I/O Management

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- 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

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- 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

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- We only need to understand how the devices are attached and how the software can control the hardware.

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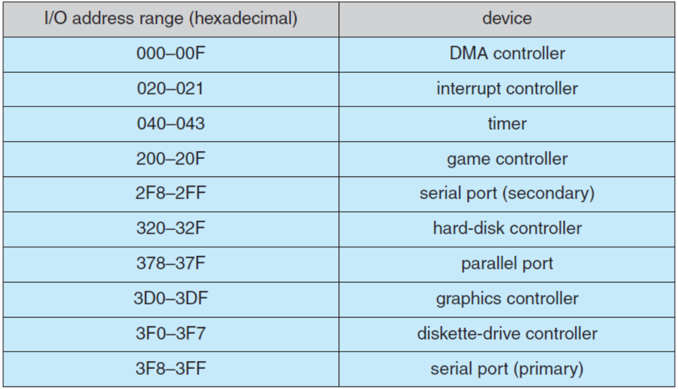
- Bus: set of wires and protocols that specify the messages that can be sent on the wires.
- Controller: integrated or separate circuit board that operate a port, a bus, or a device.

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

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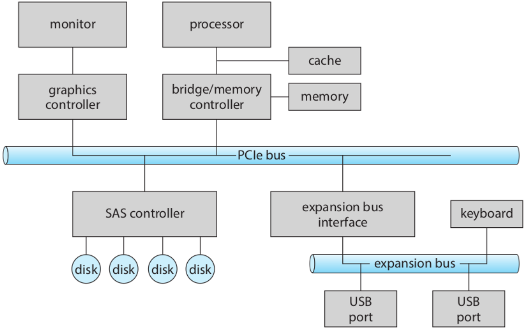

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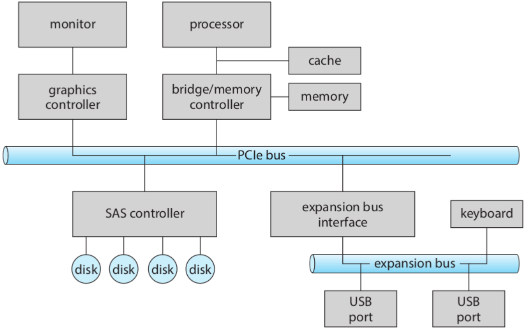

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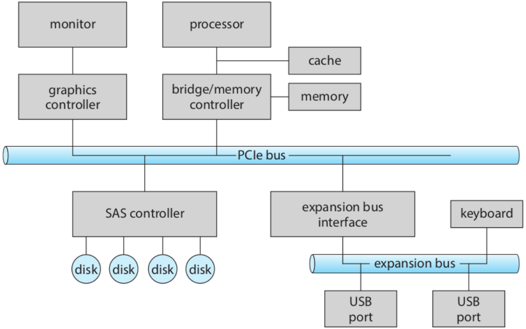
- Serial-attached SCSI (SAS)



Host-Device Interaction

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- Polling
- Interrupt
- Direct memory access (DMA)

Polling (1/2)

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  4. Controller sets the `busy` bit, executes transfer.
  5. Controller clears the `busy` bit, `error` bit, and `command-ready` bit when transfer done.

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- But inefficient if device slow.

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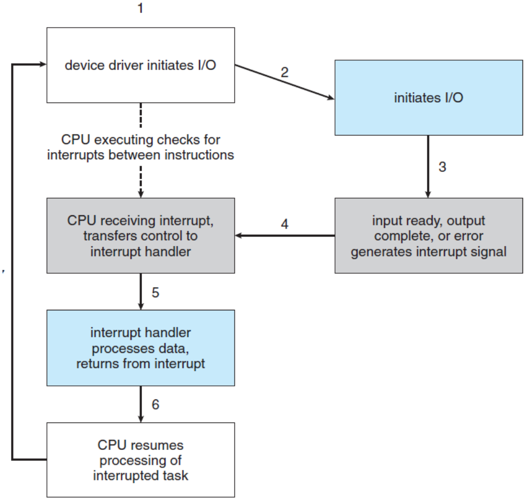
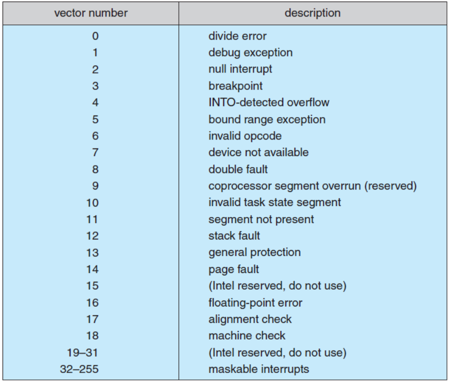
  - Saves state and jumps to interrupt-handler routine at a fixed address in memory.

Interrupts (2/3)


1
device driver initiates I/O
2
initiates I/O
CPU executing checks for interrupts between instructions
3
CPU receiving interrupt, transfers control to interrupt handler
4
input ready, output complete, or error generates interrupt signal
5
interrupt handler processes data, returns from interrupt
6
CPU resumes processing of interrupted task

Interrupts (3/3)

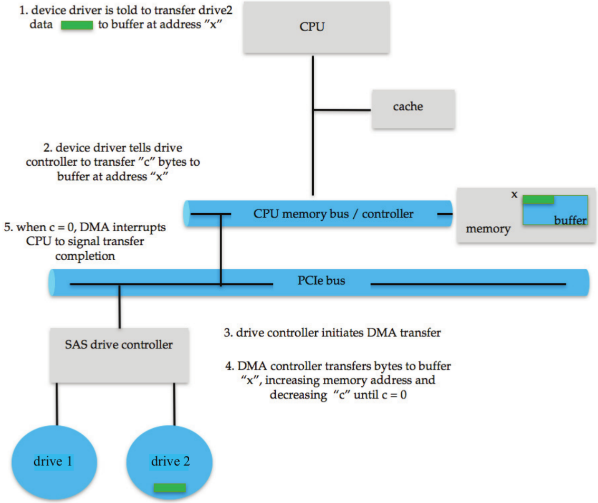
- The interrupt mechanism accepts an address: a number that selects a specific interrupt-handling routine.



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.


1. device driver is told to transfer drive2 data 🟩 to buffer at address "x"
CPU
cache
2. device driver tells drive controller to transfer "c" bytes to buffer at address "x"
CPU memory bus / controller
x
buffer
memory
5. when c = 0, DMA interrupts CPU to signal transfer completion
PCIe bus
SAS drive controller
3. drive controller initiates DMA transfer
4. DMA controller transfers bytes to buffer "x", increasing memory address and decreasing "c" until c = 0
drive 1
drive 2

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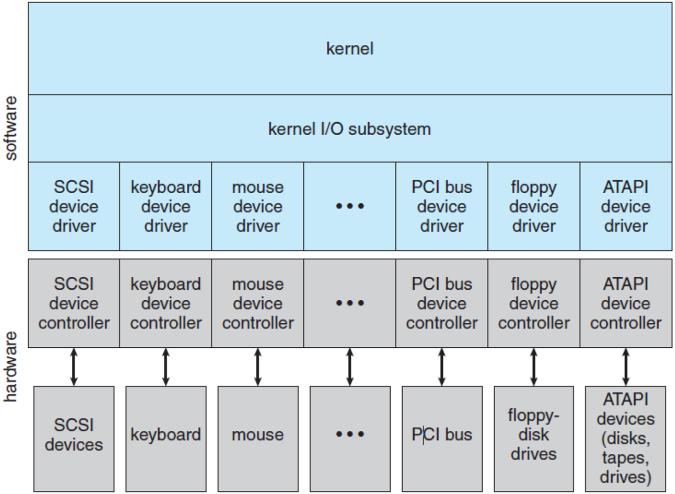
- Each OS has its own I/O subsystem structures and device driver frameworks.

A Kernel I/O Structure



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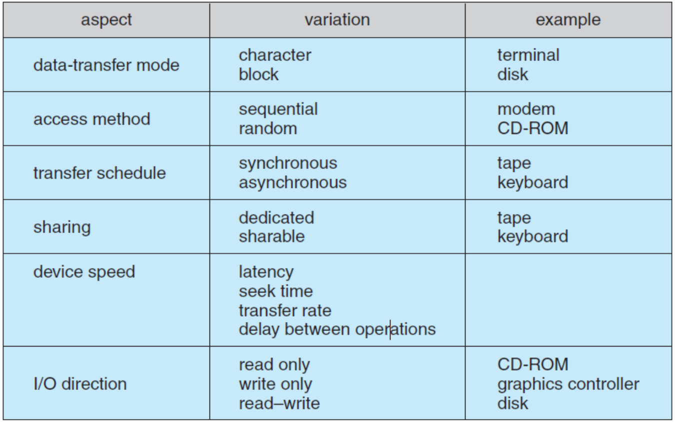
  - I/O direction: read-write, read only, or write only

Characteristics of I/O Devices (2/2)



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 read–write	CD-ROM graphics controller disk

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- Commands include `get()` and `put()`.

Block Devices

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

Network Devices

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- Linux, Unix, Windows and many others include socket interface.
  - Separates network protocol from network operation.

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- Programmable interval timer, the hardware used for timings, and periodic interrupts.
- Normal resolution about 1/60 second.
- Some systems provide higher-resolution timers.

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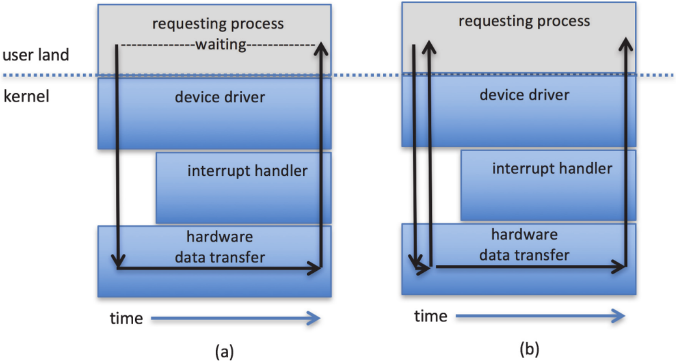
- Asynchronous: process runs while I/O executes
  - I/O subsystem signals process when I/O completed.

Synchronous vs. Asynchronous I/O Methods



Synchronous

Asynchronous

Kernel I/O Subsystem

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- Some OSs try fairness.

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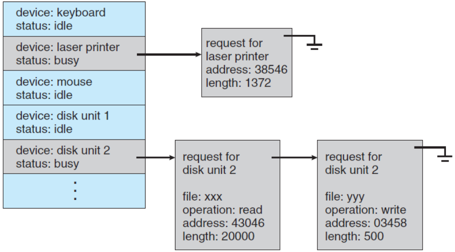

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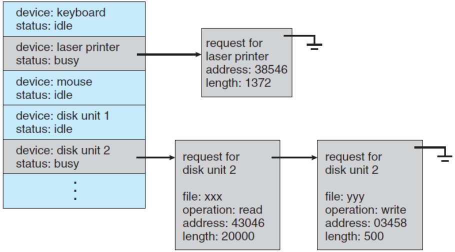

device: keyboard
status: idle

device: laser printer
status: busy

device: mouse
status: idle

device: disk unit 1
status: idle

device: disk unit 2
status: busy

⋮

request for
laser printer
address: 38546
length: 1372

request for
disk unit 2

file: xxx
operation: read
address: 43046
length: 20000

request for
disk unit 2

file: yyy
operation: write
address: 03458
length: 500

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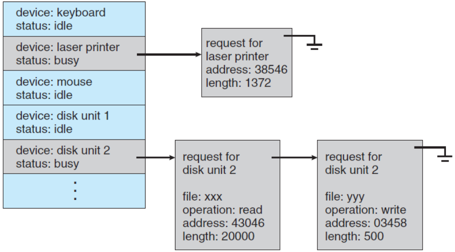
  - The OS attaches the wait queue to a device-status table.
  - The table contains an entry for each I/O device.
  - If the device is busy with a request, the type of request and other parameters will be stored in the table entry for that device.



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- **Caching**: faster device holding copy of data.
  - Always just a copy
  - Key to performance

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- 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

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  - 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.

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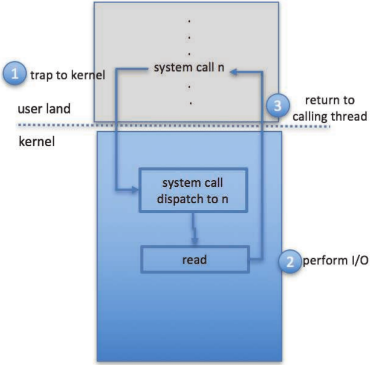
- I/O must be performed via system calls.



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- Kernel I/O: schedulling, buffering, caching, spooling, device reservation, error handling

Questions?

Acknowledgements

Some slides were derived from Avi Silberschatz slides.