
# I/O Management

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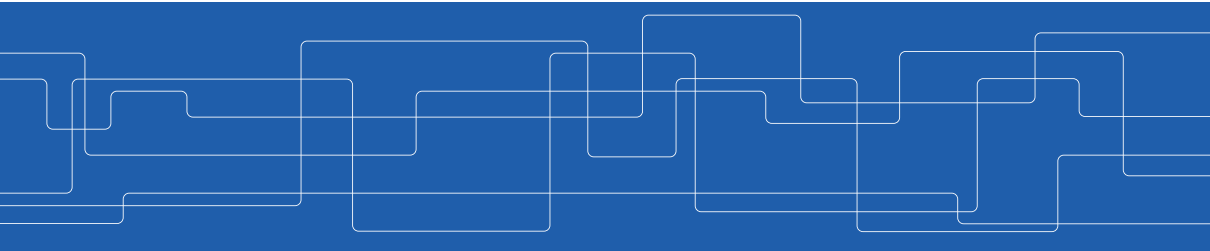



# Overview

- I/O management is a major component of OS design and operation.
- Ports, busses, device controllers connect to various devices.
- Device drivers encapsulate device details.
  - Present uniform device-access interface to I/O subsystem.


# I/O Hardware


# I/O Hardware

- Variety of I/O devices:
  - Storage, e.g., disks, tapes
  - Transmission, e.g., network connections, bluetooth
  - Human-interface, e.g., screen, keyboard, mouse, audio in and out
- We only need to understand how the devices are attached and how the software can control the hardware.


# Common Concepts in I/O Hardware

- Port: connection point for device.
- Bus: set of wires and protocols that specify the messages that can be sent on the wires.
- Controller: integrated or separate circuit board that operate a port, a bus, or a device.

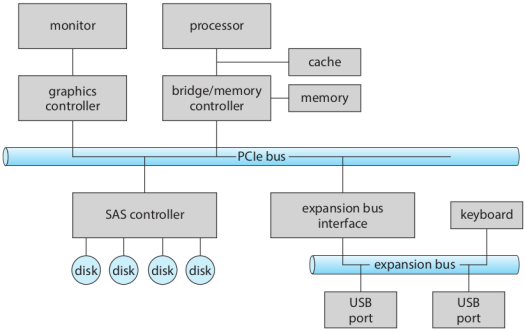
# Port

- Device I/O ports addresses on PCs.

| 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) |

# Bus

- PCI bus: connects the processor-memory subsystem to fast devices.
- Expansion bus: connects relatively slow devices.
- Serial-attached SCSI (SAS)




# Host-Device Interaction


# Host-Device Interaction

- Polling
- Interrupt
- Direct memory access (DMA)


# Polling (1/2)

- A handshake between the host and a controller.
- Assume 2 bits for coordination: `busy` and `command-ready` bits.
- For each byte of I/O:
  1. Host reads the `busy` bit from the status register until 0.
  2. Host sets the `write` bit and if write copies data into the data-out register.
  3. Host sets the `command-ready` bit.
  4. Controller sets the `busy` bit, executes transfer.
  5. Controller clears the `busy` bit, `error` bit, and `command-ready` bit when transfer done.

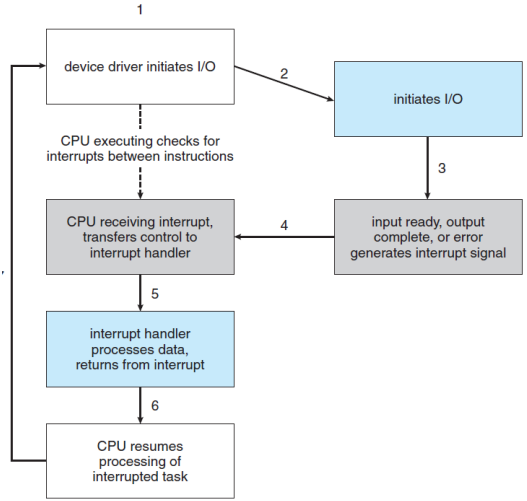

# Polling (2/2)

- Step 1 is busy-wait cycle (polling) to wait for I/O from device.
- Reasonable if device is fast.
- But inefficient if device slow.


# Interrupts (1/3)

- Polling can happen in 3 instruction cycles.
  - (1) read status, (2) extract status bit, and (3) branch if not zero.
  - Inefficient, but more efficient way?
- CPU interrupt-request line is triggered by I/O device.
  - Checked by processor after each instruction.
  - Saves state and jumps to interrupt-handler routine at a fixed address in memory.

# Interrupts (2/3)



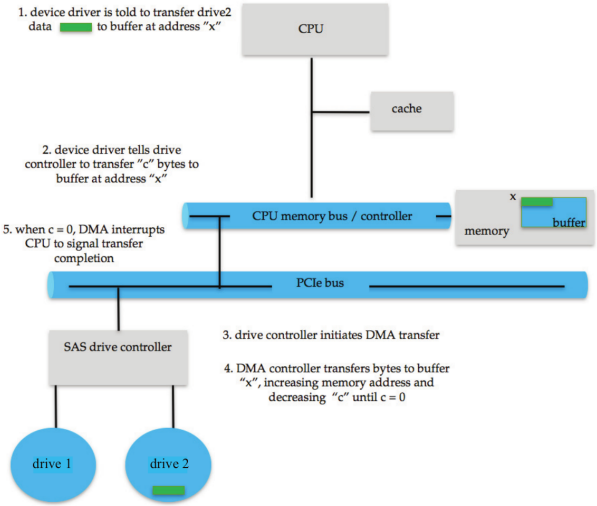
# Interrupts (3/3)

- The interrupt mechanism accepts an address: a number that selects a specific interrupt-handling routine.

| 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 |
| 19–31 | (Intel reserved, do not use) |
| 32–255 | maskable interrupts |

# Direct Memory Access (DMA)

- Bypasses CPU to transfer data directly between I/O device and memory.




# Application I/O Interface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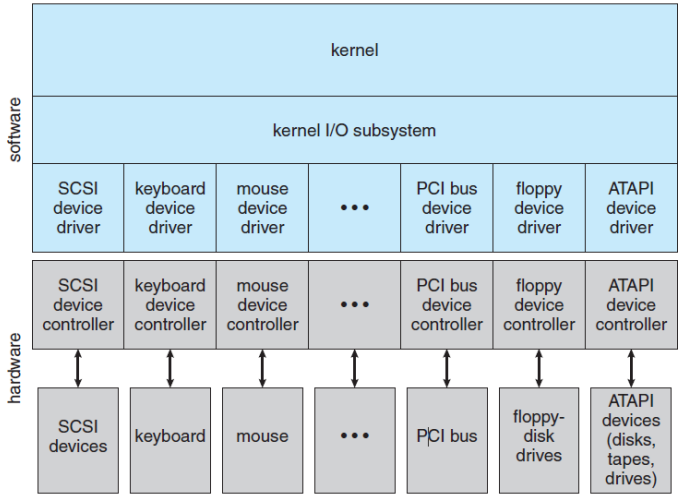
- I/O system calls encapsulate device behaviors in generic classes.
- Device-driver layer hides differences among I/O controllers from kernel.
- Each OS has its own I/O subsystem structures and device driver frameworks.

# A Kernel I/O Structure




# Characteristics of I/O Devices (1/2)

- Devices vary in many dimensions
  - Data-transfer mode: character or block
  - Access method: sequential or random-access
  - Transfer schedule: synchronous or asynchronous (or both)
  - Sharing: sharable or dedicated
  - Device speed: speed of operation
  - I/O direction: read-write, read only, or write only

# Characteristics of I/O Devices (2/2)

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


# Character Devices

- Character devices include keyboards, mouse, serial ports.
- A character device transfers bytes one by one.
- Commands include `get()` and `put()`.

# Block Devices

- Block devices include disk drives.
- Commands include `read()` and `write()` and `seek()` for random-access devices.


# Network Devices

- Varying enough from block and character to have own interface.
- Linux, Unix, Windows and many others include socket interface.
  - Separates network protocol from network operation.

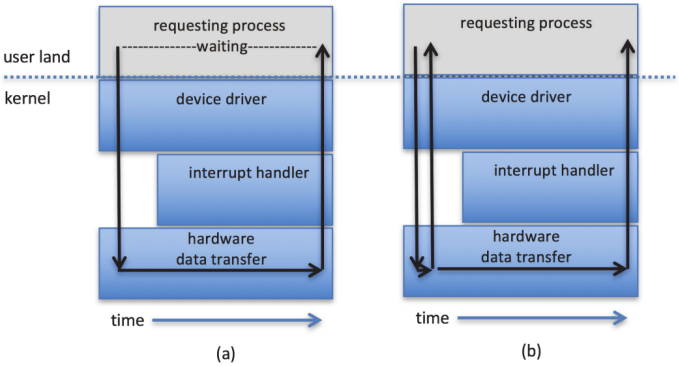

# Clocks and Timers

- Provide current time, elapsed time, and timer (trigger operation X at time T)
- Programmable interval timer, the hardware used for timings, and periodic interrupts.
- Normal resolution about 1/60 second.
- Some systems provide higher-resolution timers.


# Blocking, Nonblocking and Asynchronous I/O

- Blocking: process suspended until I/O completed
  - Insufficient for some needs
- Nonblocking: I/O call returns as much as available
  - User interface, data copy (buffered I/O)
  - Implemented via multi-threading
  - `select()` to find if data ready then `read()` or `write()` to transfers.
- Asynchronous: process runs while I/O executes
  - I/O subsystem signals process when I/O completed.

# Synchronous vs. Asynchronous I/O Methods




Synchronous Asynchronous


# Kernel I/O Subsystem


# Kernel I/O Subsystem

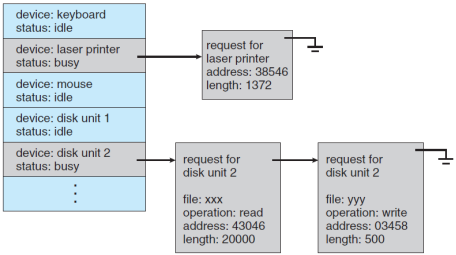
- Kernels provide many services related to I/O:
  - Scheduling
  - Buffering
  - Caching
  - Spooling
  - Device reservation
  - Error handling


# Scheduling (1/2)

- Determine a good order in which to execute I/O requests.
- Some I/O request ordering via per-device queue.
- Some OSs try fairness.

# Scheduling (2/2)

- In asynchronous I/O the kernel must be able to keep track of many I/O requests at the same time.
  - The OS attaches the wait queue to a device-status table.
  - The table contains an entry for each I/O device.
  - If the device is busy with a request, the type of request and other parameters will be stored in the table entry for that device.




# Buffering and Caching

- Buffering: stores data in memory while transferring between devices.
  - To cope with device speed mismatch.
  - To cope with device transfer size mismatch, e.g., fragmentation and reassembly of messages.
  - To maintain copy semantics.
- Caching: faster device holding copy of data.
  - Always just a copy
  - Key to performance


# Spooling and Device Reservation

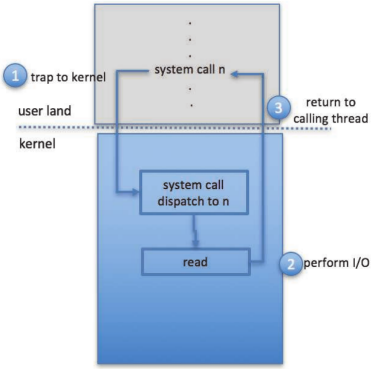
- Spooling: a buffer that holds output for a device.
  - If device can serve only one request at a time, i.e., printing
- Device reservation: provides exclusive access to a device.
  - System calls for allocation and de-allocation
  - Watch out for deadlock


# Error Handling

- OS can recover from disk read, device unavailable, and transient write failures.
  - Retry a read or write.
  - Track error frequencies, stop using device with increasing frequency of retry-able errors.
- Most return an error number when I/O request fails.
- System error logs hold problem reports.

# I/O Protection

- A user process may accidentally or purposefully attempt to disrupt normal operation via illegal I/O instructions.
- I/O must be performed via system calls.




# Summary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- I/O hardware: port, bus, controller
- Host-device interaction: polling, interrupt, DMA
- Devices: char, block, network
- Kernel I/O: schedulling, buffering, caching, spooling, device reservation, error handling


# Questions?

## Acknowledgements

Some slides were derived from Avi Silberschatz slides.