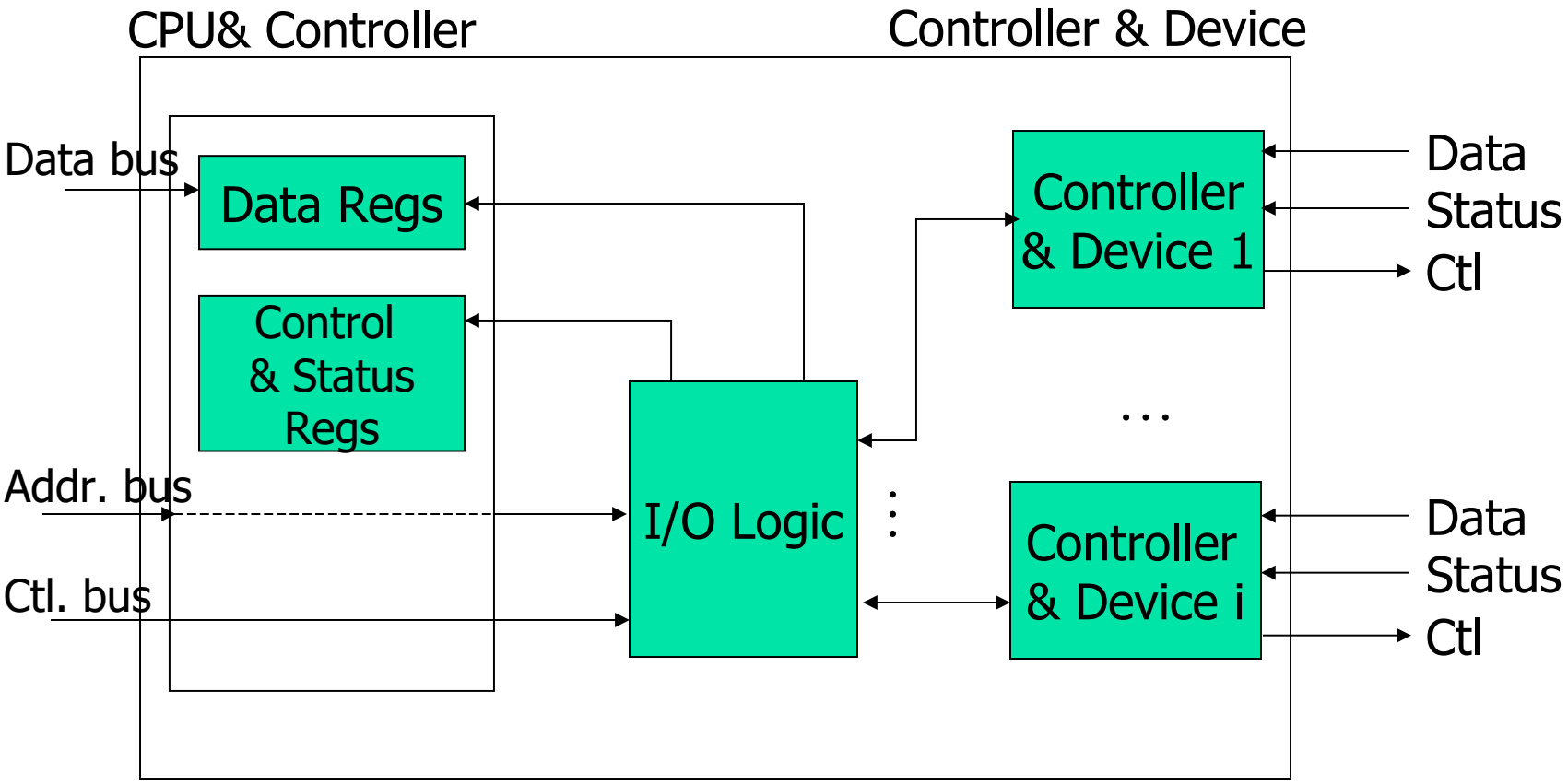
- USB2.0
  - 480Mbit/s
- USB3.0
  - 5Gbit/s
- WLAN
  - 1Gbit/s

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

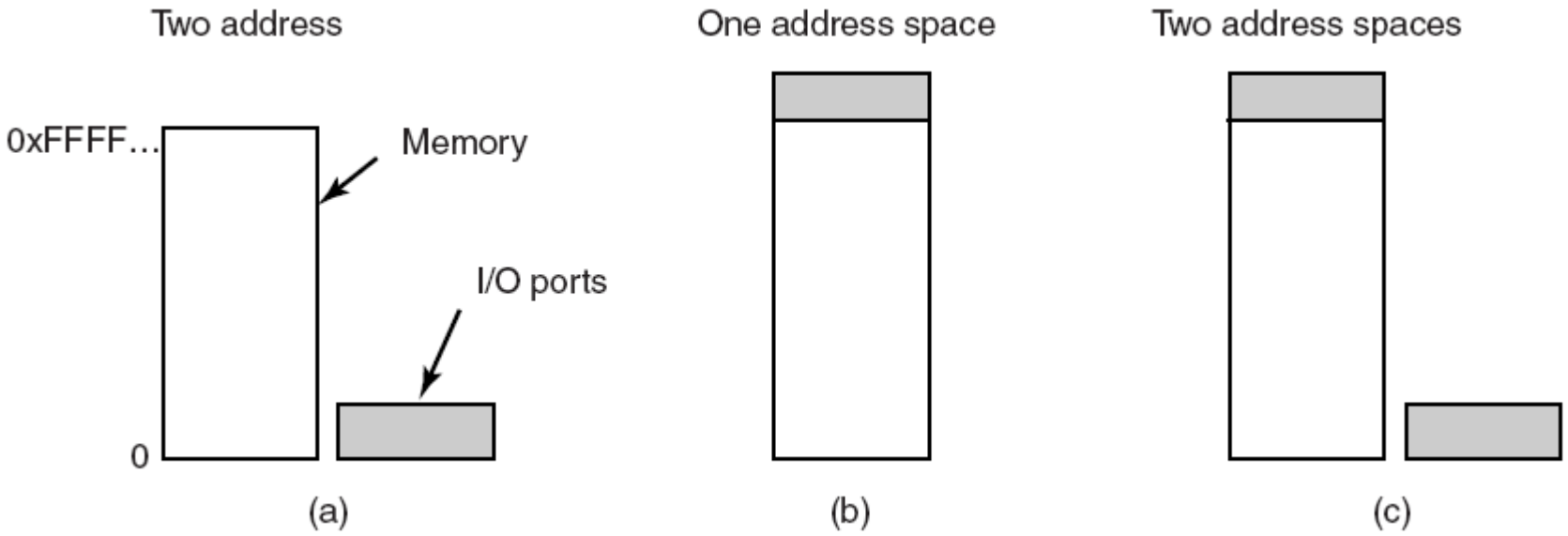


Device Controller Components

Memory-Mapped I/O

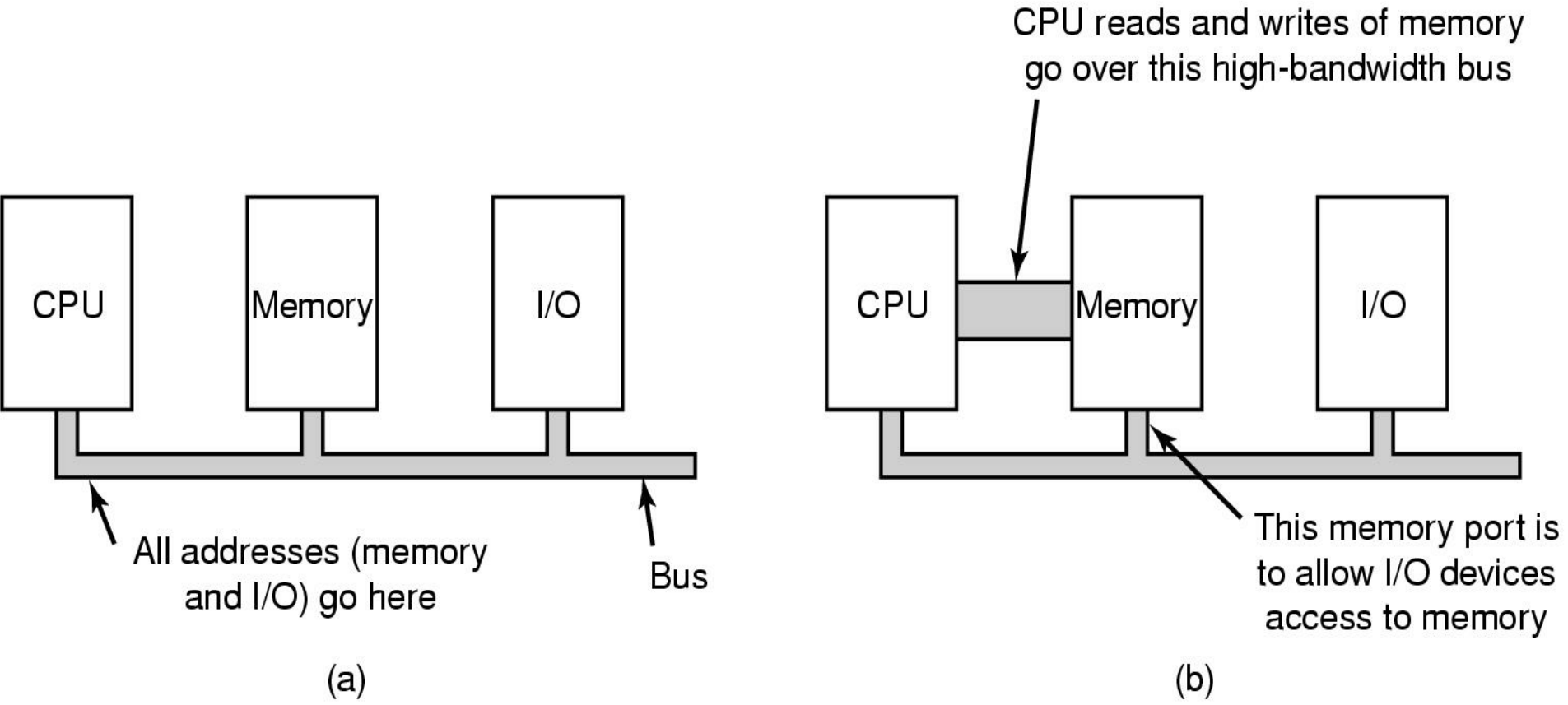
- Device controller
  - Control registers
  - A data buffer
- I/O port
- I/O port space: set of I/O ports
- Special I/O instruction
  - IN REG, PORT
  - OUT PORT, REG
- Memory-Mapped I/O
  - MOV R0, 4

Memory-Mapped I/O



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

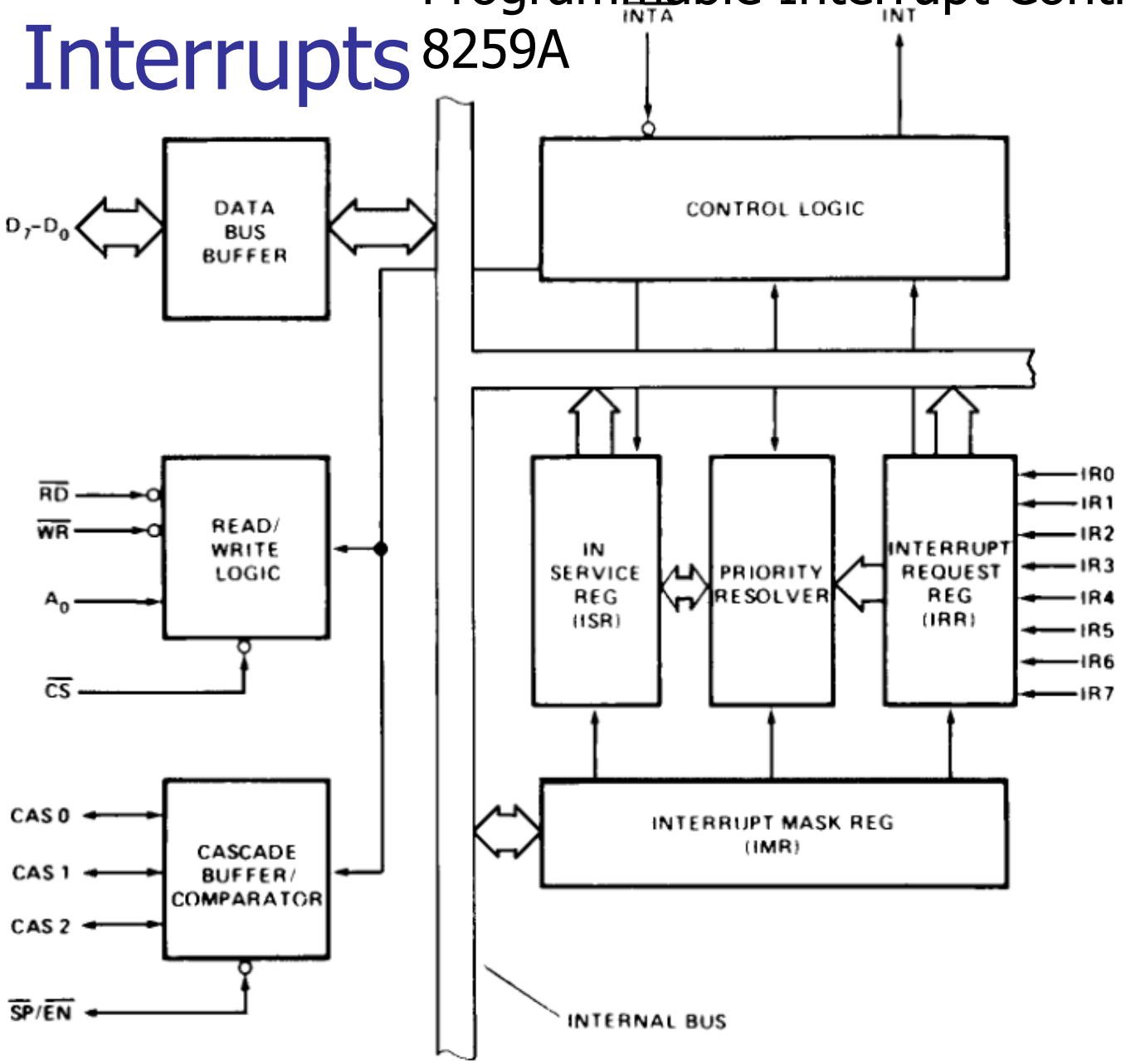
Memory-Mapped I/O



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

Interrupts

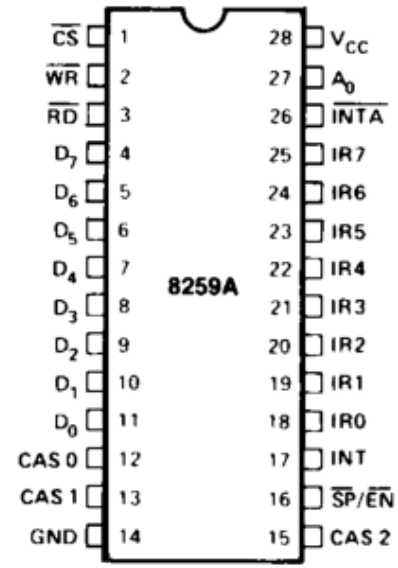
Programmable Interrupt Controller 8259A



231468–1

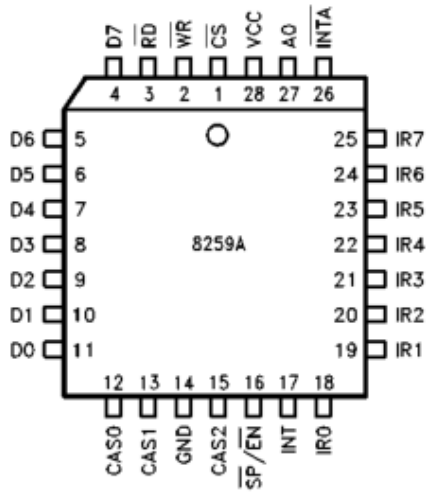
Figure 1. Block Diagram

DIP



231468–2

PLCC

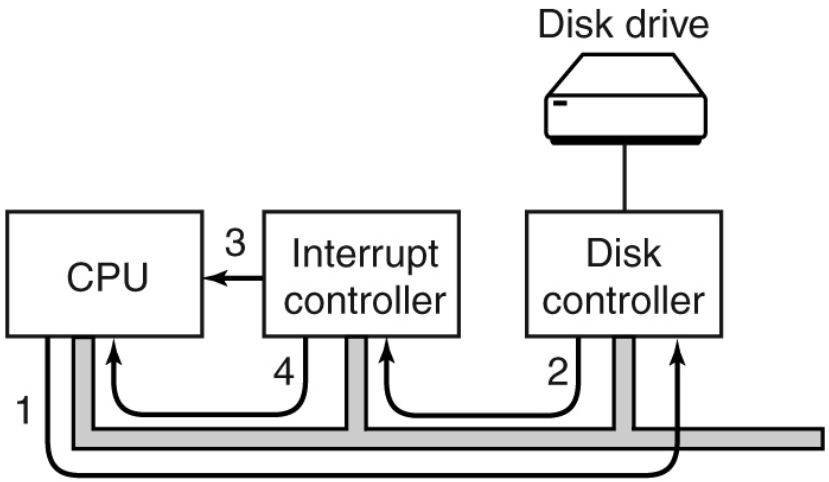


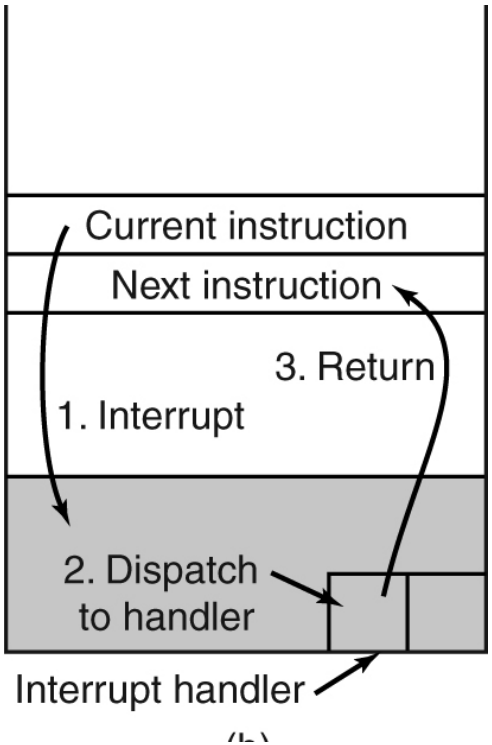
231468–31

Figure 2. Pin Configurations

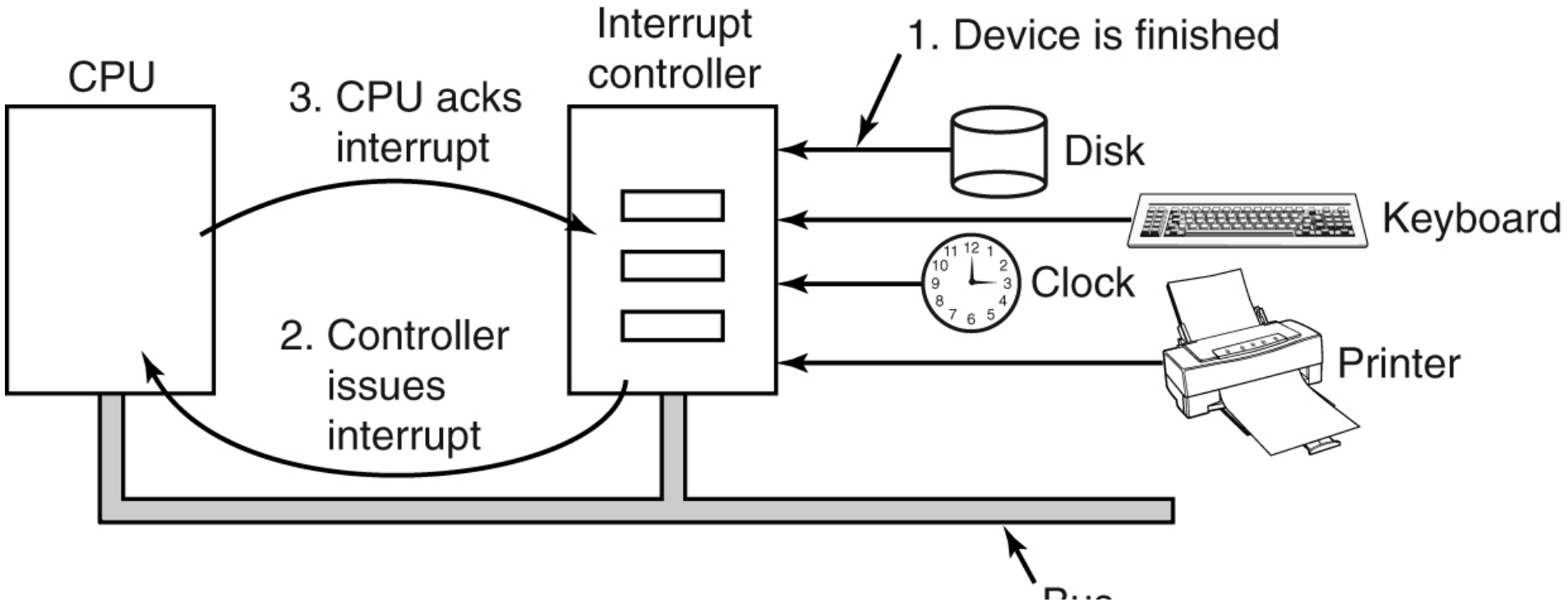
Interrupts

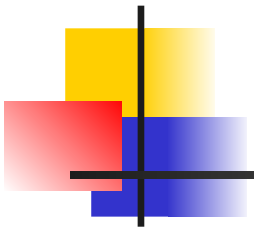
- Interrupt vector
  - 中断向量





Interrupts


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

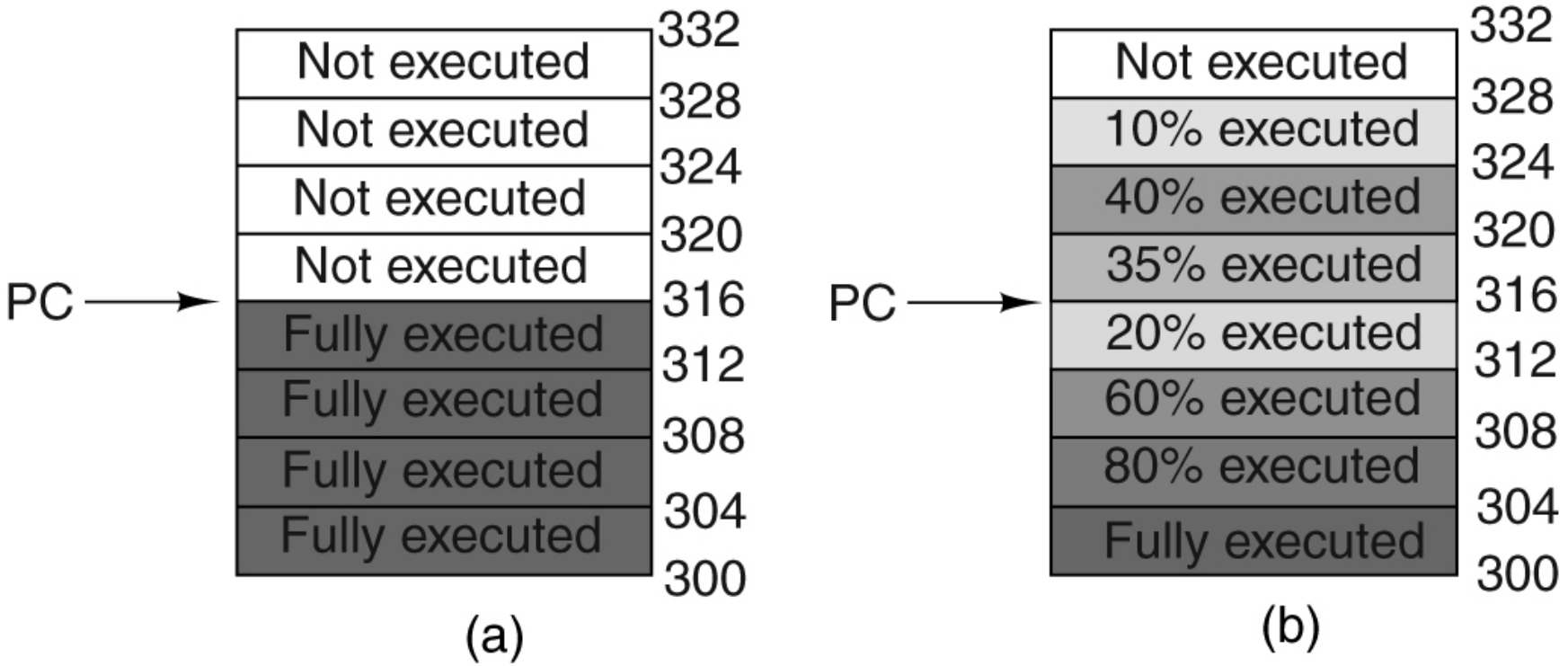


Interrupts

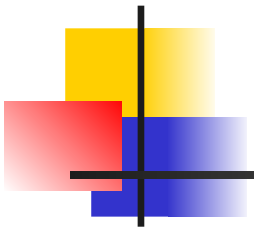
- Interrupts and traps 陷阱
  - Different interrupt source
    - Trap: current running process
  - Different interrupt handler's provider
  - Different act time
  - Different context

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

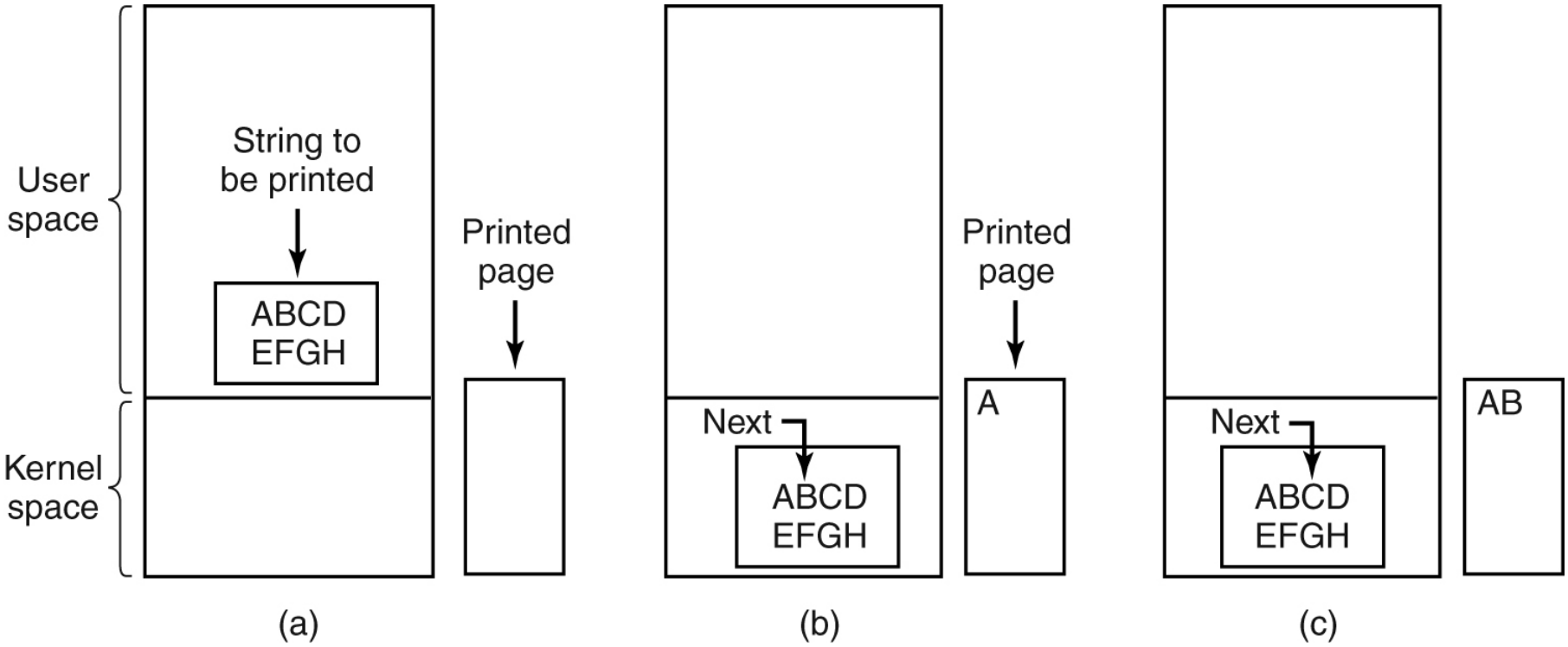
- device independence 设备独立性
  - programs can access any I/O device
  - without specifying device in advance
  - (floppy, hard drive, or CD-ROM)
- uniform naming 统一命名
  - name of a file or device a string or an integer
  - not depending on which machine
- error handling 错误处理
  - handle as close to the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

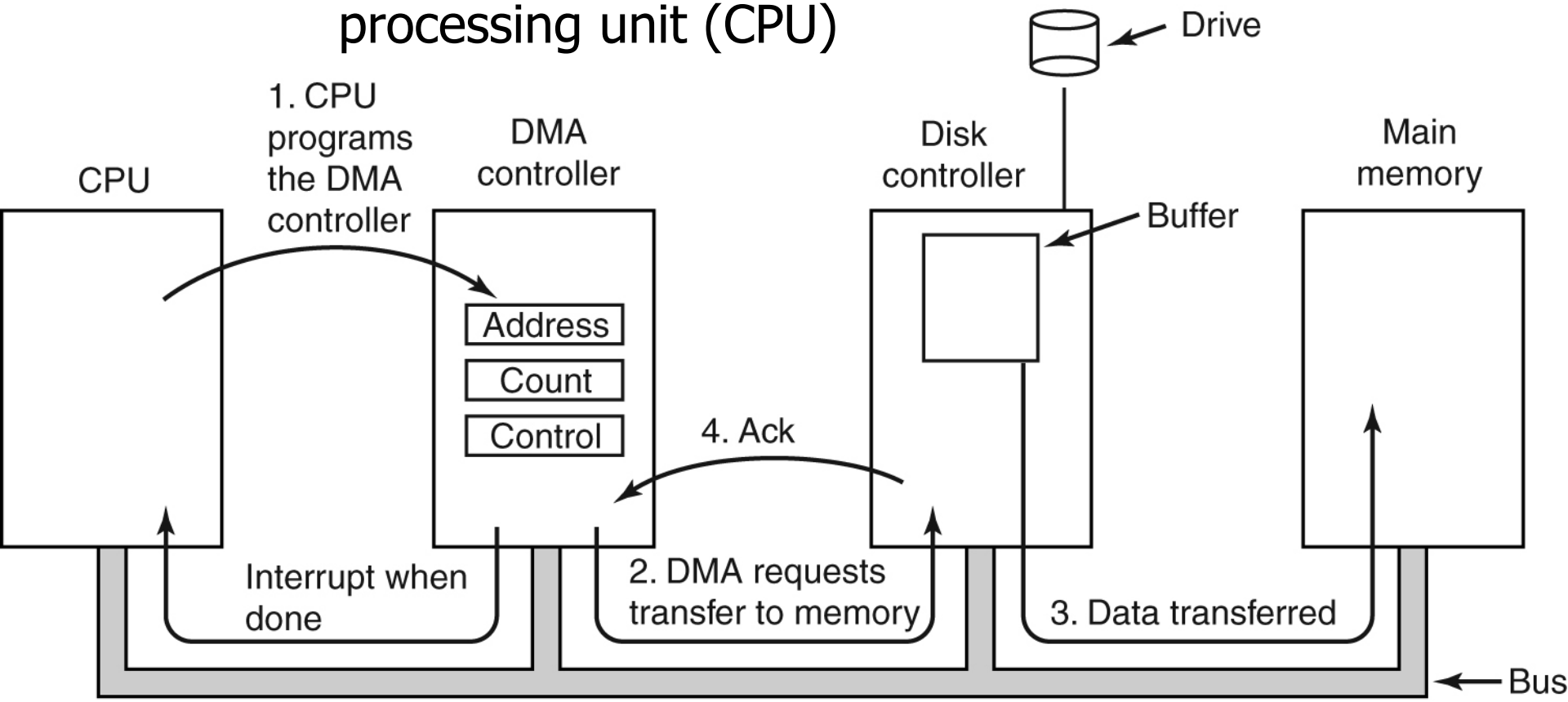
```
if (count == 0) {
    unblock_user( );
} else {
    *printer_data_register = p[i];
    count = count – 1;
     i = i + 1;
}
acknowledge_interrupt( );
return_from_interrupt( );
```

(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

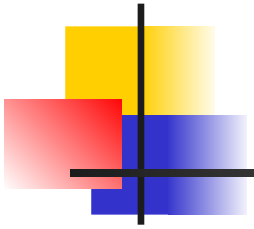
I/O Using Channel

- 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

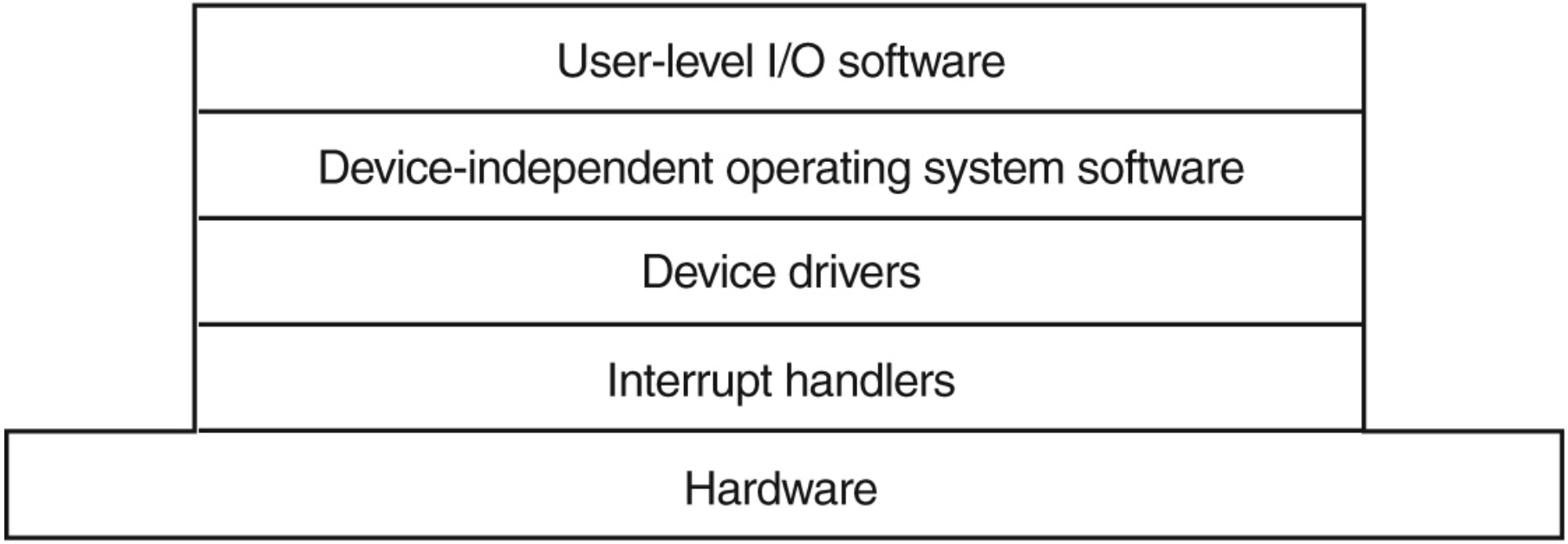
- Channel program
  - a sequence of channel command words (CCWs) which are executed by the I/O channel subsystem.

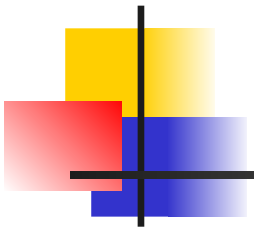
OP	P	R	Bytes	Mem Addr.
WRITE	0	0	80	813
WRITE	0	0	140	1034
WRITE	0	1	60	5830
WRITE	0	1	300	2000
WRITE	0	0	250	1850
WRITE	1	1	250	720



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.

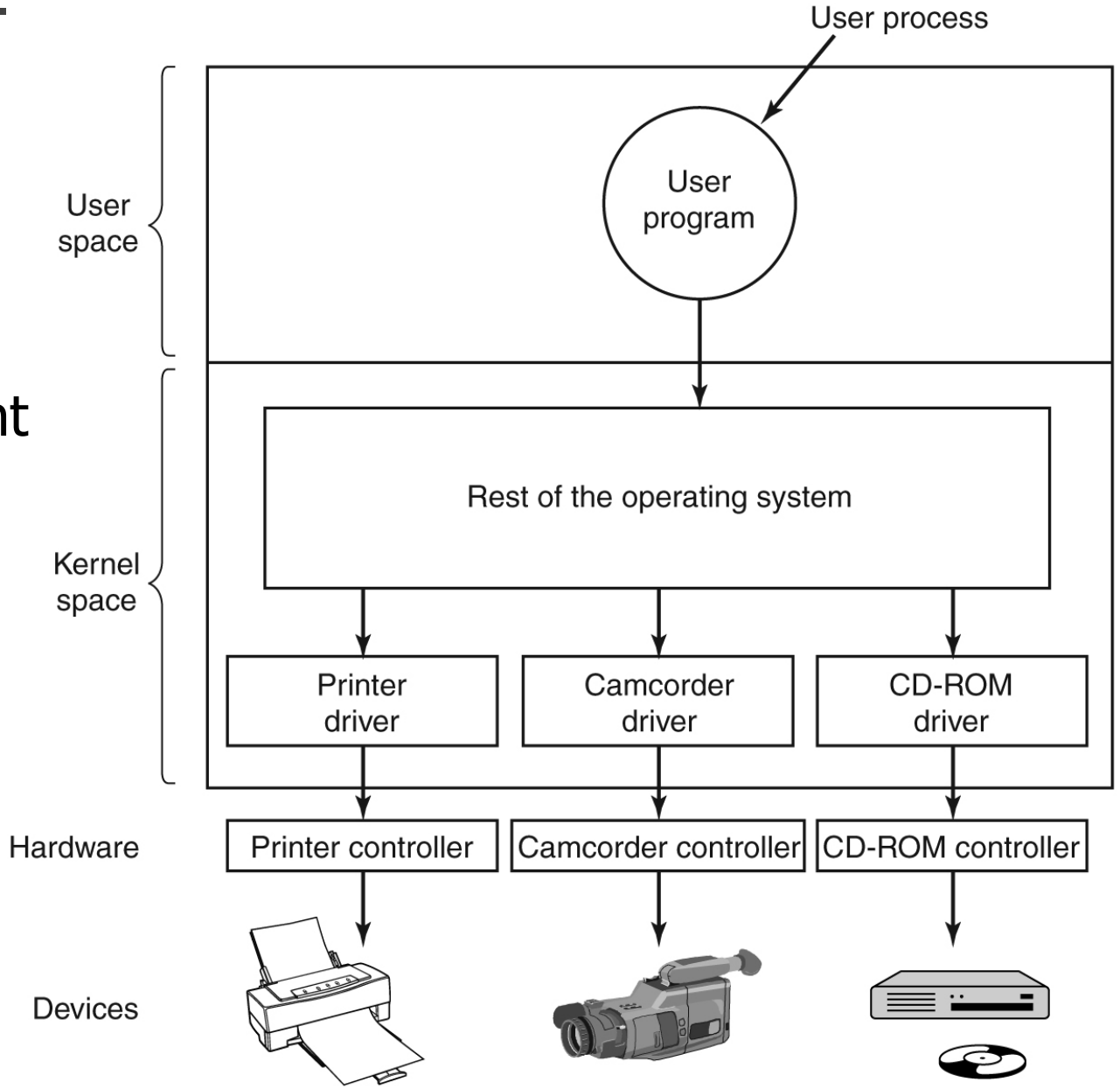
5.Copy the registers from where they were saved to the process table.

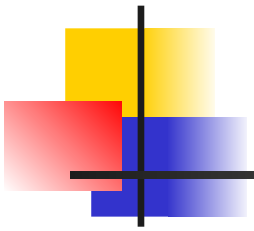
Interrupt Handlers

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

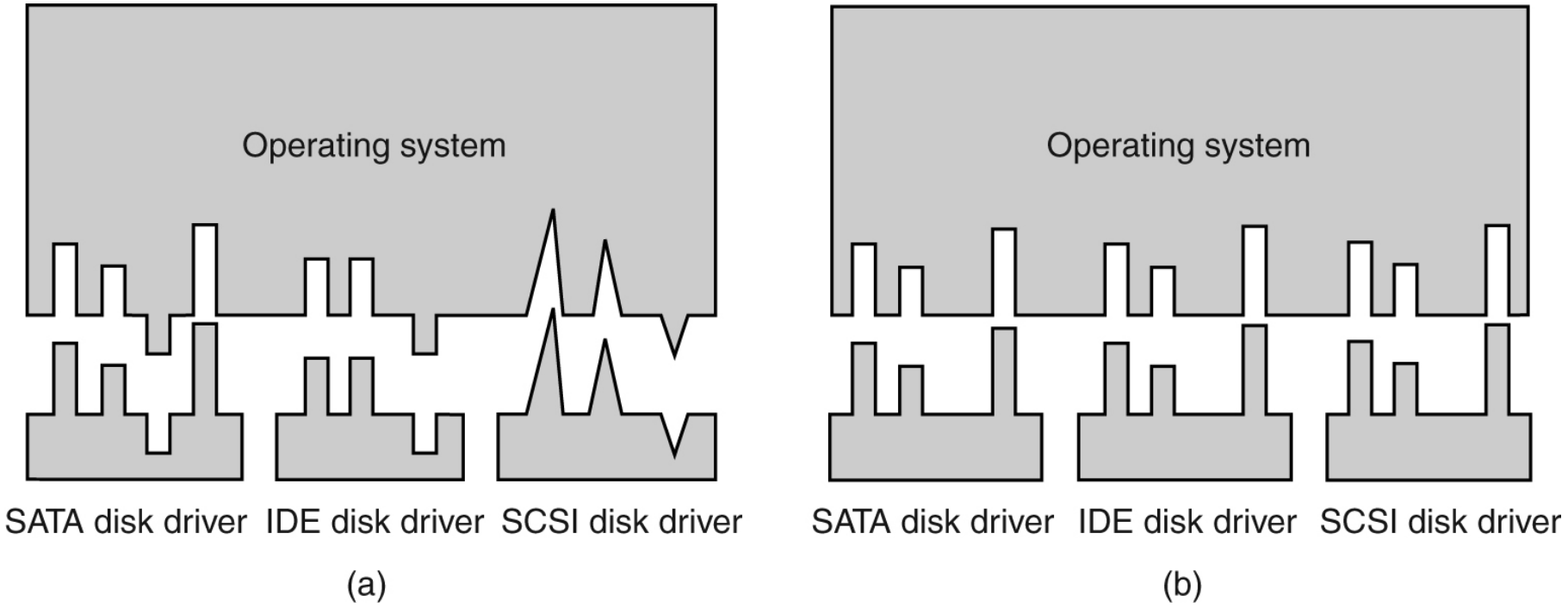
Device-Independent I/O Software

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

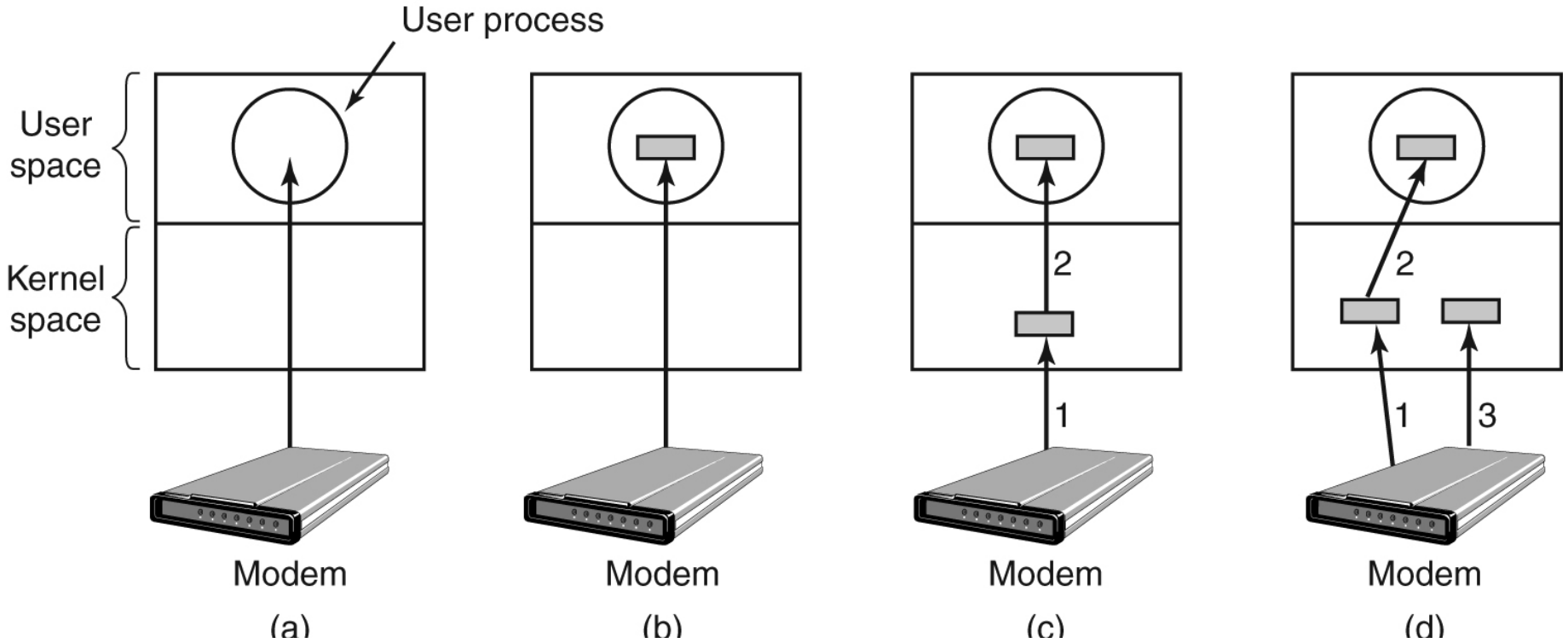
Uniform Interfacing for Device Drivers

- Major device number, minor device number

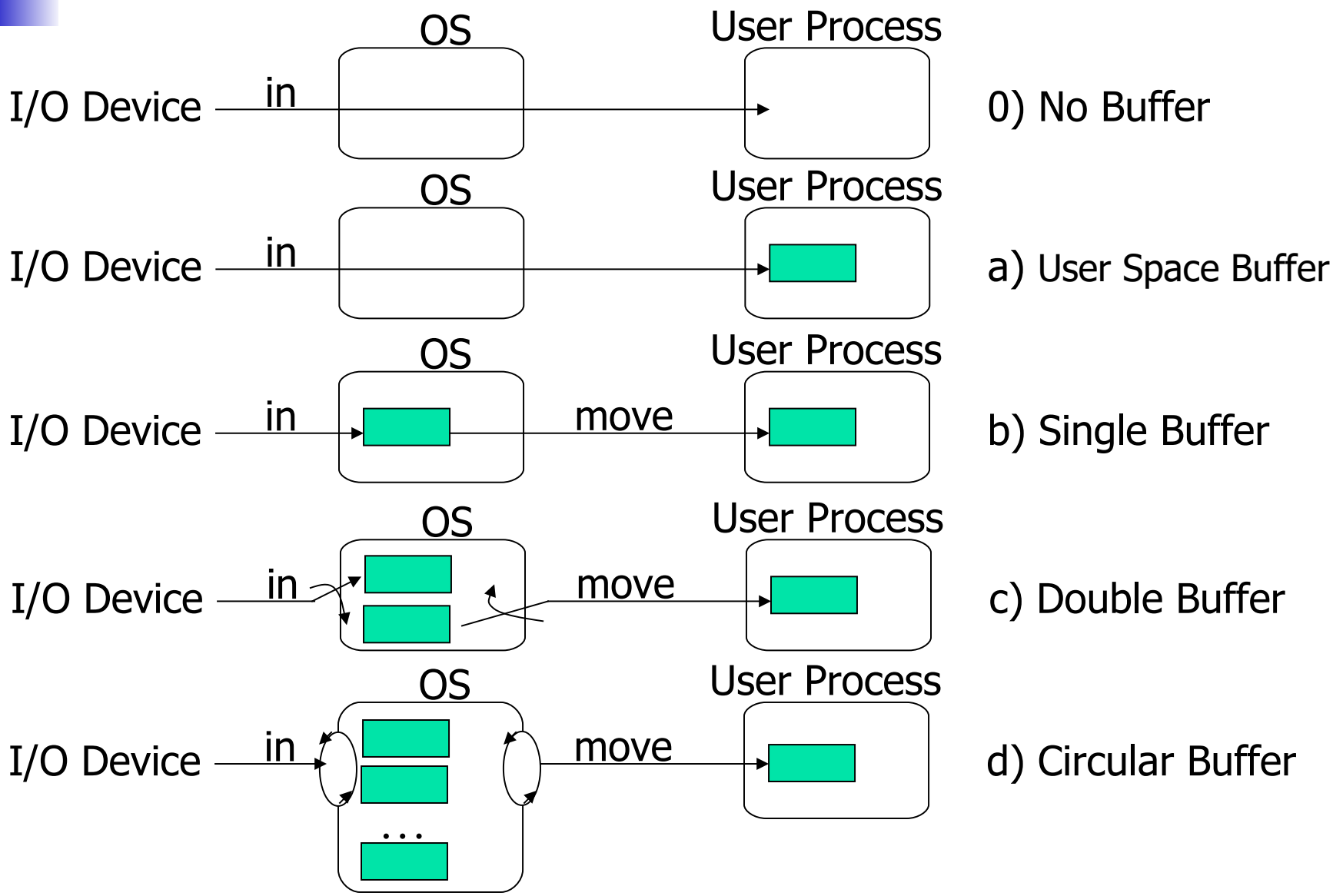


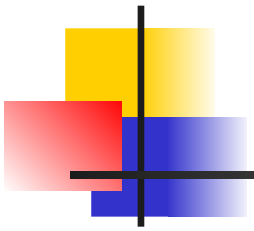
Buffering

- 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



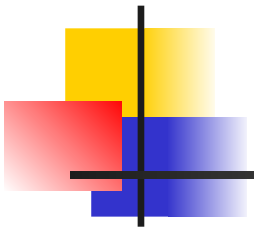
Buffering


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
  - …

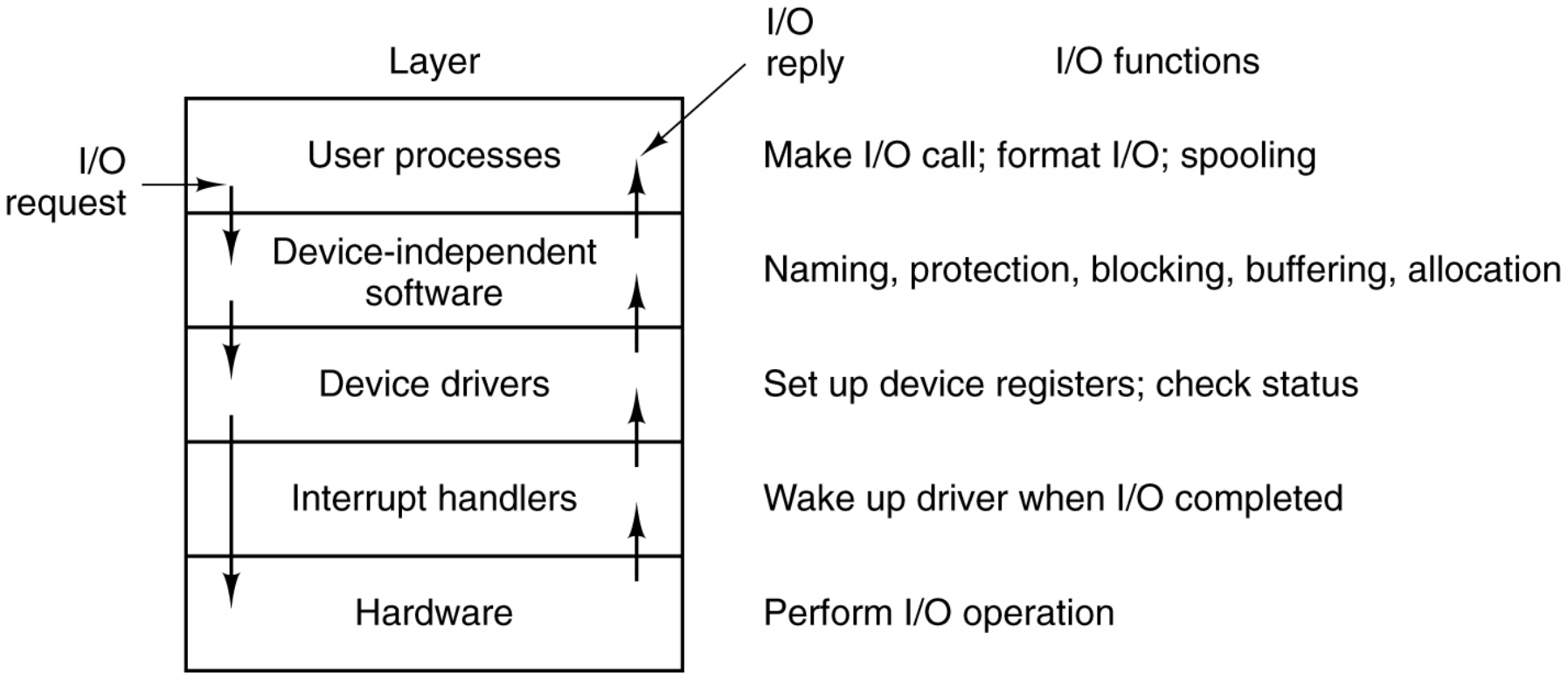


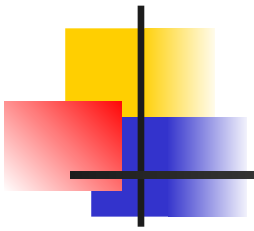
Device-Independent Block Size

- 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





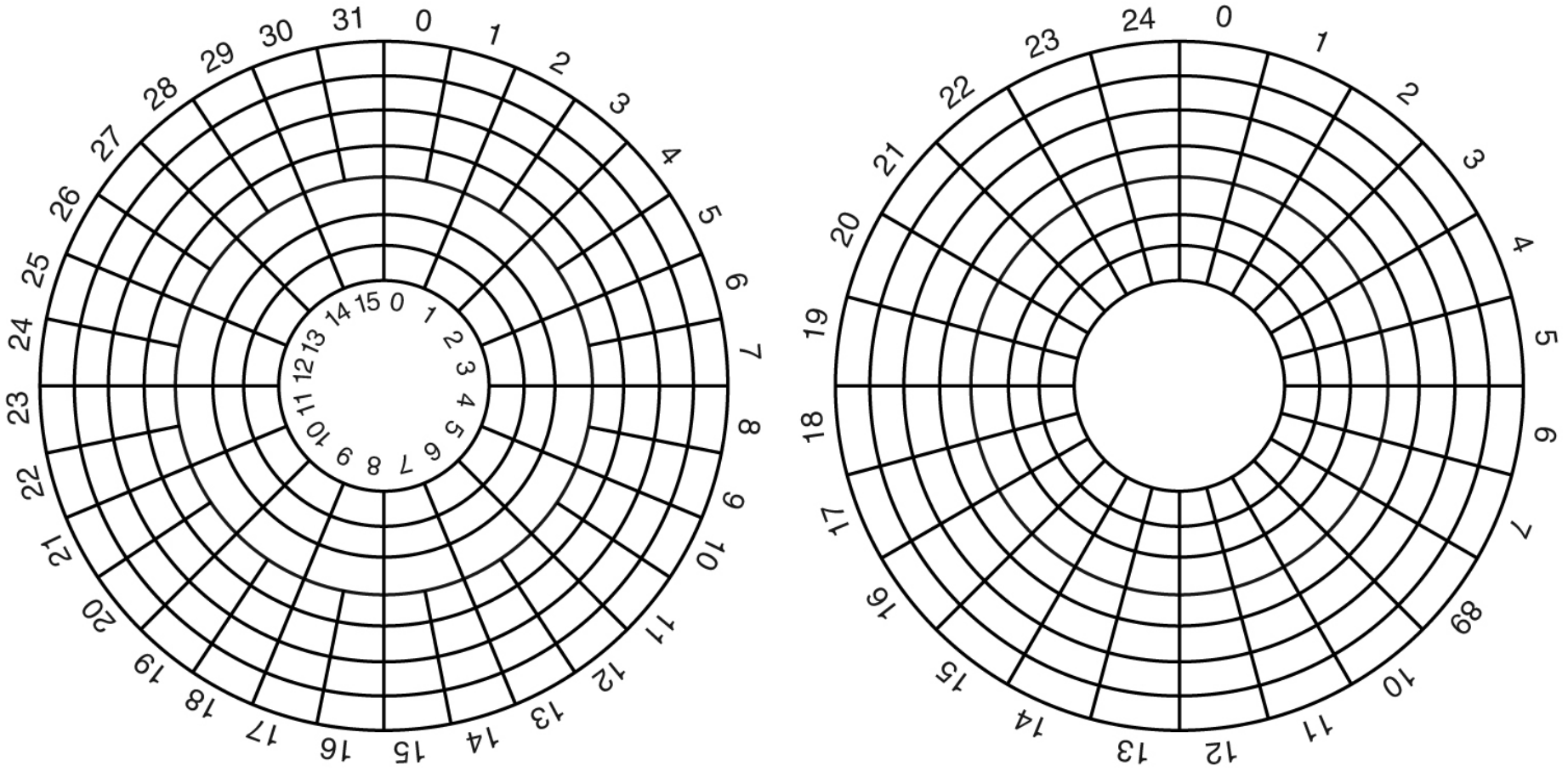
Disks

- 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



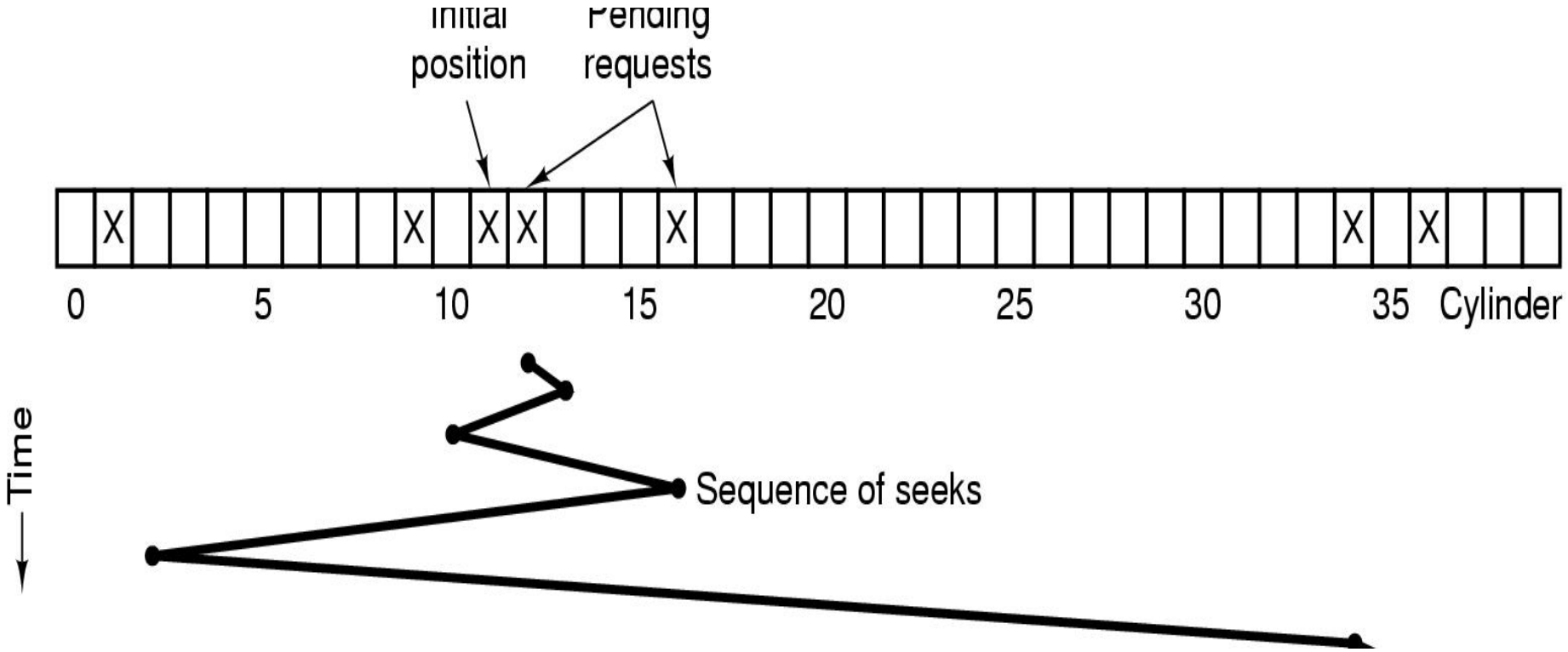
a) Physical geometry of a disk with two zones
b)A possible virtual geometry for this disk

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

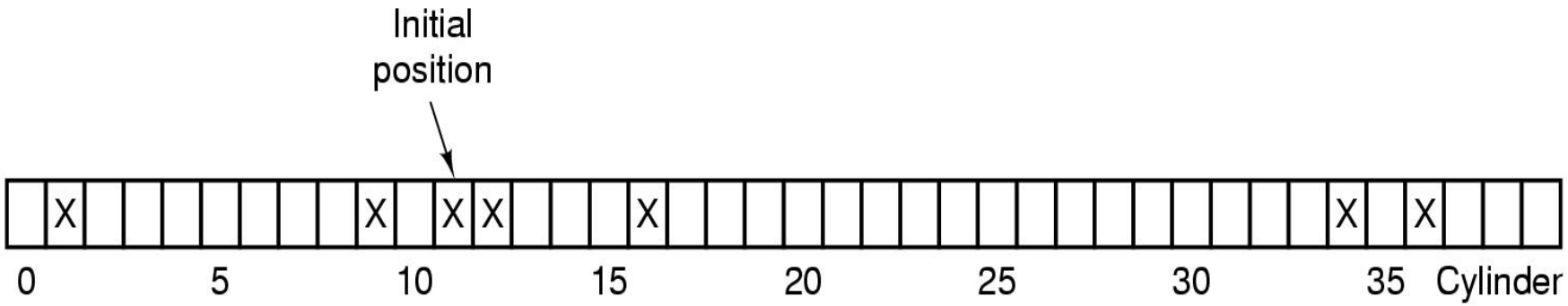
- Shortest Seek First (SSF) disk scheduling algorithm

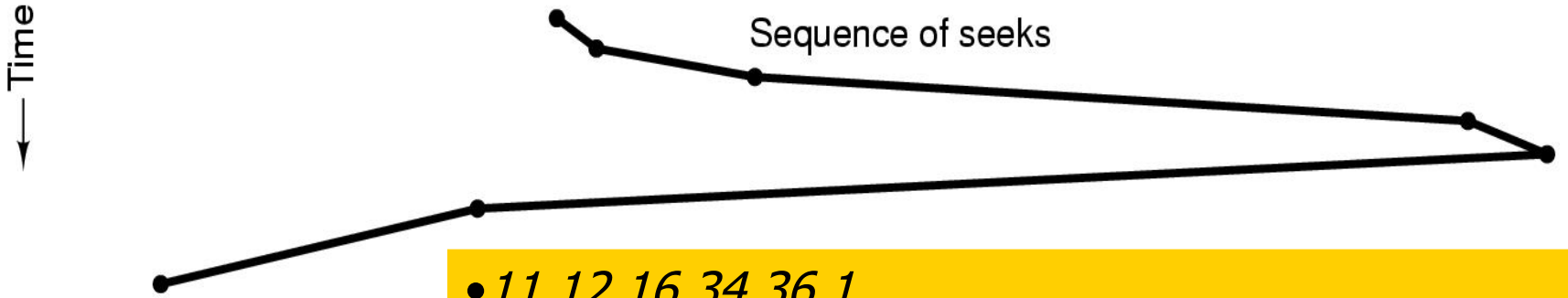


- *11,12,9,16,1,34,36*
- *61 Cylinders*

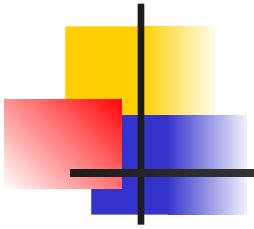
Elevator disk scheduling algorithm

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





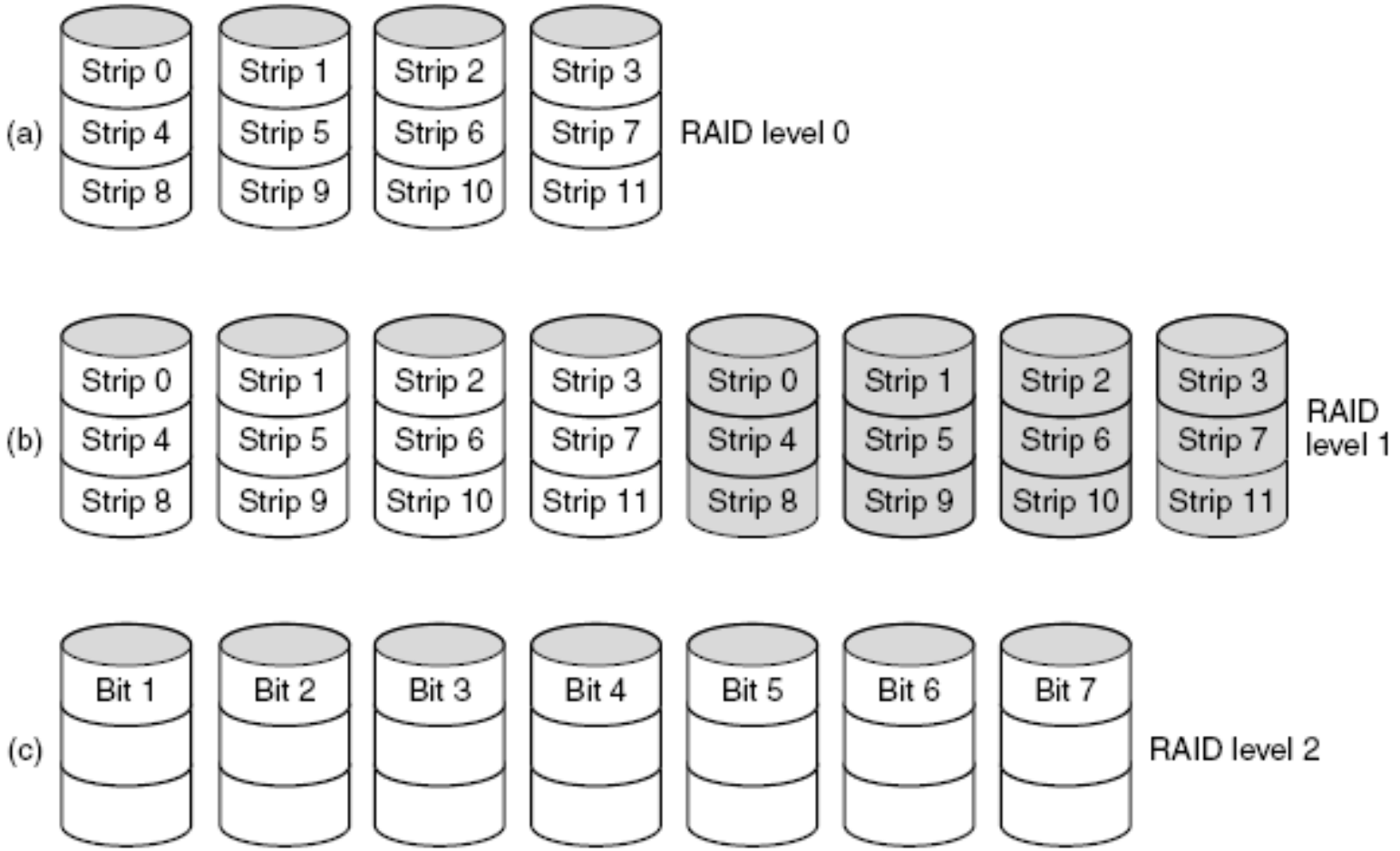
- *11,12,16,34,36,1*
- *60 Cylinders*



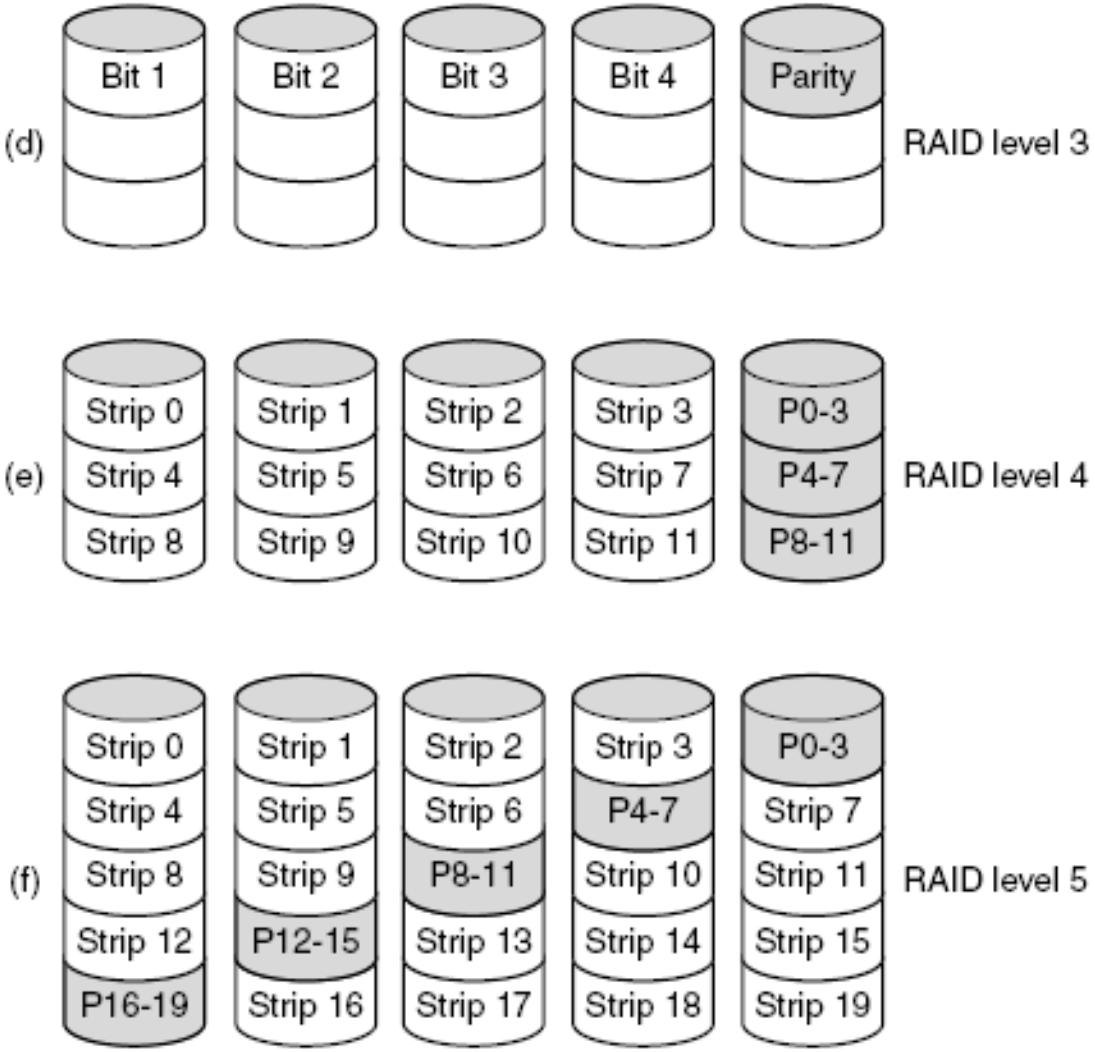
RAID

- 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?

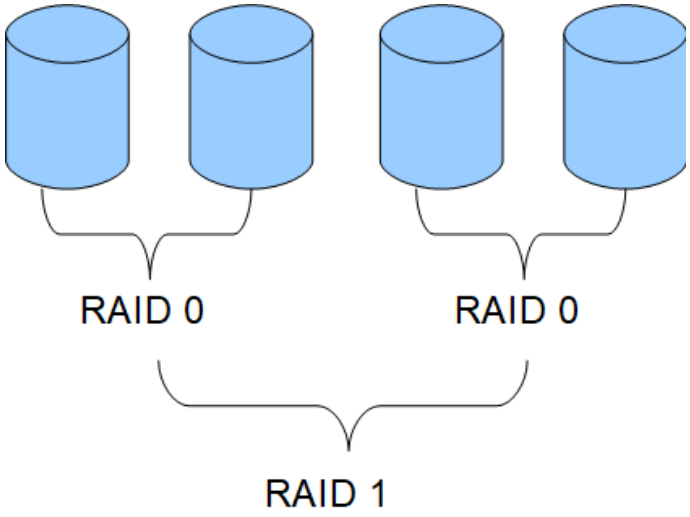


Fig. RAID 0+1

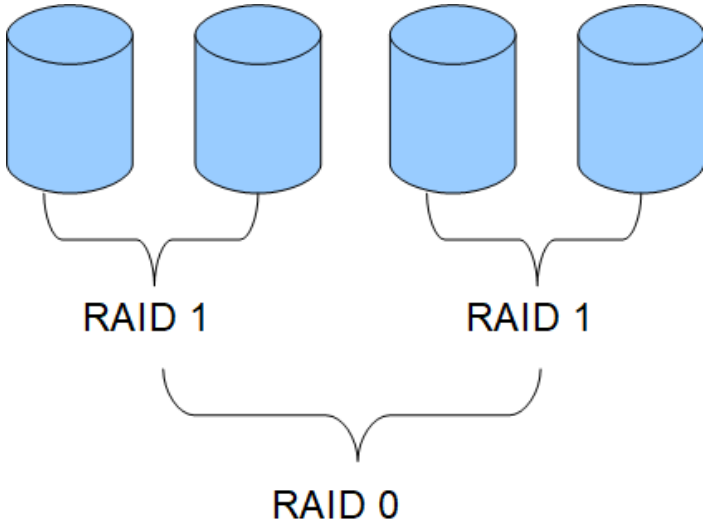
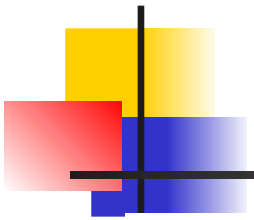


Fig. RAID 1+0

Others Storage Devices

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

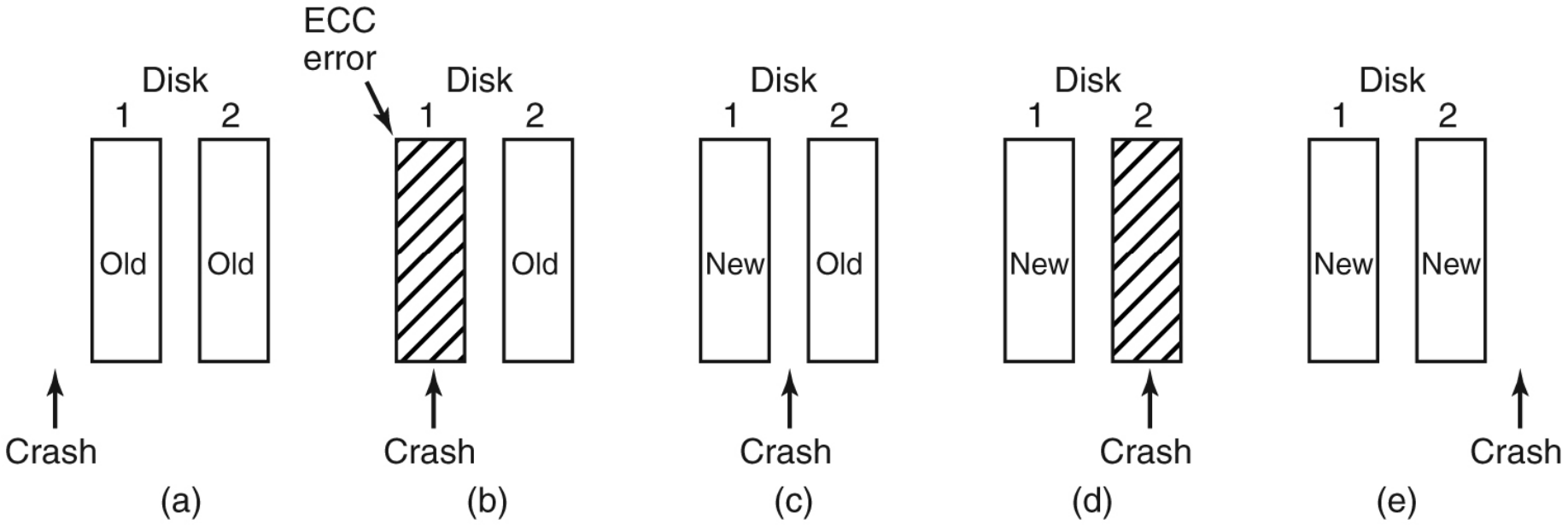


Stable Storage

- 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
  - ...

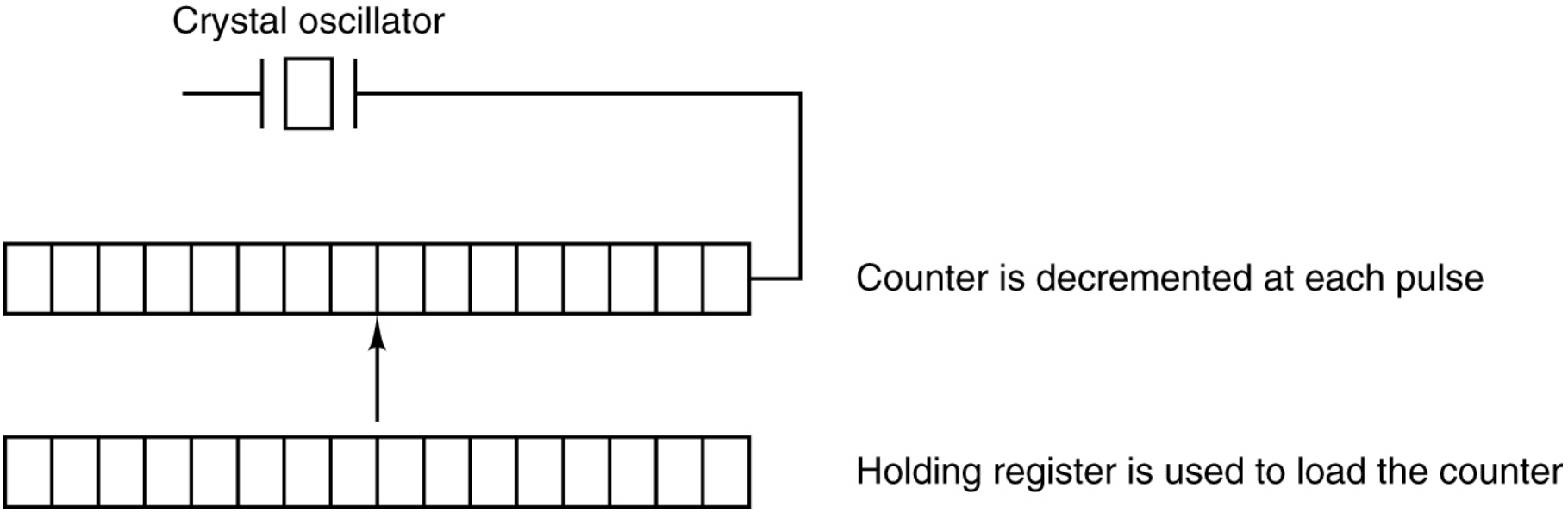
Stable Storage

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



Clocks(Timers)

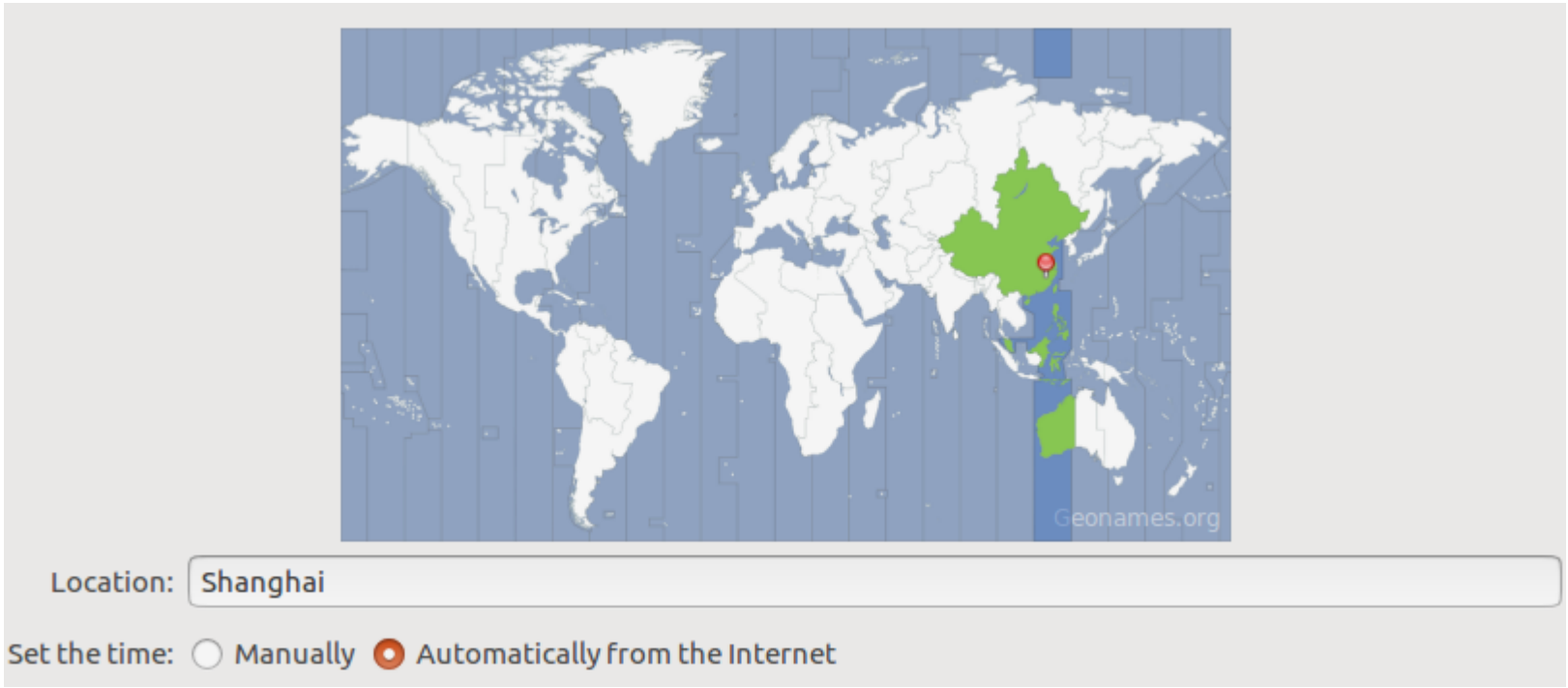
- Clock Hardware
  - Crystal oscillator 晶振体 , a counter, a holding register
  - CPU interrupt: clock tick
  - 8284/82C284
  - Two modes: One-shot mode, Square-ware mode



A Programmable Clock

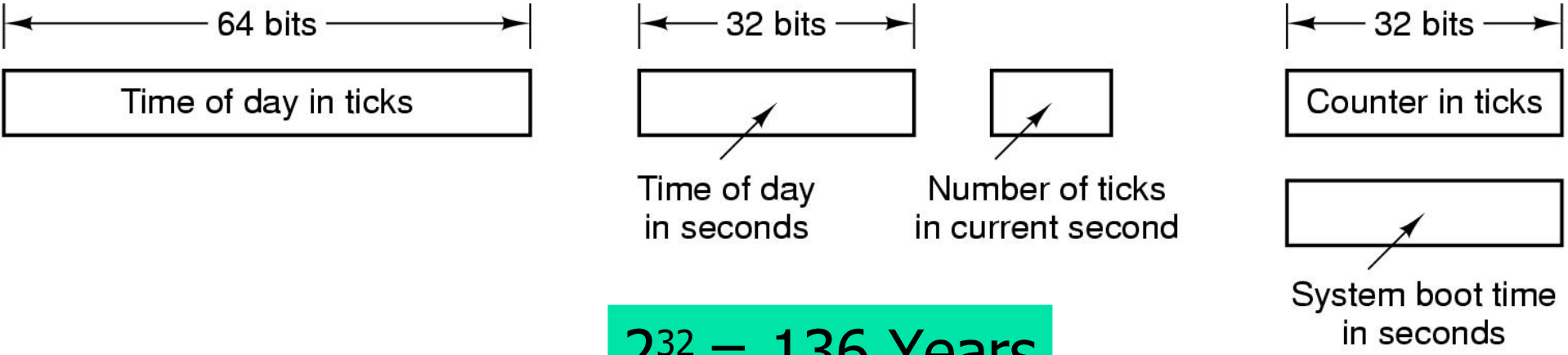
Clocks(Timers)

- Frequency Multiplier 倍频器
- UTC: Universal Coordinated Time
  - Greenwich Mean Time
  - UNIX: Jan.1, 1970
  - Windows: Jan.1, 1980



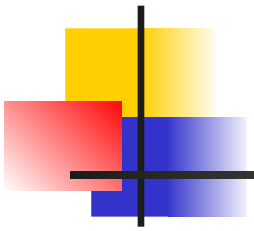
Clock

- Soft Timers
- Duties of Clock Software
  - Maintaining the time of day
  - Preventing processes from running longer than they are allowed to
  - Accounting for CPU usage
  - Handling the alarm system call made by user processes
  - Providing watchdog timers for parts of the system itself
  - Doing profiling, monitoring, and statistics gathering



2^{32} = 136 Years

2106=1970+136

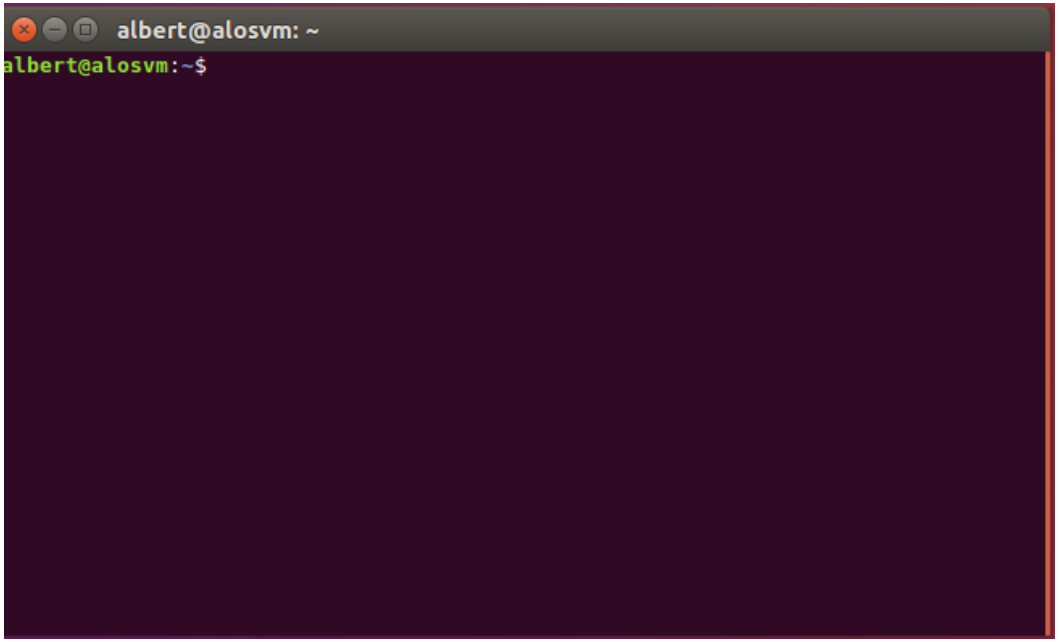


User Interface

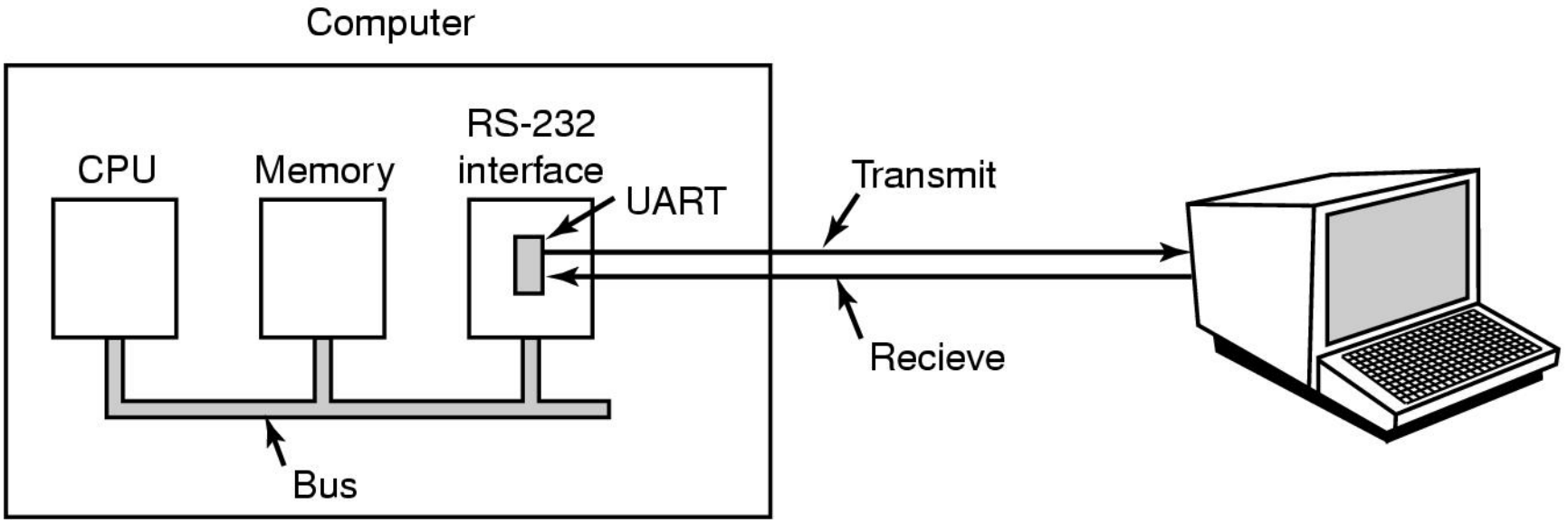
- Terminal Devices
  - Input Devices
    - Keyboard
    - Mouse
    - …
  - Output Devices
    - Monitor
    - …

Terminal 终端

- Text Terminal
  - RS-232*
- GUI Terminal
  - Graphical User Interface
  - Windows
  - X Window*
  - …
- Net Terminal*
  - SLIM: Stateless Low-level Interface Machine



Text Terminal: RS-232



- An RS-232 terminal communicates with computer 1 bit at a time
- Called a serial line – bits go out in series, 1 bit at a time
- Windows uses COM1 and COM2 ports, first to serial lines
- unix: /dev/tty1 /dev/tty2
- Computer and terminal are completely independent

Text Terminal: RS-232 Input 1/2

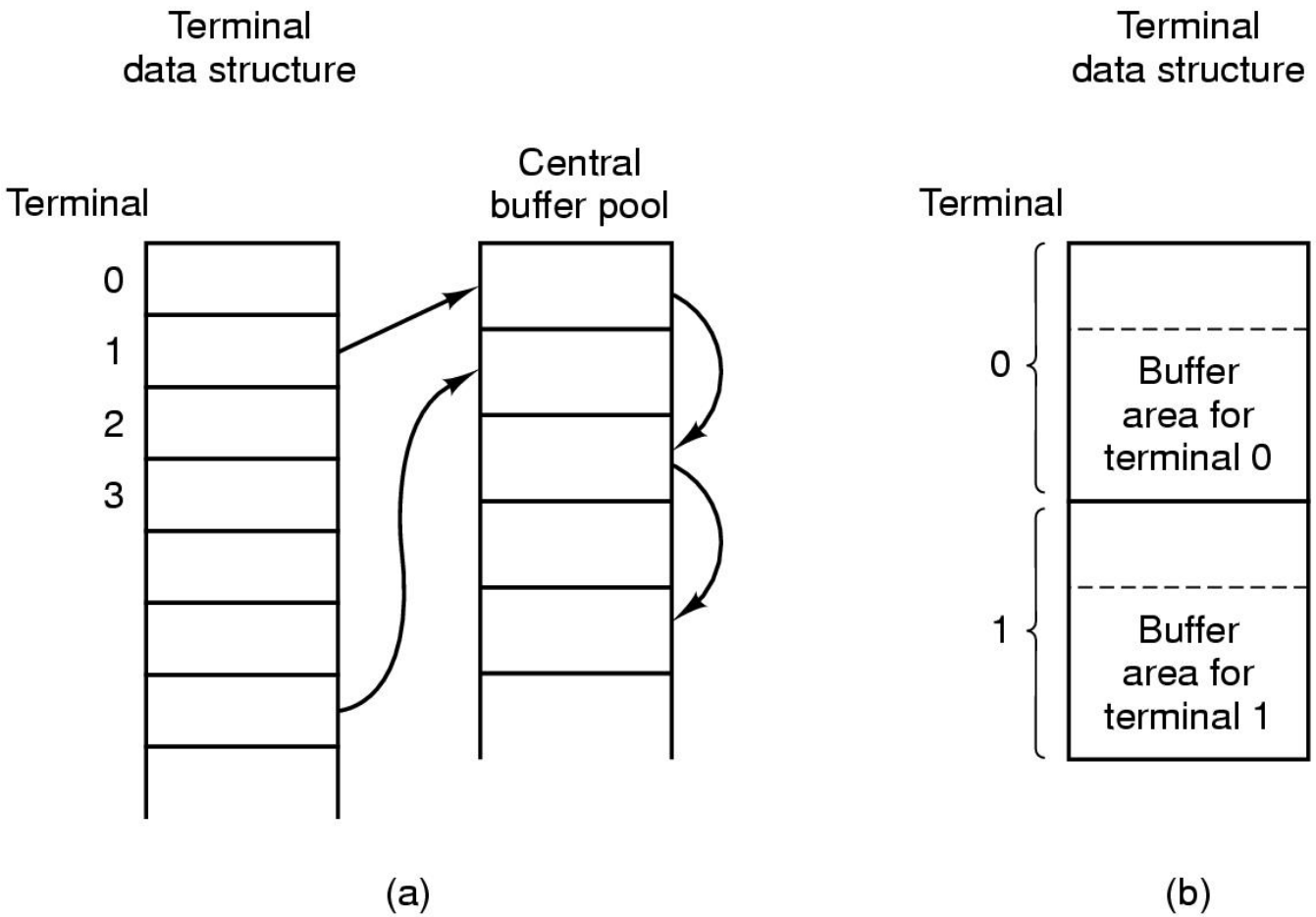
- canonical mode, noncanonical mode

Character	POSIX name	Comment
CTRL-H	ERASE	Backspace one character
CTRL-U	KILL	Erase entire line being typed
CTRL-V	LNEXT	Interpret next character literally
CTRL-S	STOP	Stop output
CTRL-Q	START	Start output
DEL	INTR	Interrupt process (SIGINT)
CTRL-\	QUIT	Force core dump (SIGQUIT)
CTRL-D	EOF	End of file
CTRL-M	CR	Carriage return (unchangeable)
CTRL-J	NL	Linefeed (unchangeable)

Characters handled specially in canonical mode

Text Terminal: RS-232 Input 2/2

- Buffer
- Echo



- Central buffer pool
  - 10 chars per buffer
- Dedicated buffer for each terminal

Text Terminal: RS-232 Output

Escape sequence	Meaning
ESC [*n* A	Move up *n* lines
ESC [*n* B	Move down *n* lines
ESC [*n* C	Move right *n* spaces
ESC [*n* D	Move left *n* spaces
ESC [*m* ; *n* H	Move cursor to (*m*,*n*)
ESC [*s* J	Clear screen from cursor (0 to end, 1 from start, 2 all)
ESC [*s* K	Clear line from cursor (0 to end, 1 from start, 2 all)
ESC [*n* L	Insert *n* lines at cursor
ESC [*n* M	Delete *n* lines at cursor
ESC [*n* P	Delete *n* chars at cursor
ESC [*n* @	Insert *n* chars at cursor
ESC [*n* m	Enable rendition *n* (0=normal, 4=bold, 5=blinking, 7=reverse)
ESC M	Scroll the screen backward if the cursor is on the top line

- The ANSI escape sequences 转义序列
  - accepted by terminal driver on output
  - ESC is ASCII character (0x1B)
  - n,m, and s are optional numeric parameters
- Termcap 终端数据库

GUI

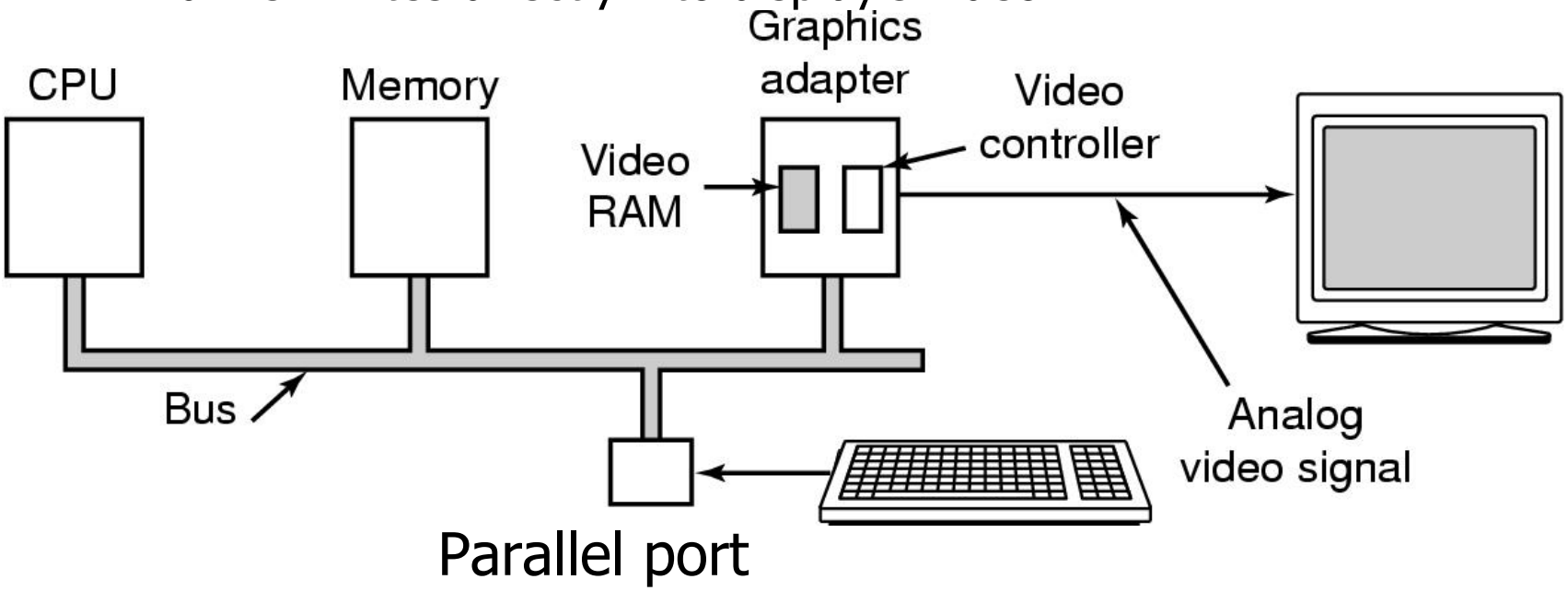
- Graphical User Interface
  - Douglas Engelbart:
    - Stanford Research Institute
    - human–computer interaction
  - Xerox PARC: copied
  - Steve Jobs(Apple Corp.): Prodution
    - Apple Lisa、 Macintosh
  - Microsoft Windows: From Apple

GUI

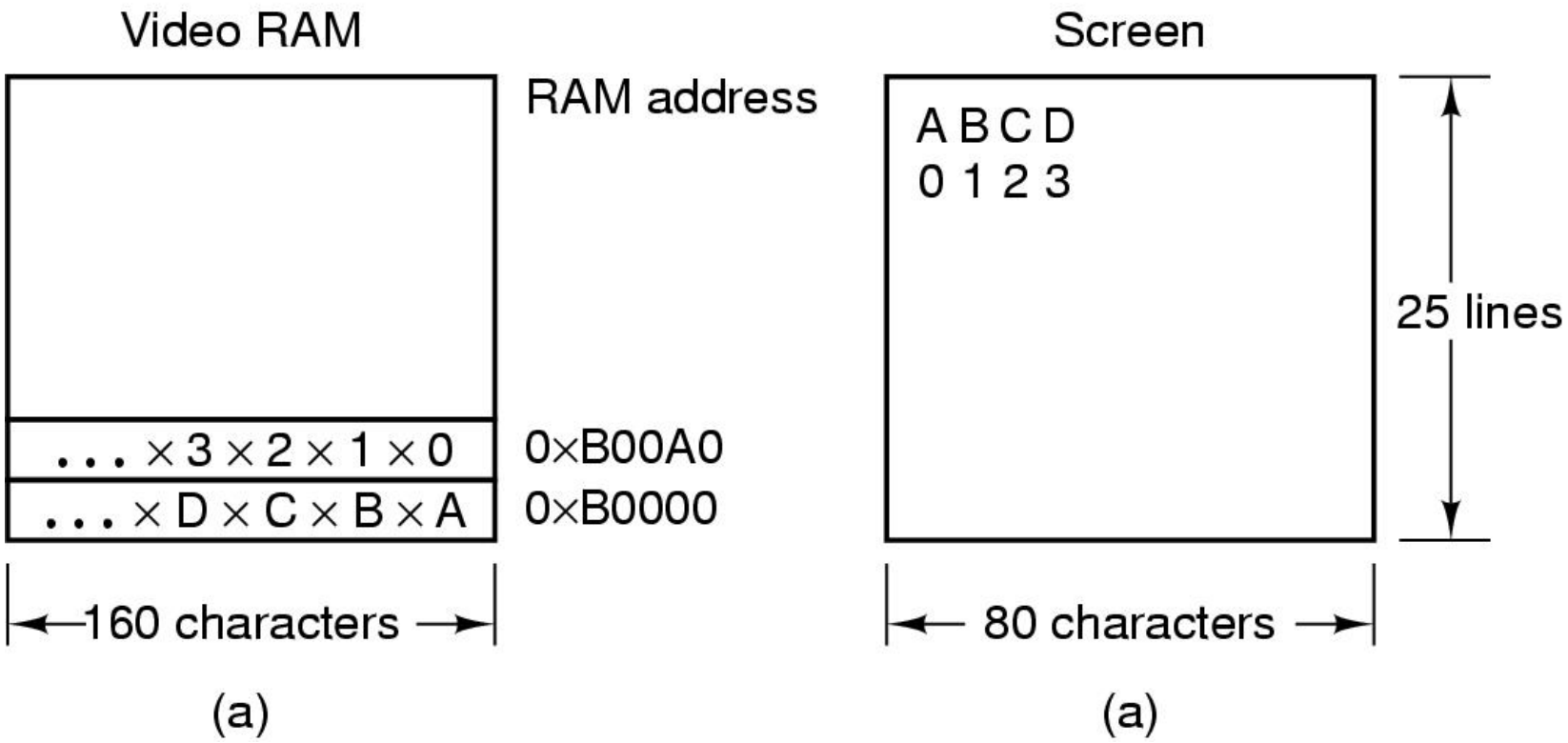
- GUI "**WIMP**"
  - Window
  - Icon
  - Menu
  - Pointing device

GUI: Display Hardware 1/2

- Display Hardware
  - Vector graphics 矢量设备
  - Raster graphics 栅格设备
    - Char mode 、 Bit mode (pixel 像素 , bitmap 位图)
- Memory-mapped displays
  - driver writes directly into display's video RAM



GUI: Display Hardware 2/2



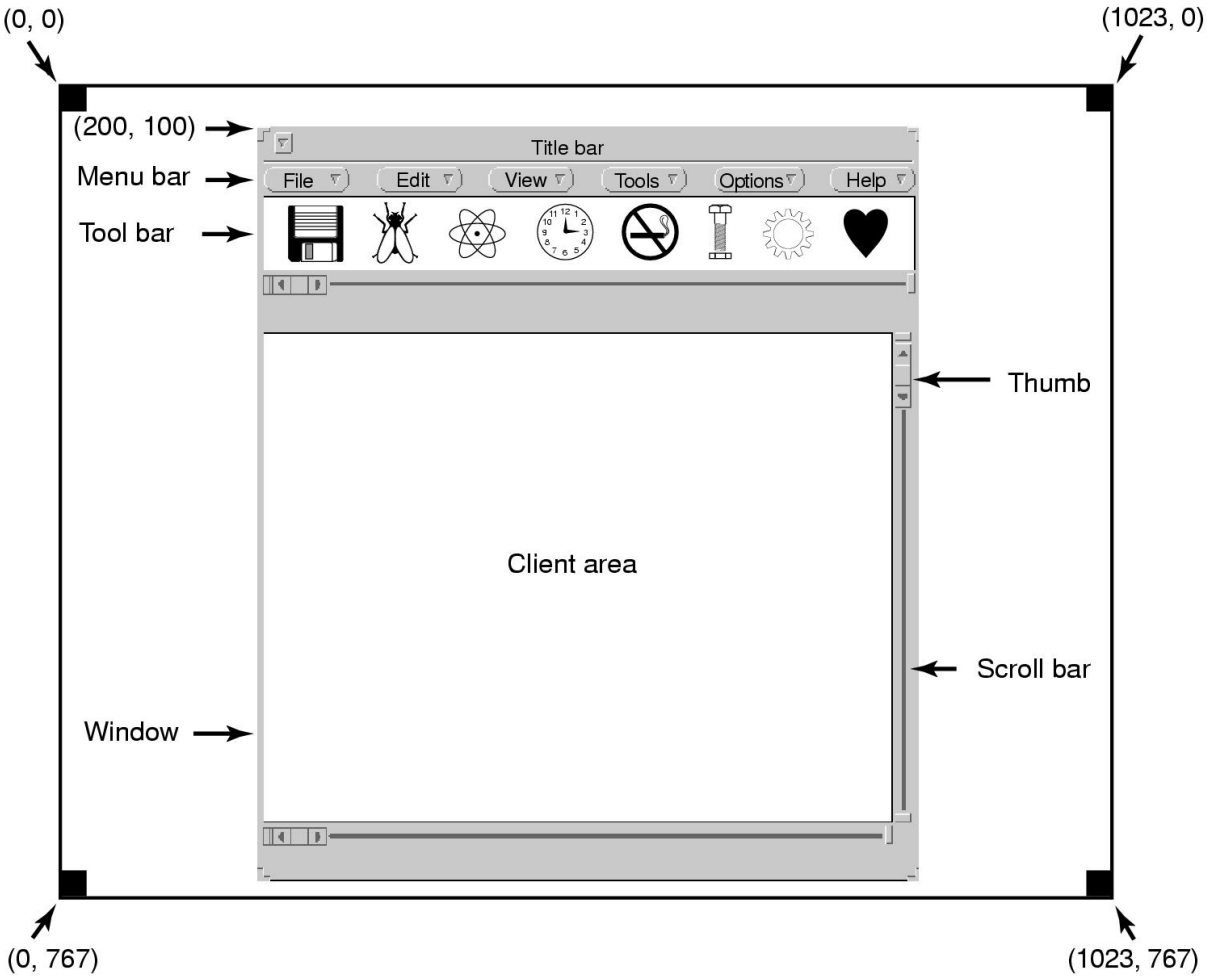
- A) A video RAM image
  - simple monochrome display
  - character mode
  - the Xs are attribute bytes
- B) Corresponding screen

GUI: Input Software

- Keyboard driver delivers a number
  - 键盘扫描码 , ASCII 码
  - driver converts to characters
  - uses a ASCII table
- Exceptions, adaptations needed for other languages
  - 键盘映射 keymap or 代码页 code page
  - many OS provide for loadable keymaps or code pages

GUI: Output Software

- Sample window located at (200,100) on XGA display



GUI: MS Windows 1/5

```
#include <windows.h>

int WINAPI WinMain(HINSTANCE h, HINSTANCE, hprev, char *szCmd, int iCmdShow)
{
      WNDCLASS wndclass;              /* class object for this window */
      MSG msg;                        /* incoming messages are stored here */
      HWND hwnd;                      /* handle (pointer) to the window object */

      /* Initialize wndclass */
      wndclass.lpfnWndProc = WndProc;          /* tells which procedure to call */
      wndclass.lpszClassName = "Program name";    /* Text for title bar */
      wndclass.hIcon = LoadIcon(NULL, IDI_APPLICATION);   /* load program icon */
      wndclass.hCursor = LoadCursor(NULL, IDC_ARROW);   /* load mouse cursor */

      RegisterClass(&wndclass);       /* tell Windows about wndclass */
      hwnd = CreateWindow ( ... )     /* allocate storage for the window */
      ShowWindow(hwnd, iCmdShow); /* display the window on the screen */
      UpdateWindow(hwnd);             /* tell the window to paint itself */
```

Skeleton of a Windows main program (part 1)

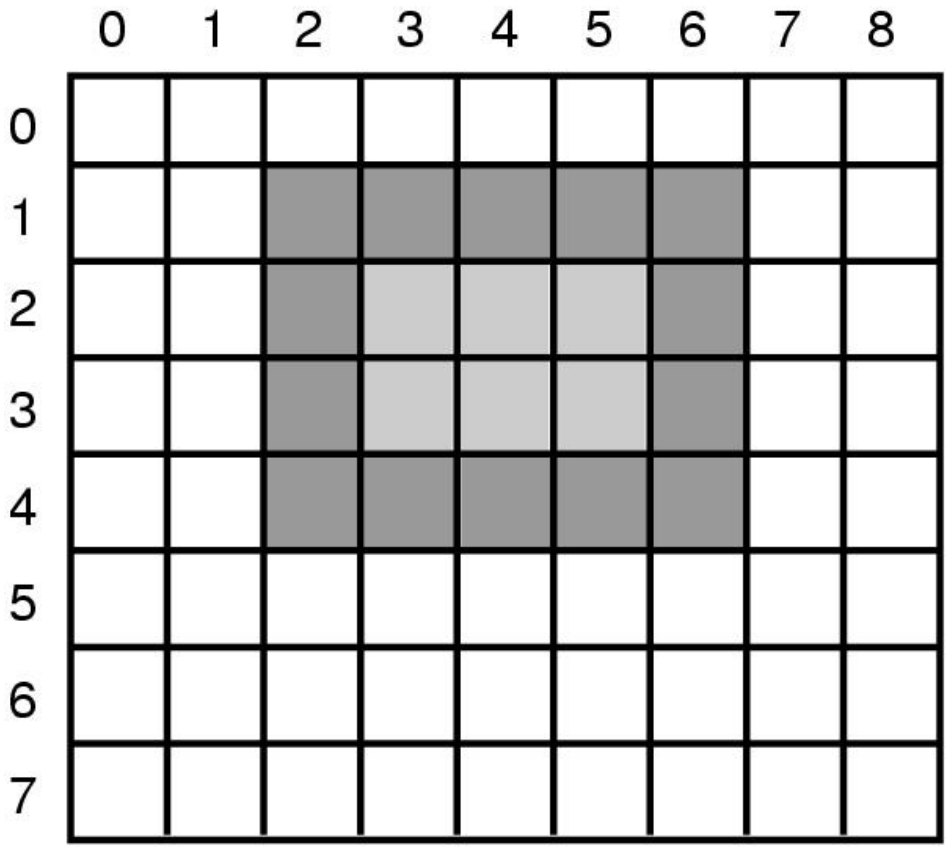
GUI: MS Windows 2/5

```
    while (GetMessage(&msg, NULL, 0, 0)) {    /* get message from queue */
        TranslateMessage(&msg);    /* translate the message */
        DispatchMessage(&msg);     /* send msg to the appropriate procedure */
    }
    return(msg.wParam);
}

long CALLBACK WndProc(HWND hwnd, UINT message, UINT wParam, long lParam)
{
    /* Declarations go here. */

    switch (message) {
        case WM_CREATE:     ... ;   return ... ;    /* create window */
        case WM_PAINT:      ... ;   return ... ;    /* repaint contents of window */
        case WM_DESTROY:    ... ;   return ... ;    /* destroy window */
    }
    return(DefWindowProc(hwnd, message, wParam, lParam));/* default */
}
```

Skeleton of a Windows main program (part 2)

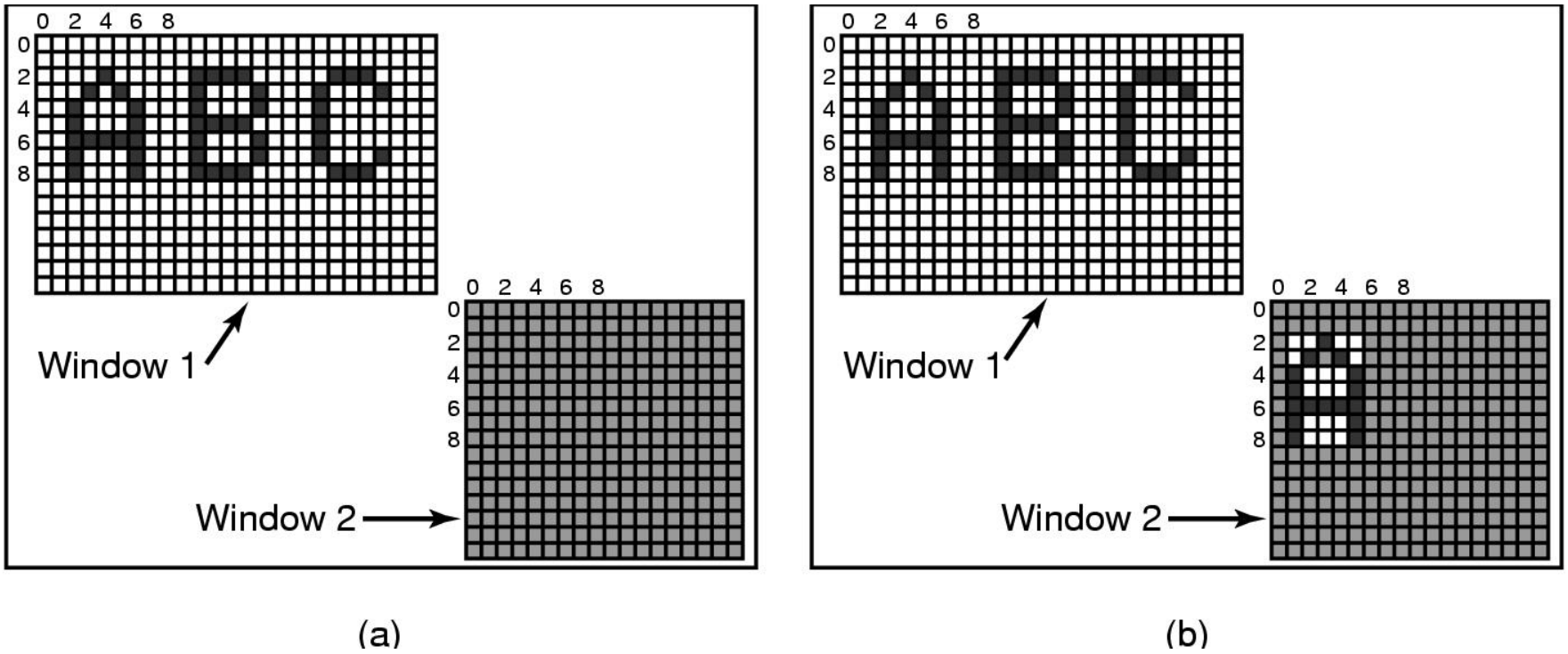
GUI: MS Windows 3/5

- Drawing
  - Lines, curves
  - Filled Areas
  - bitmaps
  - Displaying text
- An example rectangle drawn using *Rectangle*
  - Rectangle(hdc, xleft, ytop, xright, ybottom)
  - Echo box represents one pixel



GUI: MS Windows 4/5

- Bitmap 位图
  - bitBlt(dsthdc, dx, dy, width, height, srchdc, sx, sy, rasteroperator)
- Copying bitmaps using *BitBlt*
  - A) Before, B) After



GUI: MS Windows 5/5

- Fonts
  - BitBlt: bitmap
  - TrueType: outlines of the characters

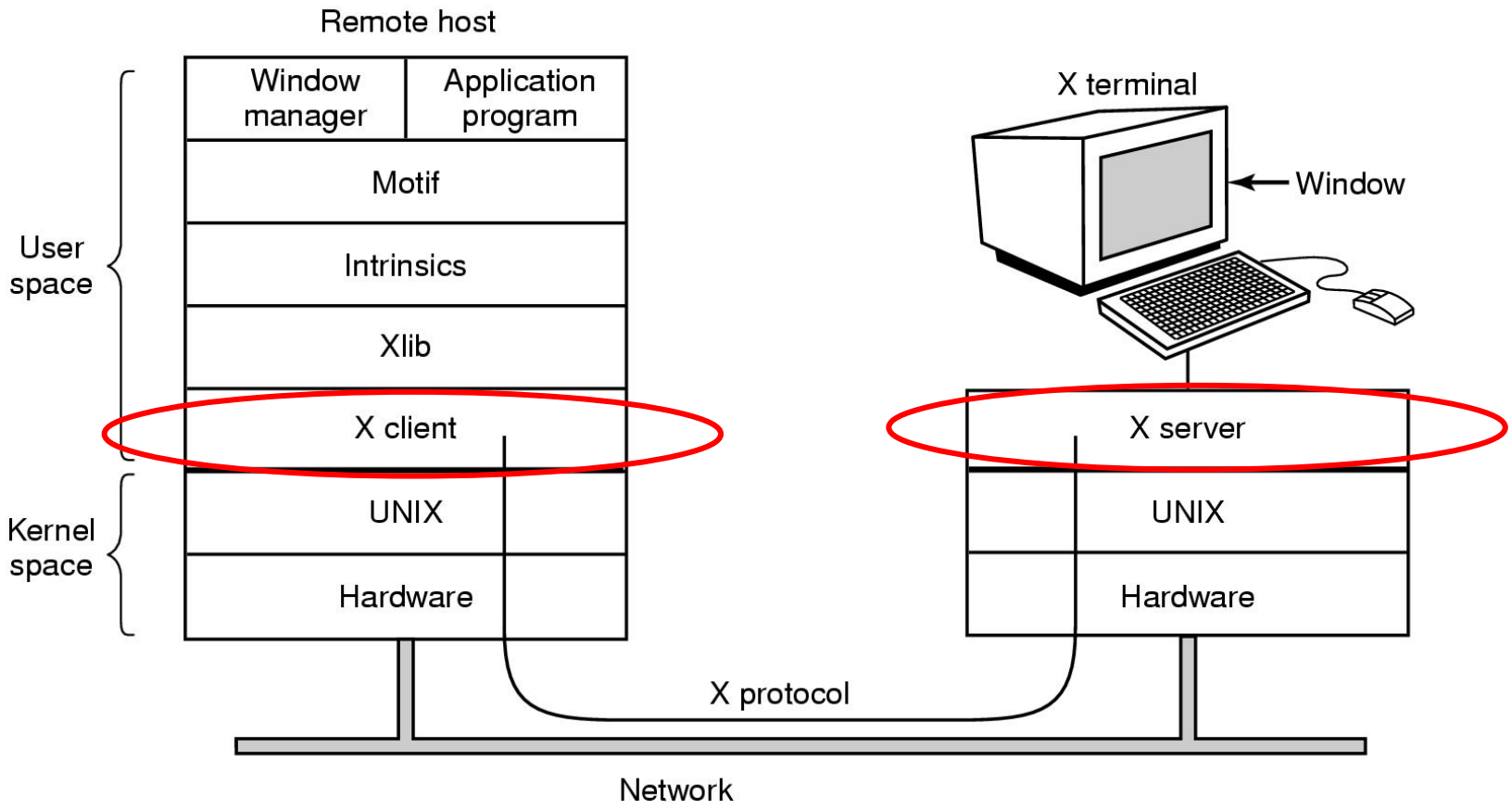
20 pt: abcdefgh

53 pt: abcdefgh

81 pt: abcdefgh

Examples of character outlines at different point sizes

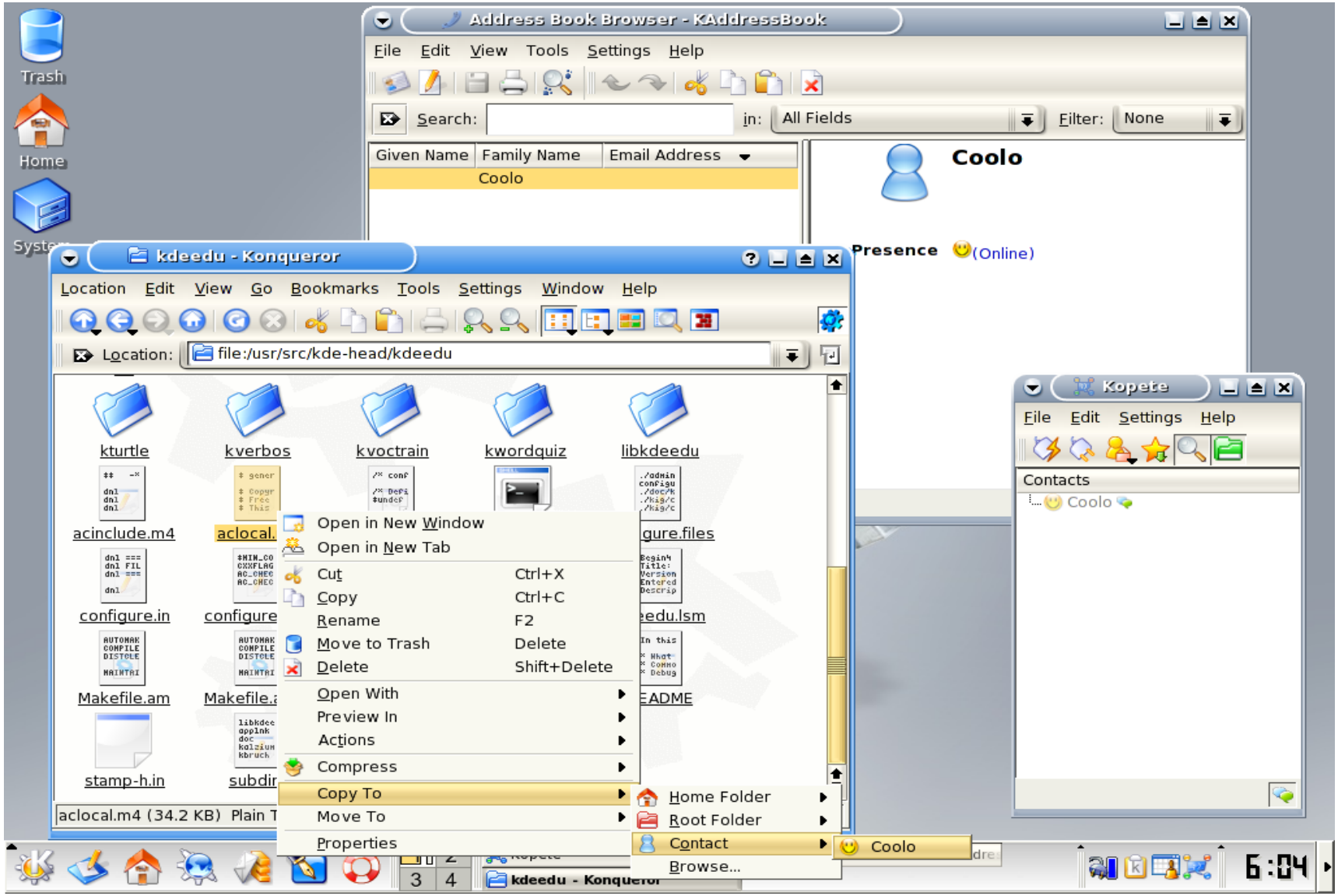
Network Terminals: X Window 1/3



Clients and servers in the M.I.T. X Window System

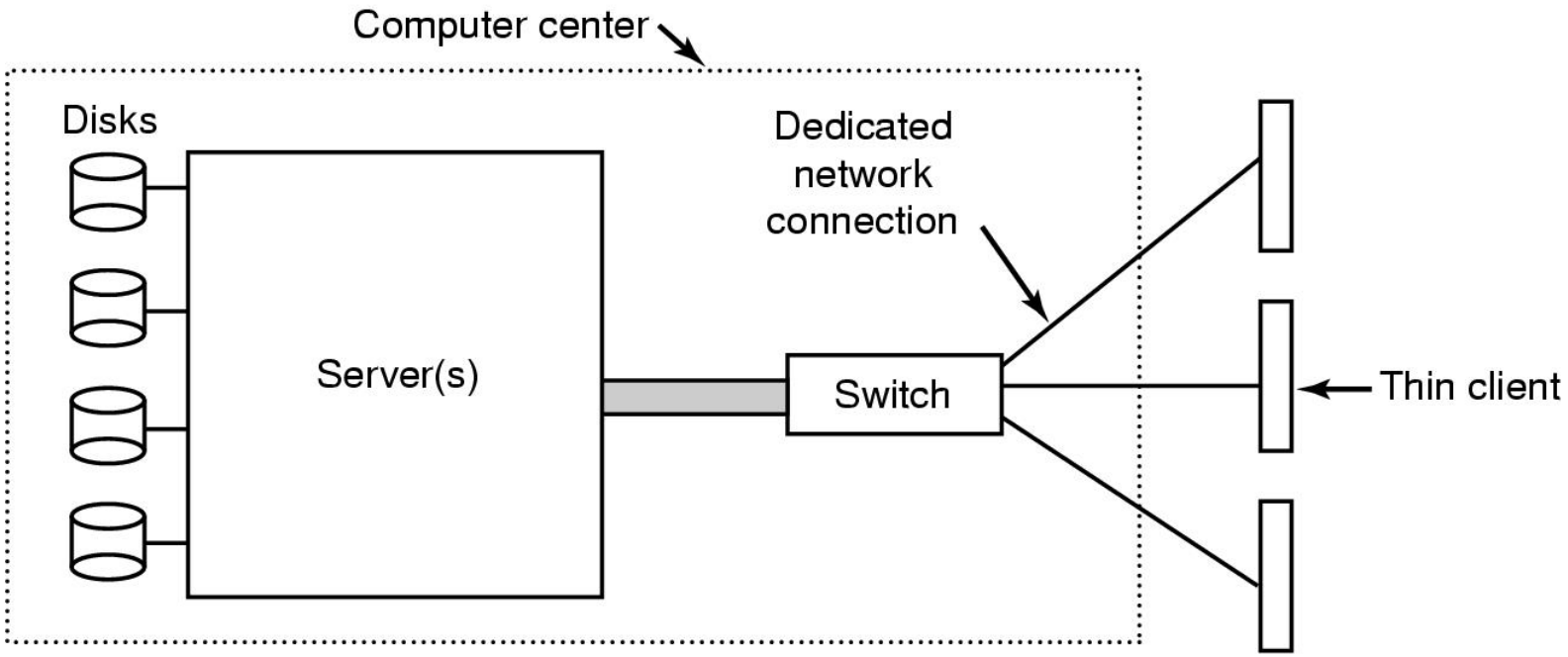
```
#include <X11/Xlib.h>
#include <X11/Xutil.h>

main(int argc, char *argv[])
{
    Display disp;                                   /* server identifier */
    Window win;                                     /* window identifier */
    GC gc;                                          /* graphic context identifier */
    XEvent event;                                   /* storage for one event */
    int running = 1;

    disp = XOpenDisplay("display_name");            /* connect to the X server */
    win = XCreateSimpleWindow(disp,  ... );         /* allocate memory for new window */
    XSetStandardProperties(disp, ...);              /* announces window to window mgr */
    gc = XCreateGC(disp, win, 0, 0);                /* create graphic context */
    XSelectInput(disp, win, ButtonPressMask | KeyPressMask | ExposureMask);
    XMapRaised(disp, win);                  /* display window; send Expose event */

    while (running) {
        XNextEvent(disp, &event);       /* get next event */
        switch (event.type) {
            case Expose:        ...;    break;    /* repaint window */
            case ButtonPress:   ...;    break;    /* process mouse click */
            case Keypress:      ...;    break;    /* process keyboard input */
        }
    }

    XFreeGC(disp, gc);                      /* release graphic context */
    XDestroyWindow(disp, win);              /* deallocate window's memory space */
    XCloseDisplay(disp);                    /* tear down network connection */
}
```

Network Terminals: X Window 3/3



Network Terminals: SLIM

- SLIM
  - Stateless Low-level Interface Machine



Network Terminals: SLIM

- SLIM Protocols
  - SET
  - FILL
  - BITMAP
  - COPY
  - CSCS

Power Management

- ENIAC
  - 180000 vacuum tubes, 140000 watts of power
- PC
  - 200-watt power supply, 85% efficient
  - If 100 million of PC are turnned on at once worldwide
    - 20000 megawattts: 20 nuclear power plants
- Battery-powered Computers
  - Heart of the problem: the batterises cannot hold enou gh charge to last very long, a few hours at most
  - No process: More Law

Power:Reuding Energy Consumption

- Way 1:
  - Turn off parts of the computer (mostly I/O de vices) when they are not in use
- Way 2:
  - The application program uses less energy
    - Possibly degrads the quality of the user experience, in order to strech out battery time

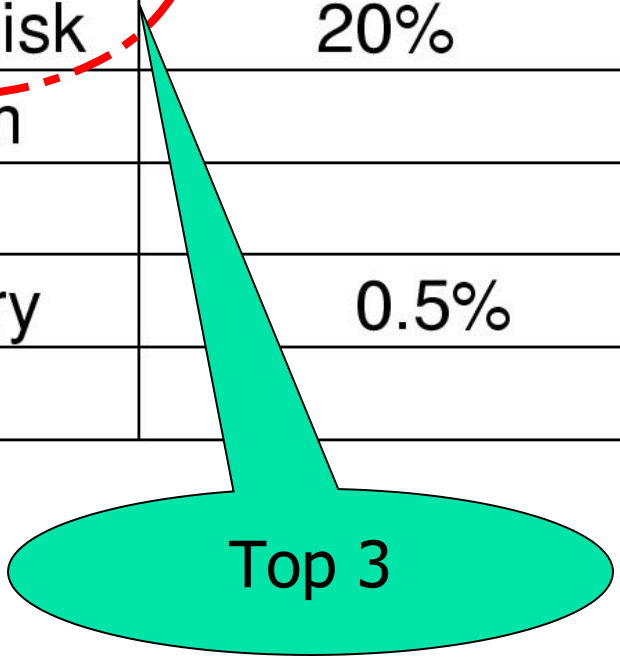
Power: Hardware Issues 1/2

- Batteries
  - disposable 一次性使用的
  - rechargeable 可再充电的
- Modes
  - Working
  - Sleeping
  - Hibernating
  - Off

Power: Hardware Issues 2/2

- Power consumption of various parts of a laptop computer

Device	Li et al. (1994)	Lorch and Smith (1998)
Display	68%	39%
CPU	12%	18%
Hard disk	20%	12%
Modem		6%
Sound		2%
Memory	0.5%	1%
Other		22%

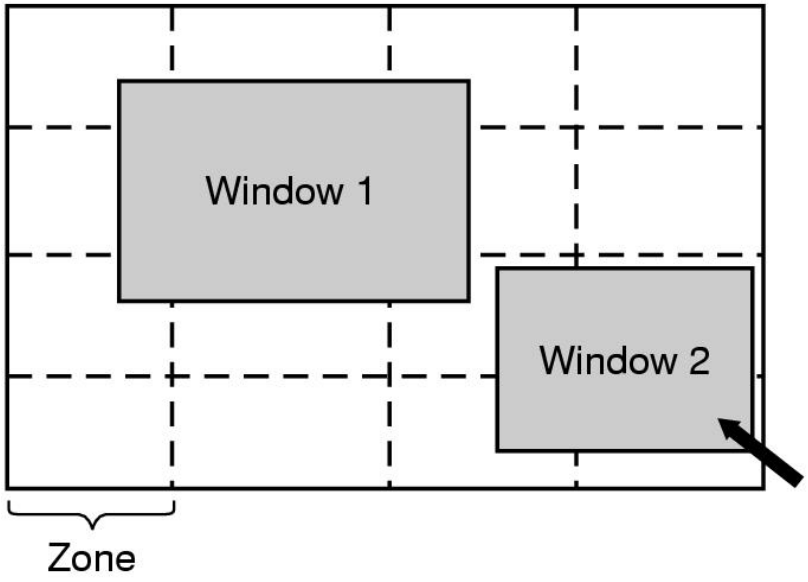


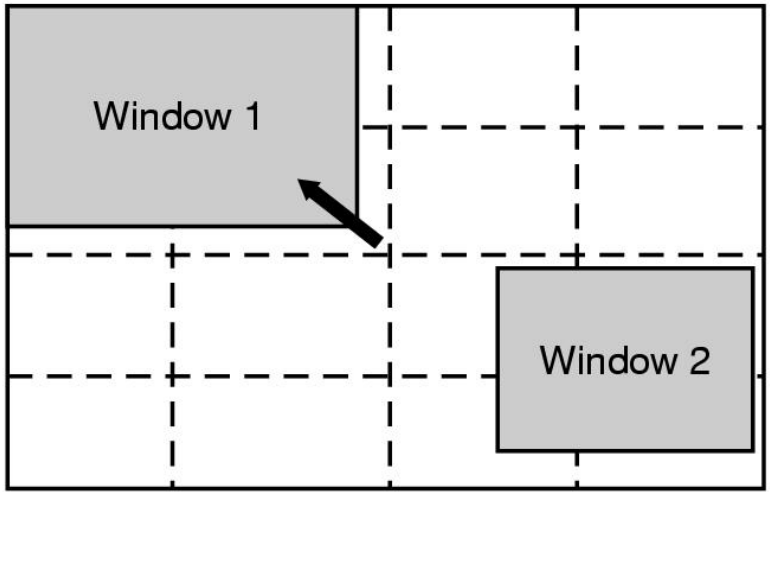
Problems of Power Management

- Which devices can be controlled?
- Are they on/off, or do they have intermediate s tates?
- How much power is saved in the low-power sta tes?
- Is energy expended to restart the device?
- Must some context be saved when going to a l ow-power state?
- How long does it take to go back to full power?

Power:Display

- To get a bright sharp image
  - The screen must be backlit and that takes substantial energy
- Way1:turn off the screen
- Way2:divide the screen into many zones, turn off part of zones
  - J. Flinn and M. Satyanarayanan, "Managing battery lifetime with energy-aware adaptation.," ACM Trans. Comput. Syst., vol. 22, no. 2, pp. 137–179, 2004.



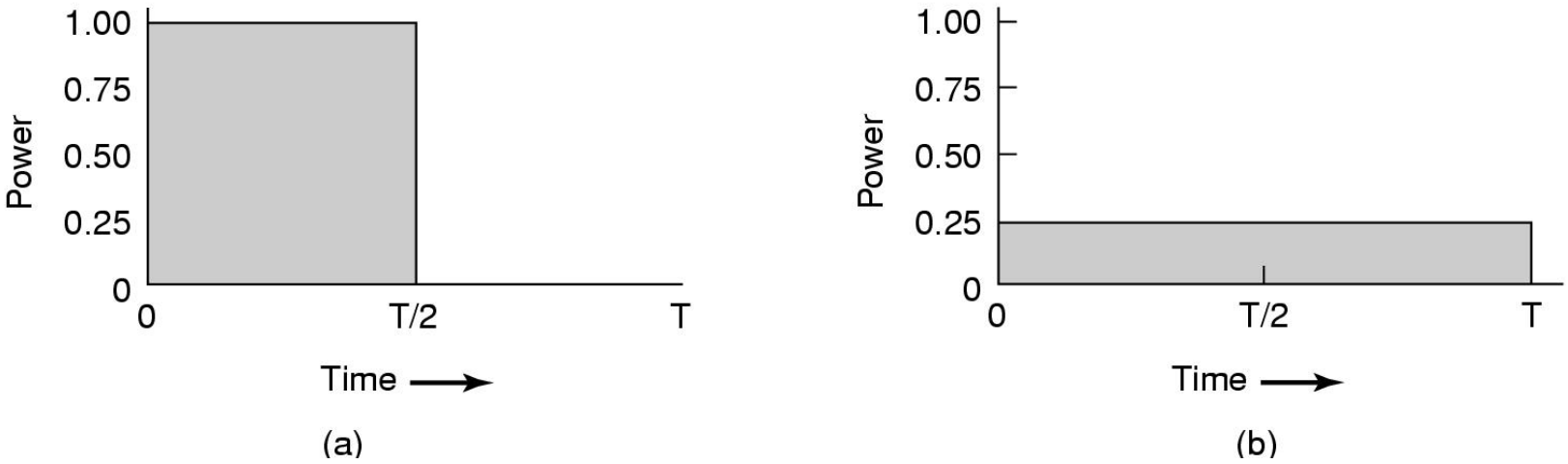


Power: hard disk

- Hard disk
  - It takes substantial energy to keep it spinning at high speed, even if there are no accesses
- Way1:Spin the disk down after a certain number of seconds or minutes of inactivity
- Way2:Have a substantial disk cache in RAM
- Way3:OS informs running programs about the disk state by sending it messages or signals

Power:CPU

- CPU
  - Sleep
  - Cut vlotage



- (a)Running at full clock speed
- (b)Cutting voltage by two: cuts clock speed by two, cuts power by four

Power:Memory

- Way1:switch off the cache
- Way2:switch off the main memory
- Reloading
  - ...

Power:Wireless Communication

- Wireless communication
  - Radio transmitter
  - Radio receiver
- Turn off the radio receiver
  - Base station,
  - Buffer?
- Ture off the radio transmitter
  - Buffer
- When should the radio be switched off?

Power:Thermal Management

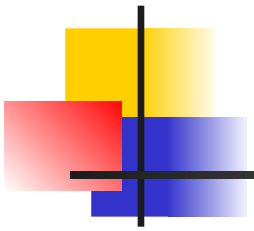
- Thermal 热量
  - Modern CPUs get extremely hot due to their high speed
- Electric Fan
  - Power of Electric Fan?
  - When should the fan be switched off/on?

Power:Battery Management

- Smart Battery
  - Can communicate with the OS
    - Report states of the battery:
      - maxmum voltage, current voltage
      - maxinum charge(负荷), current charge
      - maximum drain(消耗) rate, current drain rate
- Multiple Batteries
- ACPI
  - Advanced Configuration and Power Interface

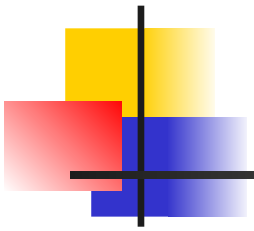
Power: Degrade

- Degrade Operation 退化运行
  - OS tells the programs to use less energy, even if theis means providing a poorer user experience
    - Better a poorer experience than no experience when the battery dies and the lights go out
- How a program can degrade its performance to save energy?
  - tradeoff



Summary

- Principles of I/O Hardware
- Principles of I/O Software
- I/O Software Layers
- Disks
- Clocks
- User Interfaces
- Power Management



Any Questions?