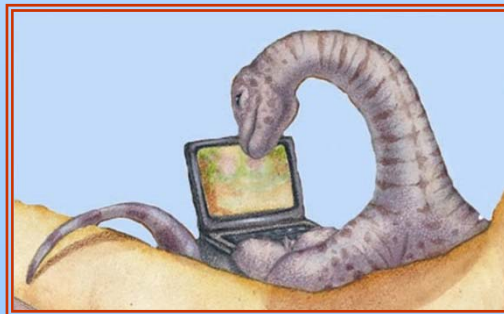


# Chapter 13: I/O Systems





# Chapter 13: I/O Systems

- I/O Hardware
- Application I/O Interface
- Kernel I/O Subsystem
- Transforming I/O Requests to Hardware Operations
- Streams
- Performance





# Objectives

- Explore the structure of an operating system's I/O subsystem
- Discuss the principles of I/O hardware and its complexity
- Provide details of the performance aspects of I/O hardware and software





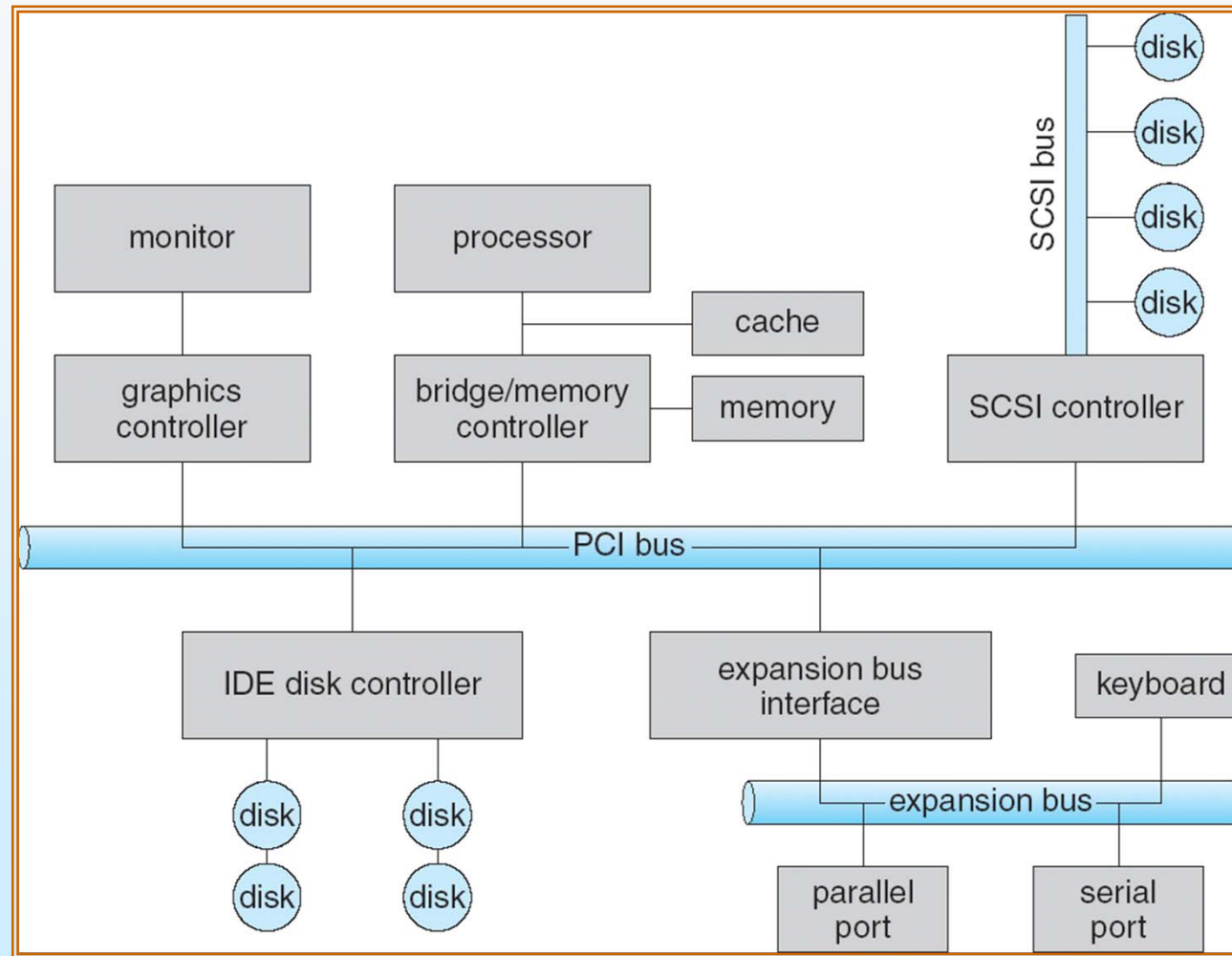
# I/O Hardware

- Incredible variety of I/O devices
- Common concepts
  - **Port**
  - **Bus (daisy chain or shared direct access)**
  - **Controller (host adapter)**
- I/O instructions control devices
- Devices have addresses, used by
  - Direct I/O instructions
  - **Memory-mapped I/O**





# A Typical PC Bus Structure





## 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)





# Polling

- Determines state of device
  - command-ready
  - busy
  - Error
- **Busy-wait** cycle to wait for I/O from device





# Interrupts

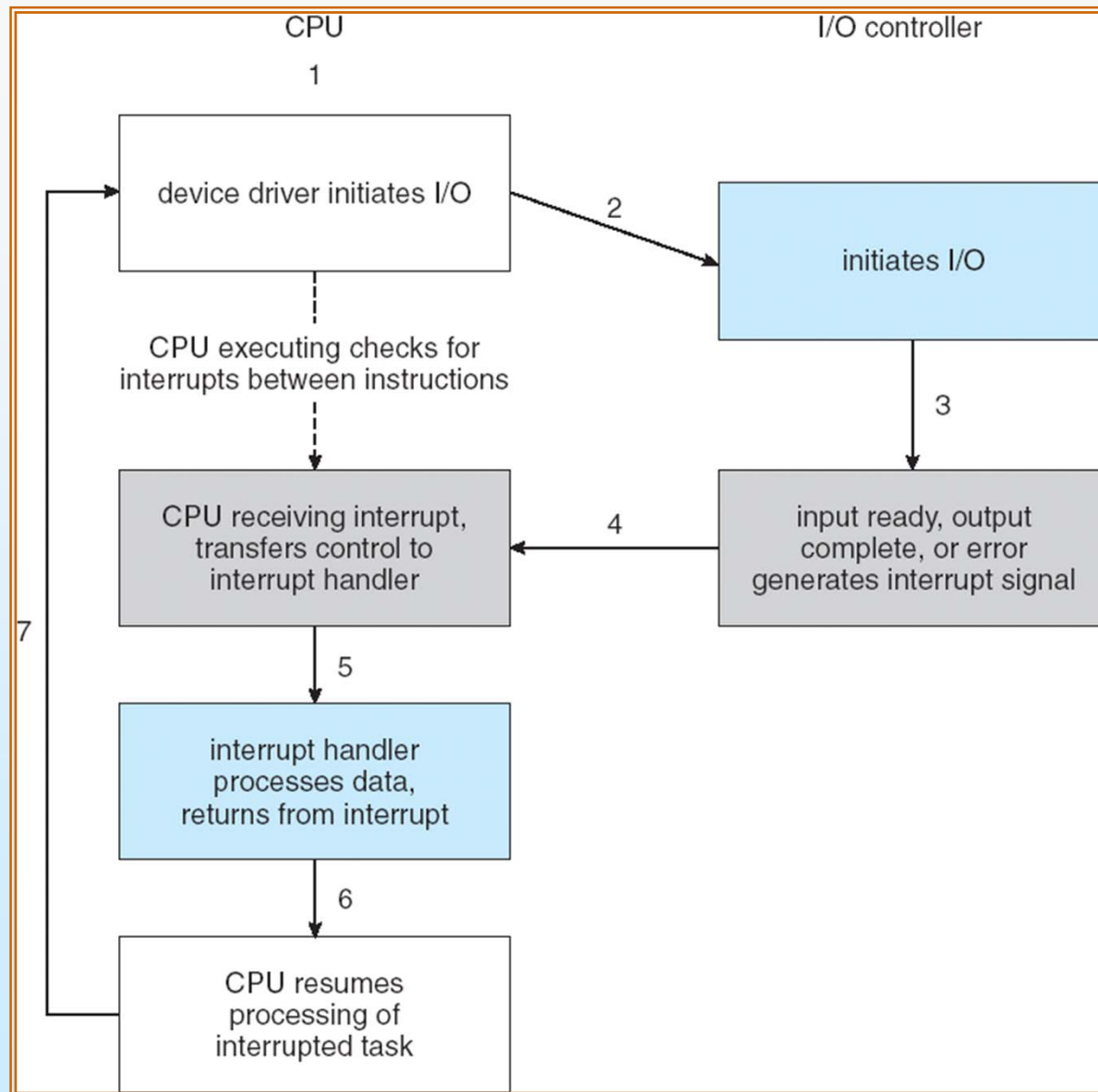
- CPU **Interrupt-request line** triggered by I/O device
- **Interrupt handler** receives interrupts
- **Maskable** to ignore or delay some interrupts
- Interrupt vector to dispatch interrupt to correct handler
  - Based on priority
  - Some **nonmaskable**
- Interrupt mechanism also used for exceptions







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





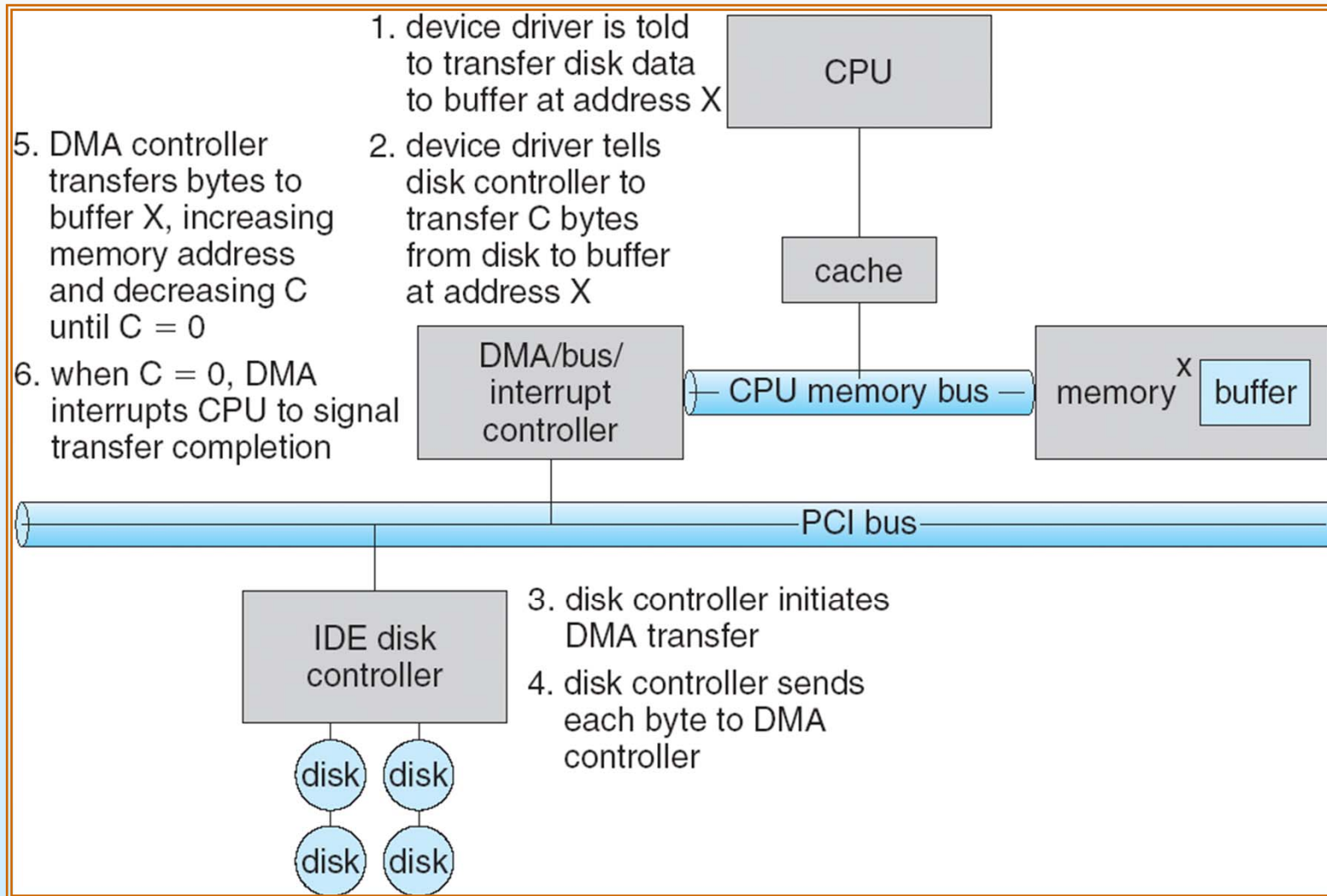
# Direct Memory Access

- Used to avoid **programmed I/O** for large data movement
- Requires **DMA** controller
- Bypasses CPU to transfer data directly between I/O device and memory





# Six Step Process to Perform DMA Transfer





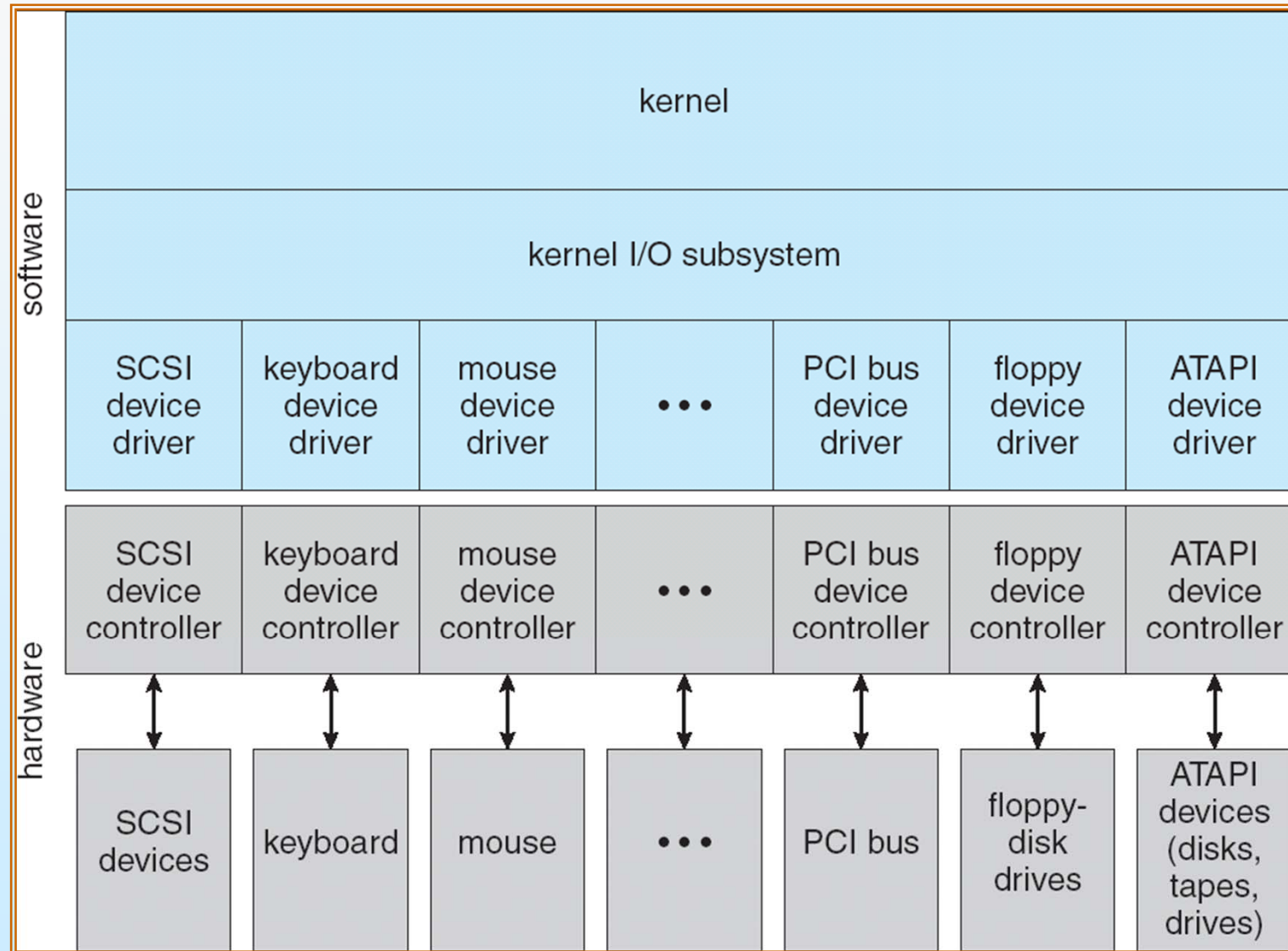
# Application I/O Interface

- I/O system calls **encapsulate** device behaviors in generic classes
- Device-driver layer **hides differences** among I/O controllers from kernel
- 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**





# A Kernel I/O Structure







# 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 read–write	CD-ROM graphics controller disk





# 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/9x/2000 include socket interface
  - Separates network protocol from network operation
  - Includes `select` functionality
- Approaches vary widely (pipes, FIFOs, streams, queues, mailboxes)





# Clocks and Timers

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





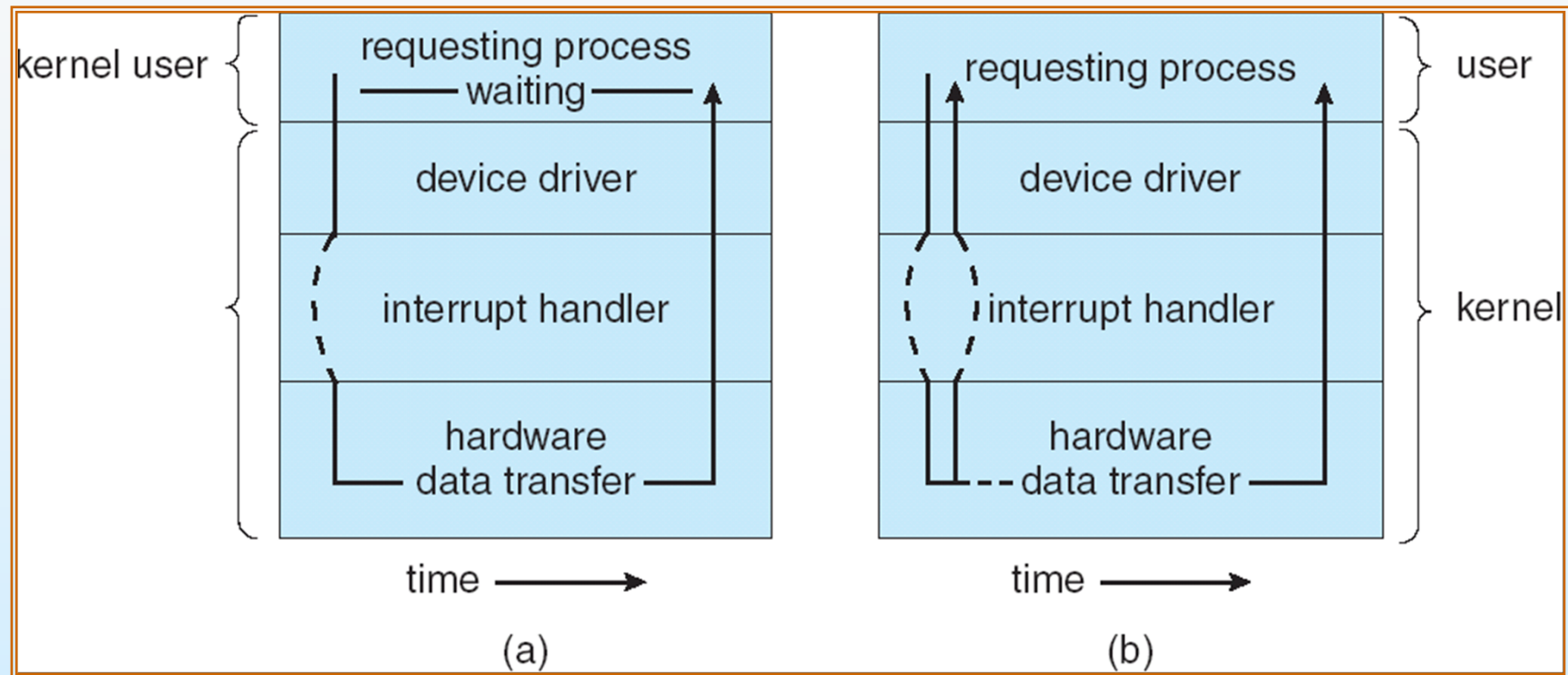
# Blocking and Nonblocking I/O

- **Blocking** - process **suspended** until I/O completed
  - Easy to use and understand
  - Insufficient for some needs
- **Nonblocking** - I/O call returns as much as available
  - User interface, data copy (buffered I/O)
  - Implemented via multi-threading
  - Returns quickly with **count of bytes read or written**
- **Asynchronous** - process runs while I/O executes
  - Difficult to use
  - I/O subsystem signals process when I/O completed





# Two I/O Methods



Synchronous

Asynchronous





# Kernel I/O Subsystem

## ■ Scheduling

- Some I/O request **ordering** via per-device queue
- Some OSs try fairness

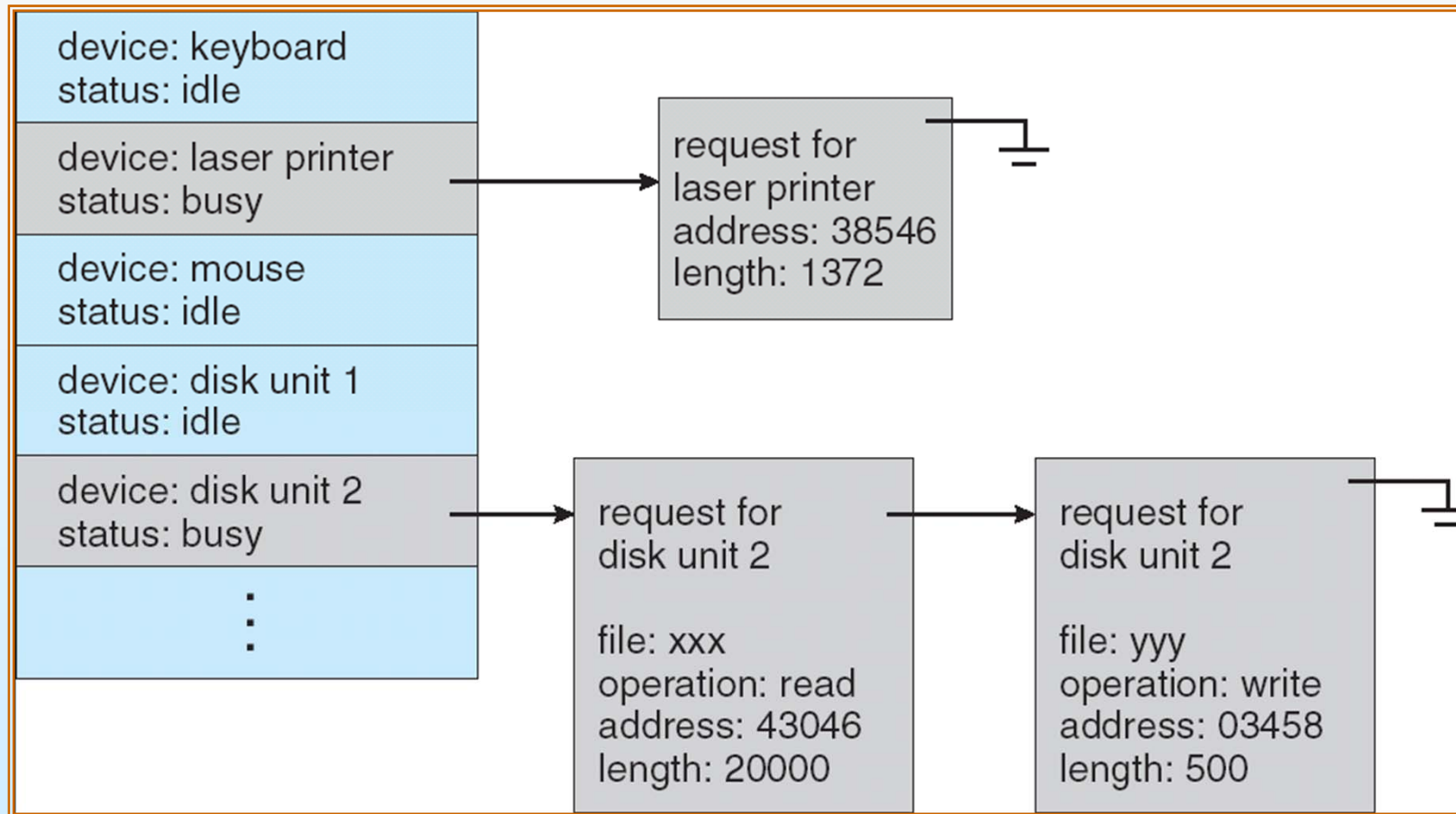
## ■ Buffering - store data **in memory** while transferring between devices

- To cope with device speed **mismatch**
- To cope with device transfer **size mismatch**
- **To maintain “copy semantics”**



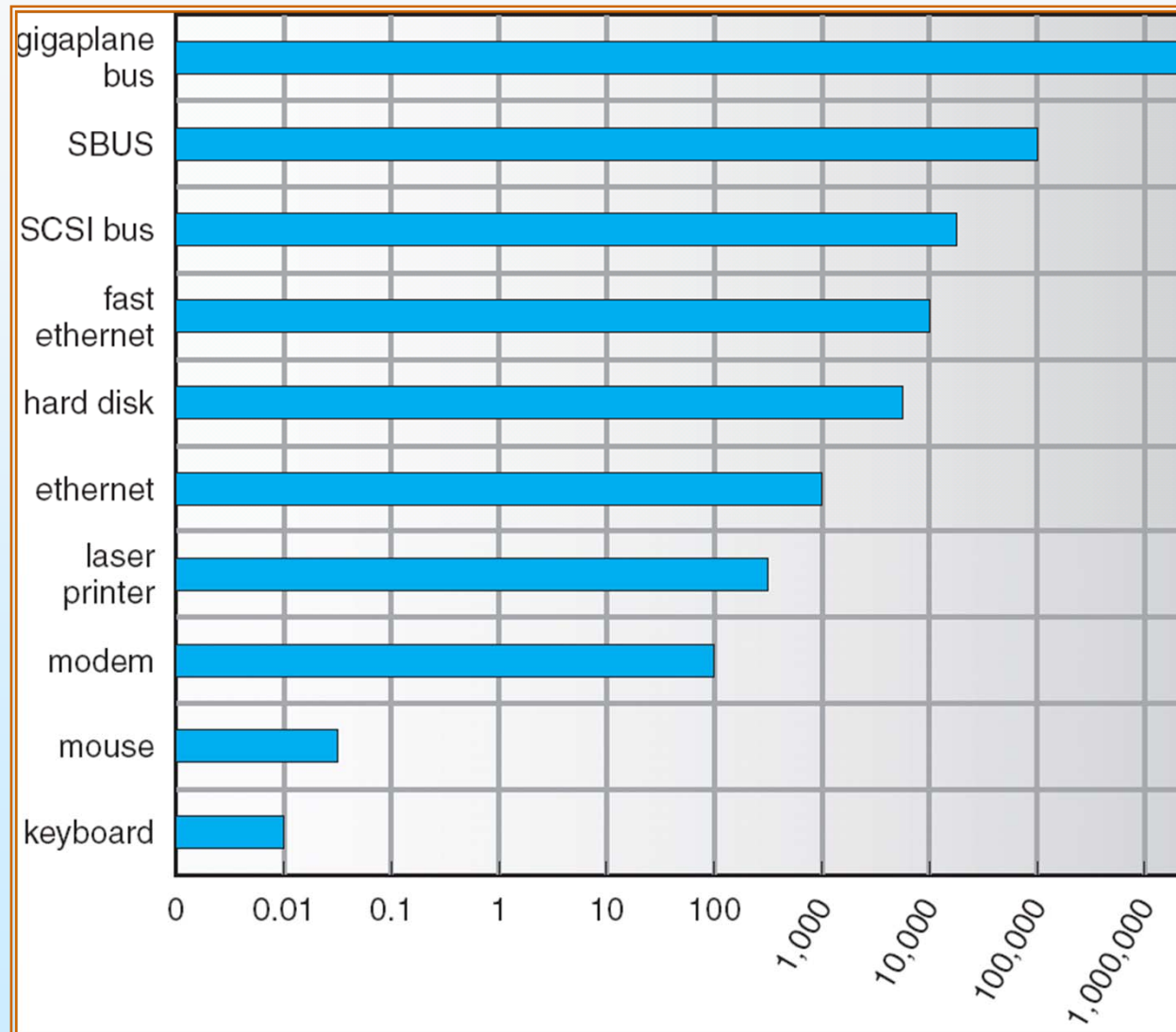


# Device-status Table





# Sun Enterprise 6000 Device-Transfer Rates





# Kernel I/O Subsystem

- **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
  - Watch out for 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





# 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



# End of Chapter 13

