UNIVERSITY of WISCONSIN-MADISON
Computer Sciences Department

CS 537
Intro to Operating Systems

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I/O Devices

Questions answered in these notes

- What are the components of the I/O system?
- How do users interact with I/O devices?
- What can the kernel do to speed up I/O requests?
- How do device drivers interact with device controllers?
- What are the characteristics of modern disks?

Readings for this topic: Chapter 12

Course Overview

- Process Management
  - Synchronization
  - Scheduling
- Memory Management
  - Storage Allocation
  - Virtual Memory
- Disk Management
  - **I/O Devices**
  - File Systems
- Communication
- Security and Protection

Motivation

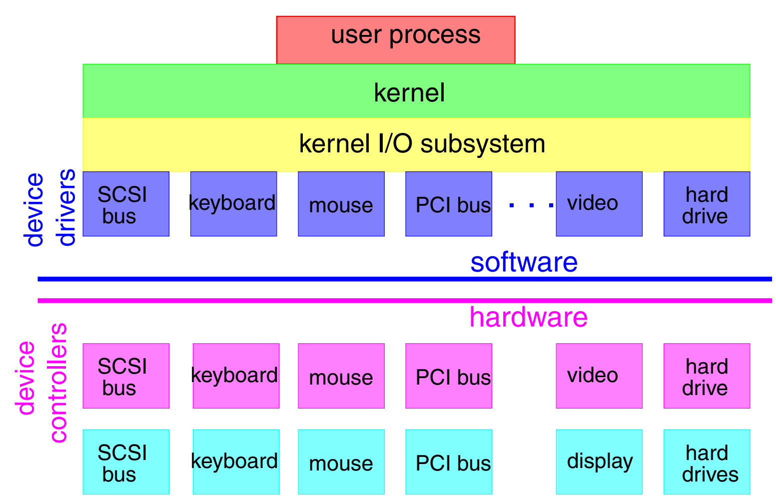
Two primary aspects of computer system

- Processing
- Input/Output

Role of Operating System

- Provide a consistent interface
  - Simplify access to hardware devices
  - Implement mechanisms for interacting with devices
- Allocate and manage resources
  - Protection
  - Fairness
- Obtain efficient performance
  - Understand performance characteristics of device
  - Develop policies

I/O Subsystem



User View of I/O

User processes cannot have direct access to devices

- Manage resources fairly
- Protects data from access-control violations
- Protect system from crashing

Operating system exports higher-level functions

- User process performs system calls (e.g., read() and write())

Blocking vs. Nonblocking I/O

- Blocking: Suspend execution of process until I/O complete
  - Not acceptable if have multiple interactive components
  - Structure application with multiple threads
- Nonblocking: Return from system call immediately
  - Notify when I/O completes in future

User View: Types of Devices

Character-stream

- Transfer one byte at a time (produce data "spontaneously")
- Interface: get() or put()
- Example: keyboard, mice, modems

Block

- Transfer a block of bytes as a unit
  - Variable or fixed-size transfers
- Interface: read() and write()
  - Random access: seek() specifies which byte to transfer next
- Example: disks and tapes

Kernel I/O Subsystem

I/O Scheduling from pool of requests

- Rearrange disk requests for efficiency
- Perform transfers that are near each other on disk

Buffering

- Deal with different transfer rates
  - Double buffer: Producer and consumer switch between two buffers
- Adjust transfer sizes
  - Fragmentation and reassembly
- Copy semantics
  - Can calling process can reuse buffer immediately?

Caching: Keep disk data in memory

- If locality, then next access to data is fast

Device Drivers

Encapsulate details of device

- Wide variety of I/O devices (different manufacturers)
- Kernel I/O subsystem not aware of device details

Load at boot time or after running

UNIX system call: ioctl (I/O control)

- Alternative to adding new system call
- Interface between user processes and device driver
  - file descriptor
  - integer: selects command implemented by device
  - pointer: an arbitrary data structure in memory

Device Driver: Accessing Controller

Special instructions

- Valid only in kernel mode
- No longer popular

Memory-mapped

- Read and write to special memory addresses
- Protect by placing in kernel address space
- Map part of device to user address space for fast access
  - Example: Network Interfaces

Device Driver: Accessing Controller

How do you start an I/O operation?

1. Programmed I/O (PIO)

- Initiate and watch for every byte of I/O operation

2. Direct Memory Access (DMA)

- Offload work to special-purpose processor responsible for large xfers
- CPU initiates DMA transfer
- Write DMA command block into main memory
  - Pointer to source and destination addresses
  - Size of transfer
- Inform DMA controller of address of command block
- DMA controller handles transfer with I/O device controller
- DMA controller interrupts CPU when entire transfer complete
- DMA can use physical or virtual addresses (DVMA)

Interacting with Device Controllers

How to know when event is complete?

1. Polling

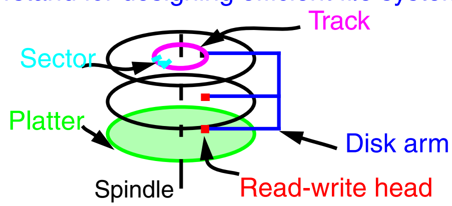
- **Handshake** by setting and clearing flags
- Disadvantage: Busy-waiting
  - Waste cycles when I/O device is slow
  - Must be attentive when device becomes ready (lose data)

2. Interrupts

- Goal: Handle asynchronous events
- Assert **interrupt request line** when device is ready
- CPU jumps to appropriate **interrupt service routine** (ISR)
  - Interrupt vector: Table of ISR addresses
  - Index by interrupt number
- Lower priority interrupts postponed until higher priority finished
- Disadvantage: Costly to be interrupted for every event (use DMA!)

Disk Characteristics

Important to understand for designing efficient file systems



- Sector: Minimum unit of transfer (512 bytes or 1K)
- Two disk arms per platter (except skip outside surfaces)
- Cylinder: Corresponding track on each platter (surface)

To read or write disk block

- **Seek:** Position heads over destination cylinder (worst-case: 5 ms)
- **Rotational delay:** Wait for sector to rotate underneath head (8 ms)
- **Transfer:** Transfer bytes at bandwidth (5 MB/s)

Average performance?

Disk Sectors

How to pick the size of disk sector?

Goal: Increase density of sectors per track

- Increase capacity of disk
- Increase bandwidth (given fixed RPM)

Limitations

- Need space between sectors
    - ECC bits
    - Prevent overwriting next sector
- Internal fragmentation
    - Entire sector may not be filled with useful information

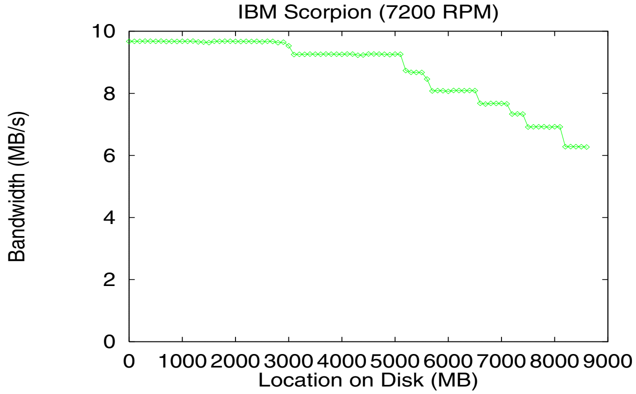
Tracks at outside of disk are longer

- Constant number of sectors per track
    - More space between sectors on outside track
- Constant bit density (multi-zone disks)

Multi-Zone Disks

Outside tracks have more sectors

- Deliver more bandwidth at outside tracks



Implication: Empty disk delivers better bandwidth

Disk Technology Trends

Data --> More dense

- More bits per square inch
- Disk head closer to surface
- Create smaller disks with same capacity

Disk diameter --> smaller

- Spin faster --> Increase bandwidth and shorter rotational delay
- Less distance for head to travel across --> faster seeks
- Lighter weight --> Good for laptops

Disk price --> Cheaper

- Decrease by factor of 2 per year (since 1991)

Density improving more than speed (mechanical limitations)