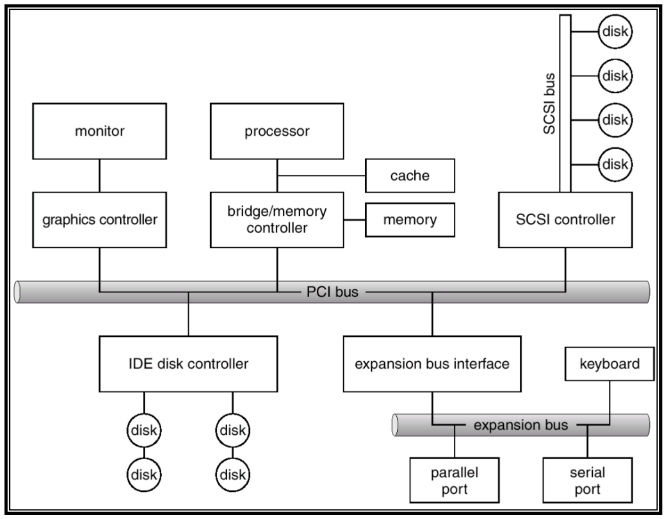
CMSC 412
Fall 2004

I/O Subsystem

Announcements

- Reading
  - Chapter 13
- Project 5 due Wednesday, 6pm
  - Late deadline extended to Friday 6pm
- Project 6 posted Wednesday
  - Due a week from Thursday, 6pm
  - On I/O (stdin, stdout, message passing)

A Typical PC Bus Structure



I/O Hardware

- I/O instructions control devices
- Devices have addresses, used by
  - Direct I/O instructions
    - **`inb, outb`** on Intel x86
  - Memory-mapped I/O
- Device registers to communicate with device
  - Status register, Command register, Data-in register, Data-out register, etc.

Device I/O Port Locations on PCs (partial)

I/O address range (hexadecimal)	device
000-00F	DMA controller
020-021	interrupt controller
040-043	timer
200-20F	game controller
2F8-2FF	serial port (secondary)
320-32F	hard-disk controller
378-37F	parallel port
3D0-3DF	graphics controller
3F0-3F7	diskette-drive controller
3F8-3FF	serial port (primary)

Programmed I/O

- I/O between memory and device is controlled by the CPU
- Two forms
  - Polling/Handshaking I/O
  - Interrupt-driven I/O

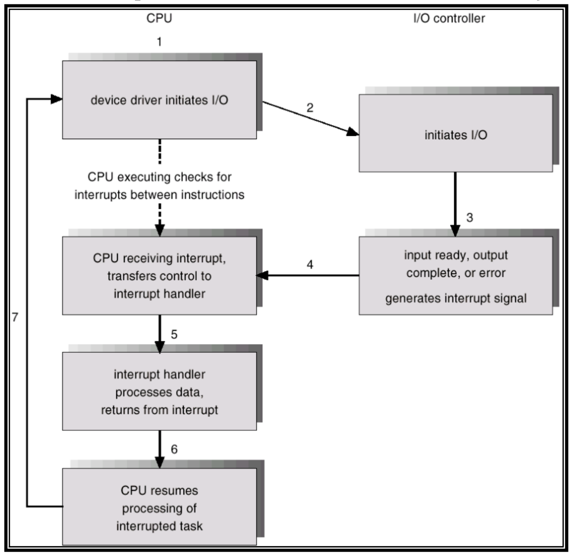
Polling

- CPU checks device status repeatedly (the status bit)
  - If data is available, the CPU will read it (Data-in register).
  - If CPU has data to write, waits until the device is ready, then writes a byte (Sets Command register, writes to Data-out register)

Interrupts

- Device readiness signaled by an interrupt
  - Maskable to ignore or delay some interrupts
  - Interrupt vector to dispatch interrupt to correct handler
    - Based on priority
    - Some unmaskable

Interrupt-Driven I/O Cycle



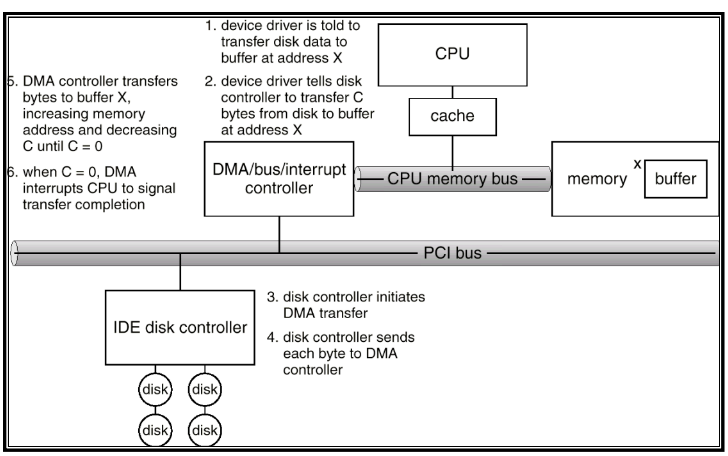
Intel Pentium Processor Event-Vector Table

vector number	description
0	divide error
1	debug exception
2	null interrupt
3	breakpoint
4	INTO-detected overflow
5	bound range exception
6	invalid opcode
7	device not available
8	double fault
9	coprocessor segment overrun (reserved)
10	invalid task state segment
11	segment not present
12	stack fault
13	general protection
14	page fault
15	(Intel reserved, do not use)
16	floating-point error
17	alignment check
18	machine check
19Ð31	(Intel reserved, do not use)
32Ð255	maskable interrupts

Direct Memory Access (DMA)

- Used to avoid programmed I/O for large data movement
- Requires DMA controller
  - Shepherds the data transfer rather than the CPU
  - Uses the memory bus, preventing the CPU from using it

Six Step Process to Perform DMA Transfer



Coping with Many Devices

- Devices vary in many dimensions
  - Character-stream or block
  - Sequential or random-access
  - Sharable or dedicated
  - Speed of operation
  - read-write, read only, or write only
- May have multiple devices of the same type (e.g. two serial ports, two disks)

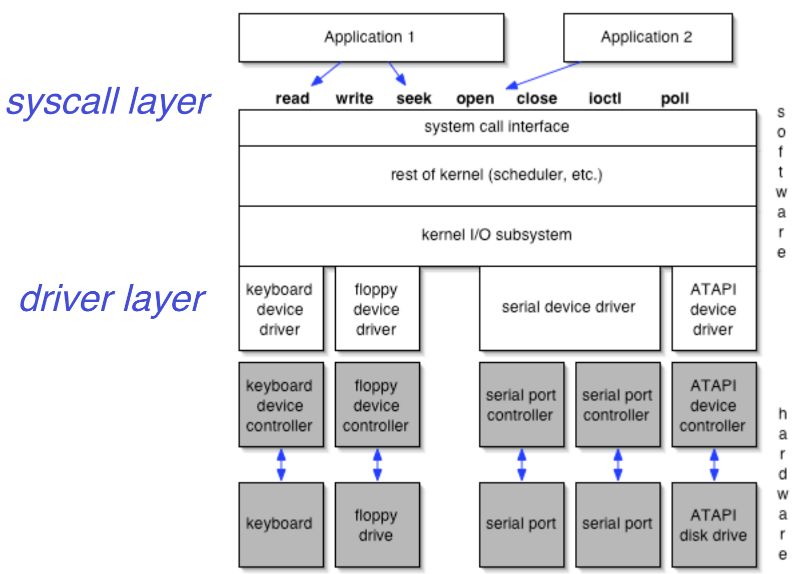
Characteristics of I/O Devices

aspect	variation	example
data-transfer mode	character block	terminal disk
access method	sequential random	modem CD-ROM
transfer schedule	synchronous asynchronous	tape keyboard
sharing	dedicated sharable	tape keyboard
device speed	latency seek time transfer rate delay between operations	
I/O direction	read only write only readÐwrite	CD-ROM graphics controller disk

Abstracting the I/O Interface

- Goal: hide complexity (differences) of different devices from different parts of the OS and applications
  - System call layer encapsulates device behaviors in generic classes
  - Device-driver layer hides differences among I/O controllers (of the same class) from kernel

A Kernel I/O Structure



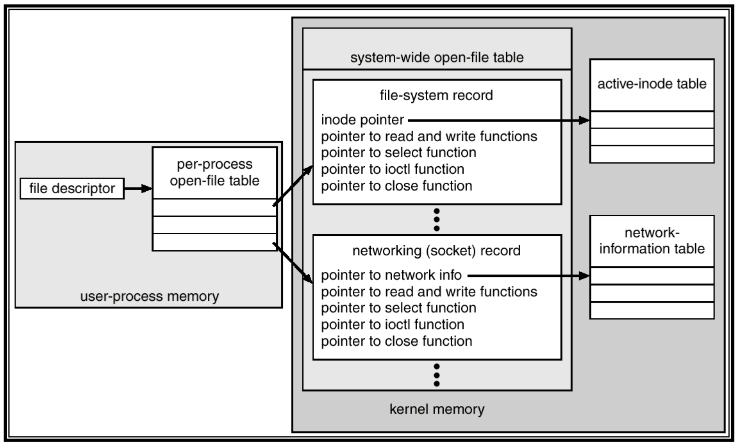
Device Driver

- Device-specific code that implements I/O subsystem's device-generic API
  - For example, there are many kinds of disks supporting the same operations. A driver for disk *X* implements those operations for disk *X*, while another driver does so for disk *Y*.
- How to determine this API? What if a new device supports additional operations?

I/O subsystem

- Kernel keeps state info for I/O components, including open file tables, network connections, character device state
- A key technique is to treat I/O components as objects, each with their own "methods" for implementing I/O API operations.
  - Allows new devices to be added later with little change to I/O subsystem code.

UNIX I/O Kernel Structure



System Call Layer

- Another abstraction boundary
  - Hides differences in device APIs from user application.
- Example: read() system call
  - Can perform on a file, a network socket, a message queue (pipe), a keyboard, …
  - Some of these are block-oriented, some are character-oriented. I/O subsystem hides that fact from user

Block and Character Devices

- Block devices include disk drives
  - Commands include **`read`**, **`write`**, **`seek`**
  - Raw I/O or file-system access
  - Memory-mapped file access possible
- Character devices include keyboards, mice, serial ports
  - Commands include **`get`**, **`put`**
  - Libraries layered on top allow line editing

Network Devices

- Varying enough from block and character to have own interface
- Unix and Windows NT/9*i*/2000 include socket interface
  - Separates network protocol from network operation
- Implementation approaches vary widely (pipes, FIFOs, streams, queues, mailboxes)

Clocks and Timers

- Provide current time, elapsed time, timer
- If programmable interval time used for timings, periodic interrupts
- **`ioctl`** (on UNIX) covers odd aspects of I/O such as clocks and timers

Blocking and Nonblocking I/O

- Blocking - process suspended until I/O completed
  - Easy to use and understand
  - Inhibits application-level concurrency
- Nonblocking - I/O call returns as much data as is available, fails, etc.
  - Returns count of bytes read or written
  - **`select()`** system call to poll
    - Used to implement user-level multi-threading

Example

- Read a key from the keyboard in GeekOS (**`keyboard.c`**)
- Non-blocking: **`Read_Key`**
- Blocking: **`Wait_For_Key`**

Asynchronous I/O

- Process runs while I/O executes
  - Event-driven notification: I/O subsystem signals process when I/O completed. For example, OS invokes a “callback” routine registered by the application at the time of I/O dispatch.

I/O Subsystem Duties

- Scheduling
  - Some I/O request ordering via per-device queue
  - Some OSs try fairness
- Buffering - store data in memory while transferring between devices
  - To cope with device speed mismatch
  - To cope with device transfer size mismatch
  - To maintain “copy semantics”

I/O Subsystem Duties

- Caching - fast memory holding copy of data
  - Always just a copy
  - Key to performance
- Spooling - hold output for a device
  - If device can serve only one request at a time
  - i.e., Printing
- Device reservation - provides exclusive access to a device
  - System calls for allocation and deallocation
  - Possibility of deadlock

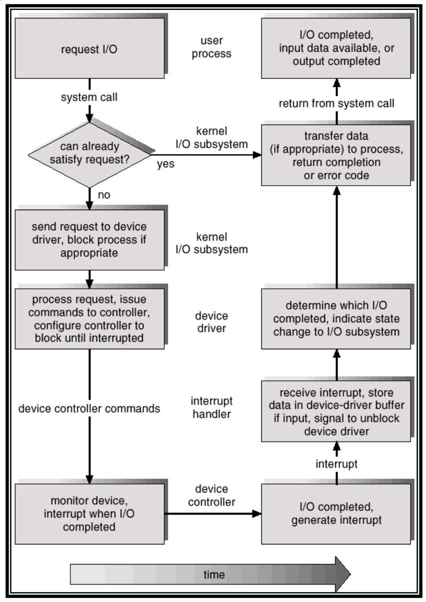
Error Handling

- OS can recover from disk read, device unavailable, transient write failures
- Most return an error number or code when I/O request fails
- System error logs hold problem reports

I/O Requests to Hardware Operations

- Consider reading a file from disk for a process:
  - Determine device holding file
  - Translate name to device representation
  - Physically read data from disk into buffer
  - Make data available to requesting process
  - Return control to process

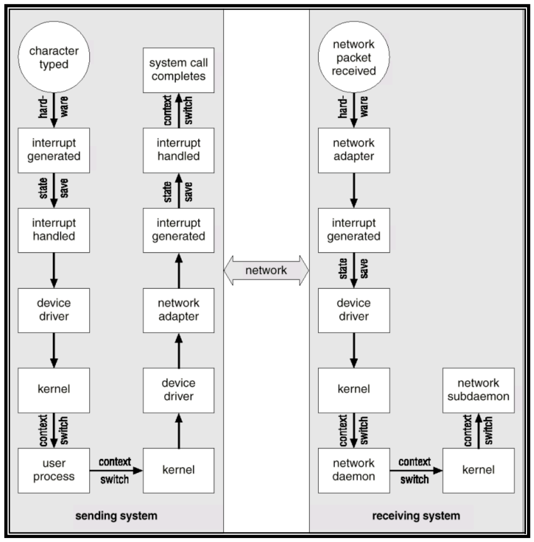
Life Cycle of An I/O Request



Performance

- I/O a major factor in system performance
  – Demands CPU to execute device driver, kernel I/O code
  – Context switches due to interrupts
  – Data copying
  – Network traffic especially stressful

Intercomputer Communications



Improving Performance

- Reduce number of context switches
- Reduce data copying
- Reduce interrupts by using large transfers, smart controllers, polling
- Use DMA
- Balance CPU, memory, bus, and I/O performance for highest throughput

New Device-Functionality Progression