Outline

- Diversity of I/O devices
  - block and character devices
- Organization of I/O subsystem of kernel
  - device drivers
- Common hardware characteristics of device
- I/O subsystem tasks

I/O subsystem

- Lowest layer of the OS that separates rest of kernel from complexity of managing I/O devices
  - storage
  - transmission (nic/modem)
  - interface (kbd, mouse, screen, printer)
  - special purpose devices

Diversity of devices

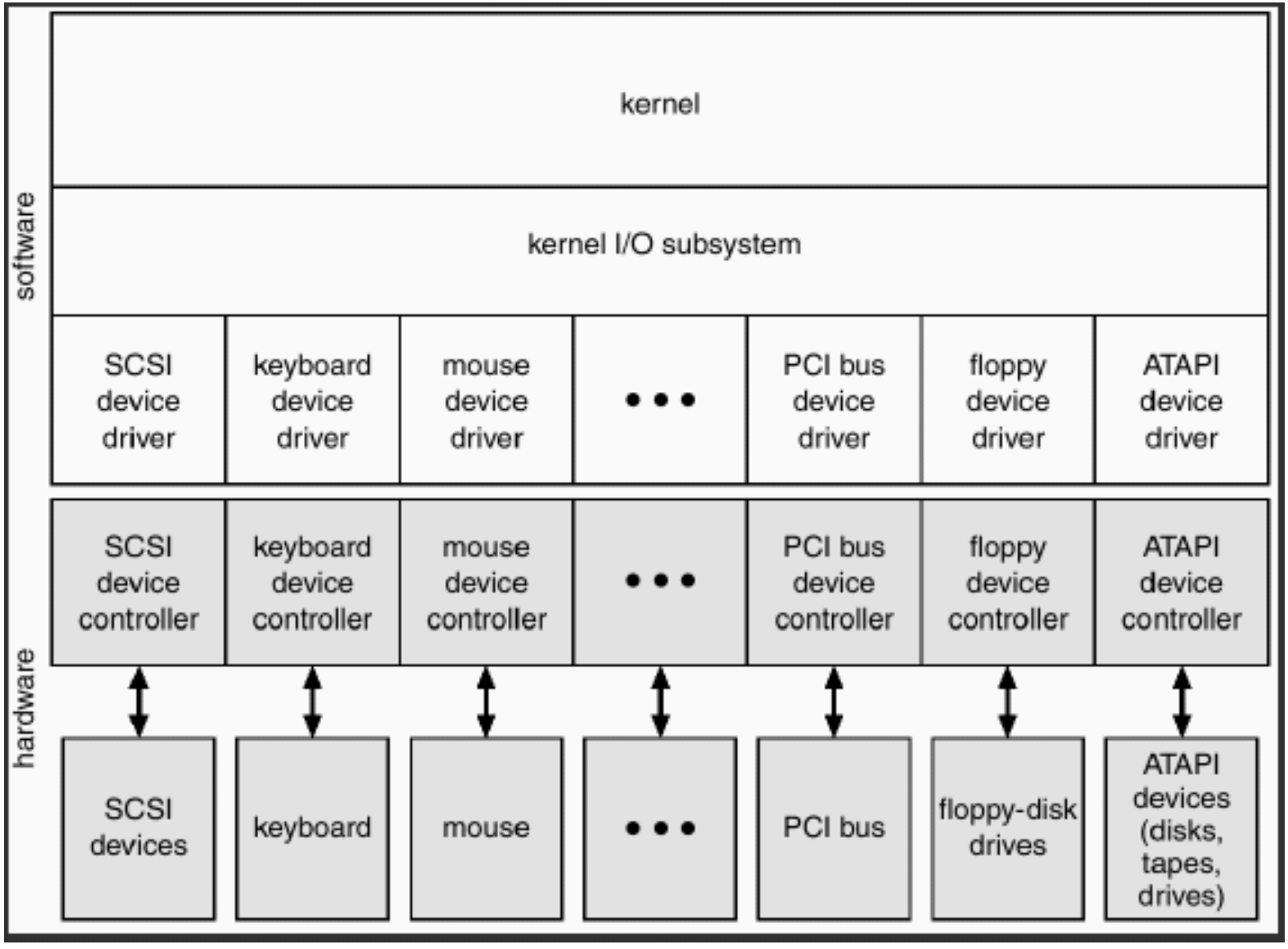
aspect	variation	example
data-transfer mode	character block	terminal disk
access method	sequential random	modem CD-ROM
transfer schedule	synchronous asynchronous	tape keyboard
sharing	dedicated sharable	tape keyboard
device speed	latency seek time transfer rate delay between operations	
I/O direction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

Organization

- I/O devices are grouped into some conventional types
  - each group is accessed via a standardized interface (set of functions)
- I/O subsystem of kernel uses **device drivers** to manage individual devices in each group
- Device driver routines:
  - handle hardware-specific details of operation of devices
  - present uniform interface through which devices are accessed
- `ioctl(fd, OPCODE, buf)` – general I/O control system call
  - enables any application to access any functionality implemented by any device driver

NOTE: hardware manufacturers design devices to be compatible with existing controller interface, or write drivers to provide required interface to the OS.

Organization



Block and character devices

Block devices:

- Unit of data transfer: a block of bytes
- Example: disk drives
- Operations: read, write, seek
- Usually accessed via a filesystem interface
  - raw I/O: OS, DBMS may directly access device as a linear array of blocks

Character devices:

- Unit of data transfer: one byte
- Example: keyboard, terminal, mouse, modem, printers
- Operations:
  - getting / putting one character
  - line-at-a-time access with buffering and editing services

Network devices

- Use a **socket** interface
- Operations:
  - connecting to a remote socket
  - accepting connections to a local socket
  - sending / receiving packets
  - **select** from a set of sockets

Clocks and timers

- Operations: give current time, give elapsed time, set timers / alarms
- Hardware support:
  - clock may send interrupt at every “tick” (coarse)
  - clock may be high-frequency counter (high resolution)
    - value of counter may be read from device register
- Uses of programmable interval timer:
  - time-slicing
  - periodic flushing of buffers to disk
  - network timeouts

Blocking / nonblocking I/O

- Blocking I/O: calling process suspended till I/O completes
- Non-blocking I/O: process gets whatever input is available + status code
- Asynchronous I/O:
  - I/O request is scheduled, process returns immediately
  - completion of I/O communicated via
    - setting a variable
    - calling a callback procedure
    - sending a signal

Hardware components

- **Port:** connection point between device and computer (host)
- **Bus:** set of wires connecting device(s) to host
  - communication between host and device (for control instructions / data) uses well-defined protocol
  - arrangment: daisy chain or shared direct access
- **Controller:** circuit that operates a port / bus / device

  Examples:
  - serial port controller – controls signals on serial port wires
  - SCSI bus controller – circuit that controls SCSI bus
    - contains processor, microcode, private memory to handle SCSI protocol
    - usually implemented on a separate circuit board
  - Disk controller – circuit that implements the disk side of the protocol for the connection type (IDE, SCSI, etc.)
    - contains processor, microcode to handle prefetching, buffering, caching, etc.

Controllers

- Contain registers for data / control signals
  - processor communicates with controller by writing / reading bit patterns into / from these registers
  - **data-in**, **data-out** – read/written to get / send data
    - 1–4 bytes long
  - **control** – commands
  - **status** – whether current command has completed, whether a byte is available for reading, error conditions, etc.
- May contain FIFO chips
  - extension of data register
  - can hold several bytes of input / output data until device / host is able to receive the data

Controllers

- Communication methods:
  - using special I/O instructions
    - triggers bus lines to select proper device and move bits into/ out of DRs
  - using memory mapped I/O
    - DRs are mapped into CPU's address space
    - standard `LOAD`, `STORE` instructions used to read / write DRs
  - combination of I/O instructions + memory-mapped I/O

    Example: some graphics controllers
    - I/O ports used for basic control operations
    - large memory-mapped region used to hold screen contents
      (processor sends I/O to screen by writing data into memory-mapped region)

I/O subsystem tasks: scheduling

Aim: to determine a “good” order of execution for a set of I/O requests

- improve overall system performance
- reduce average waiting time for I/O completion
- ensure better service to higher priority / delay-sensitive requests (e.g. from virtual memory sub-system)
- ensure fairness (?)

I/O subsystem tasks: buffering/caching

- Aim:
  - to cope with speed mismatch between producer and consumer of data
    (i) data arriving from slow device is accumulated in a buffer until full
    (ii) full buffer written to fast device in single operation
    (iii) 2nd buffer used while 1st buffer is being written to disk
  - to adapt between devices with different data transfer sizes (e.g.network packet fragmentation and reassembly)
  - to support “copy semantics” for I/O
    - write operations write single version of data (no mixing of old and new data can happen)
- Same space may be used for both caching and buffering

NOTE: *Buffer* may hold only existing copy of data (e.g. network I/O buffer)
Cache necessarily holds a copy of a data item that is originally stored elsewhere.

I/O subsystem tasks: spooling

- Spool: buffer that holds output for a device that cannot accept interleaved data streams from multiple concurrent applications (e.g. printer, tape drive)
- I/O subsystem serializes concurrent output from multiple processes
- Implementation:
  (i) output from separate processes is spooled to separate files
  (ii) spooling system queues spool files for output to device
- Spooling system interface typically provides control interface for viewing, pausing, removing jobs

I/O subsystem tasks: error handling

- Transient failures handled by kernel
  e.g. disk-read / network-send failure $\Rightarrow$ automatic retry
- SCSI devices error reporting
  - *sense key:* specifies general nature of failure
    (e.g. h/w error, illegal request, etc.)
  - *additional sense code:* category of failure
    (e.g. bad command parameter, self-test failure, etc.)
  - *additional sense code qualifier:* more detailed information
    (e.g. which command parameter, which subsystem failed, etc.)

Disk structure

- Sector 0: 1st sector of 1st track of outermost cylinder
- Sectors numbered sequentially by sector, track, cylinder (outer $\rightarrow$ inner)
- Zones: groups of cylinders for which # sectors per track is constant
  (outer zones have $\sim 40\%$ more sectors per track than innermost zones)
- # sectors/track: ~ 100; # cylinders/disk: $\sim 10^3$

I/O time: seek time + rotational latency + transfer time

Disk scheduling

- **FCFS**
  - fair algorithm (no starvation)
  - poor performance
- **Shortest seek-time first**: choose pending request that is closest to current head position
  - starvation possible
  - better than FCFS, but non-optimal
- **SCAN/Elevator**: disk arm moves from one end to the other and back, servicing requests
- **C-SCAN**: no requests serviced on return trip
  - more uniform wait time
- **LOOK, C-LOOK**: disk arm moves till farthest request in each direction (instead of end of disk)

OS issues:

- Physical layout of directories and files
- Scheduling algorithms may be implemented in hardware / software