

CS420: Operating Systems

I/O Systems

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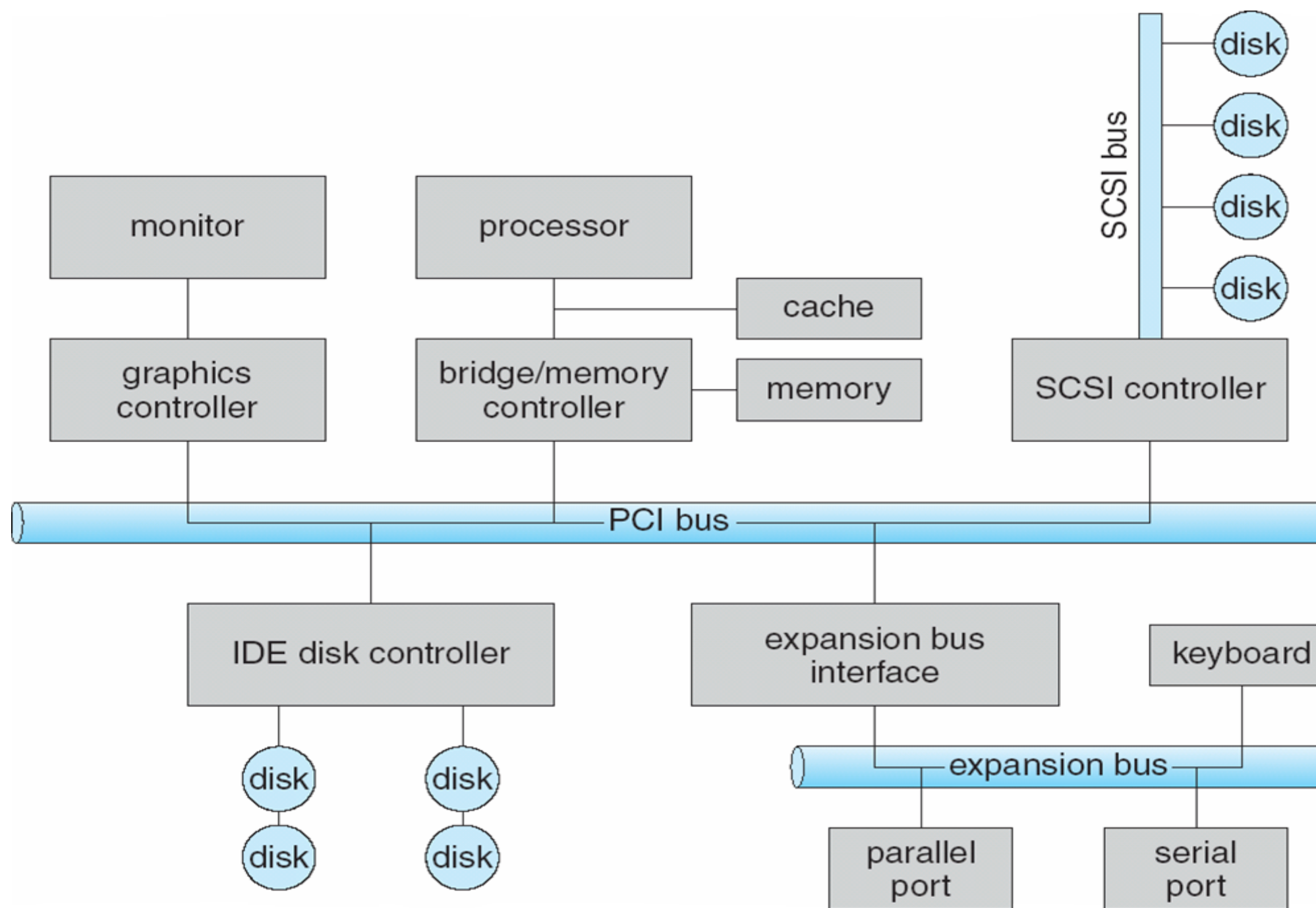
Overview

- **I/O management is a major component of operating system design and operation**
 - Important aspect of computer operation
 - I/O devices vary greatly
 - Various methods to control them
 - Performance management
 - New types of devices frequent
- **Ports, buses, device controllers connect to various devices**
- **Device drivers encapsulate device details**
 - Present uniform device-access interface to I/O subsystem

I/O Hardware

- **Incredible variety of I/O devices**
 - Storage (hard disk drives, flash drives, CDs, DVD, etc.)
 - Transmission (wireless network cards, Ethernet cards, modems ;-)
 - Human-interface (mouse, keyboard, trackpad, etc.)
- **Common concepts – signals from I/O devices interface with computer**
 - **Port** – connection point for device
 - **Bus** - daisy chain or shared direct access
 - **Controller (host adapter)** – electronics that operate port, bus, device
 - Sometimes integrated into device
 - Sometimes separate circuit board
 - Contains processor, microcode, private memory, bus controller, etc

A Common PC Bus Structure



I/O Hardware (Cont.)

- **I/O instructions control devices**
- **Devices usually have registers where device driver places commands, addresses, and data to write, or read data from registers after command execution**
 - Data-in register, data-out register, status register, control register
 - Registers are typically 1-4 bytes, or FIFO buffer
- **Devices have addresses, used by**
 - Direct I/O instructions
 - Memory-mapped I/O
 - Device data and command registers mapped to processor address space
 - Especially useful for large address spaces (graphics)

Device I/O Port Locations on PCs (partial list)

| 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

- **One option when communicating between the host and a controller is polling**
 - For each byte of I/O
 - Read busy bit from status register until 0 (**busy-waiting**)
 - Host sets read or write bit and if write copies data into data-out register
 - Host sets command-ready bit
 - Controller sets busy bit, executes transfer
 - Controller clears busy bit, error bit, command-ready bit when transfer done
 - Step 1 is busy-wait cycle to wait for I/O from device
 - Reasonable if device is fast
 - But inefficient if device slow
 - If CPU switches to another task, data may be lost (buffer overflows)

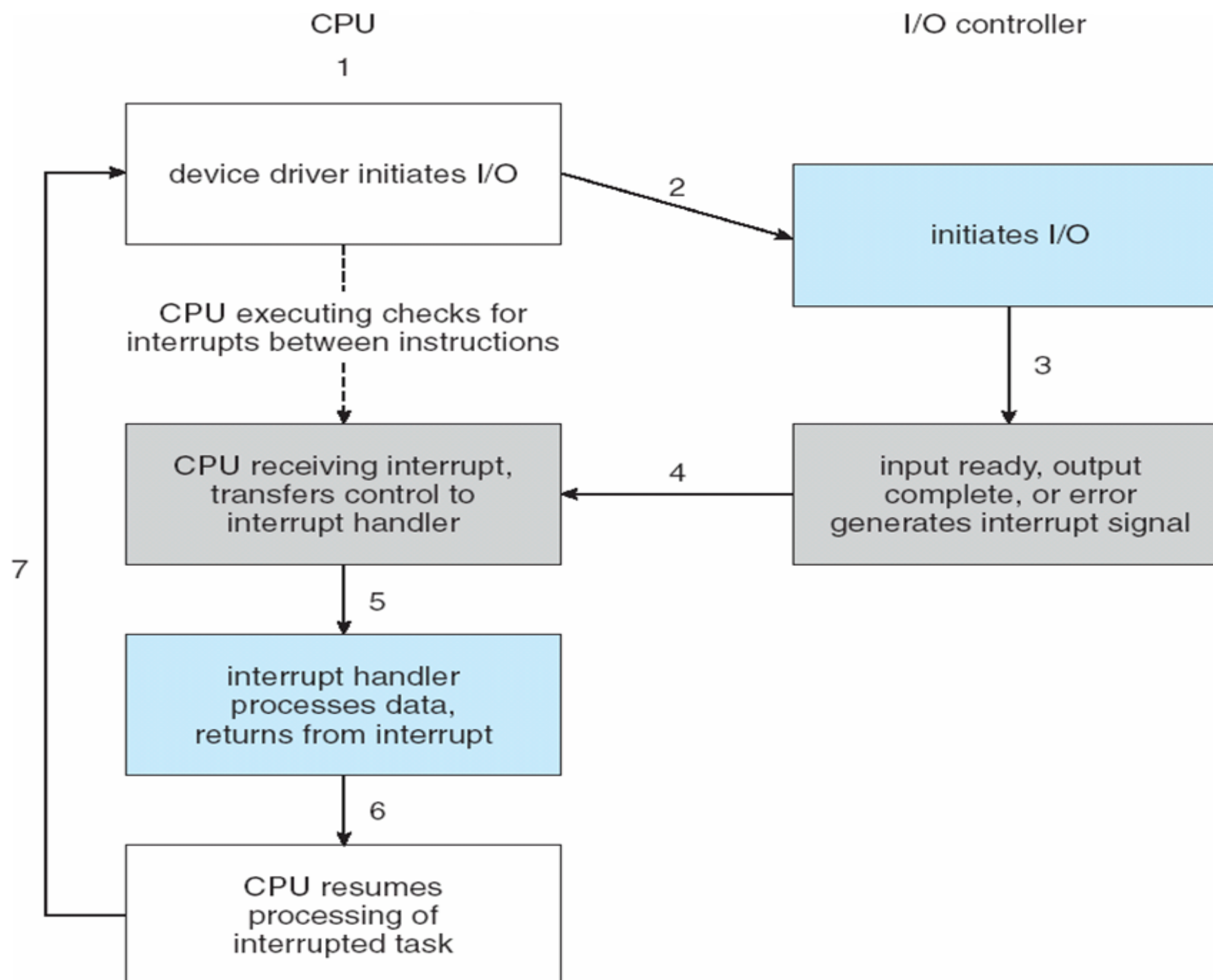
Interrupts

- **Polling can happen in 3 instruction cycles**
 - Read status, logical-and to extract status bit, branch if not zero
 - How to be more efficient if non-zero infrequently?
- **CPU Interrupt-request line triggered by I/O device**
 - Checked by processor after each instruction
- **Interrupt handler receives interrupts**
 - Maskable to ignore or delay some interrupts -- important when kernel is modifying shared data structures
- **Interrupt vector is used to dispatch interrupt to correct interrupt handler**
 - Context switch at start and end
 - Priority based
 - Some interrupts in vector are non-maskable
 - May need to chain interrupts if more than one device at same interrupt number

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 |

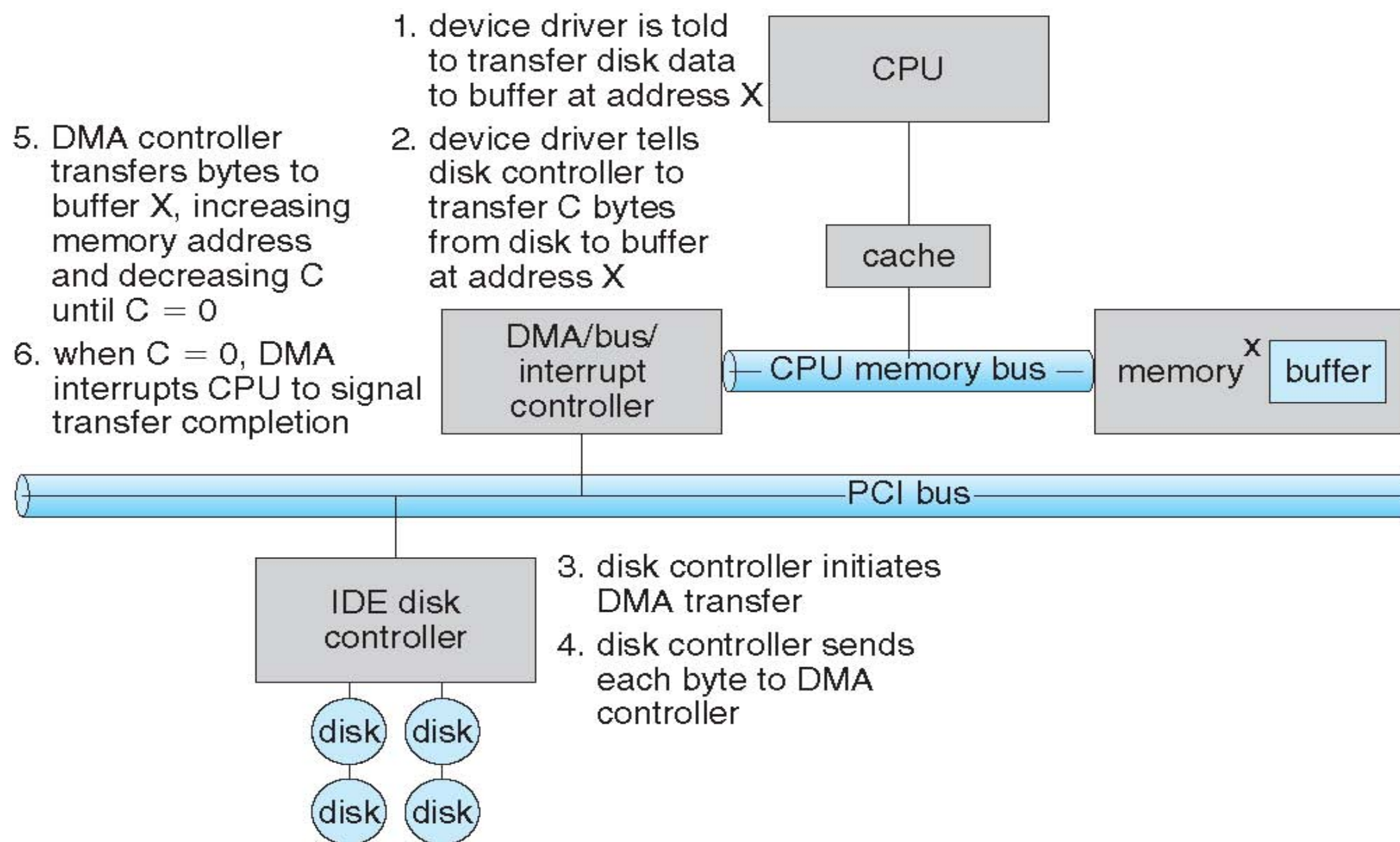
Interrupt-Driven I/O Cycle



Direct Memory Access

- Used to avoid **programmed I/O** (one byte at a time) for large data movement
- Requires **DMA controller**
- **Bypasses CPU to transfer data directly between I/O device and memory**
 - Don't want to waste CPU cycles to do something as simple as transferring data
- **OS writes DMA command block into memory**
 - Source and destination addresses
 - Read or write mode
 - Count of bytes
 - Writes location of command block to DMA controller
 - Bus mastering of DMA controller – grabs memory bus from CPU (**CPU CANNOT use memory bus during this time**)
 - When done, interrupts to signal completion

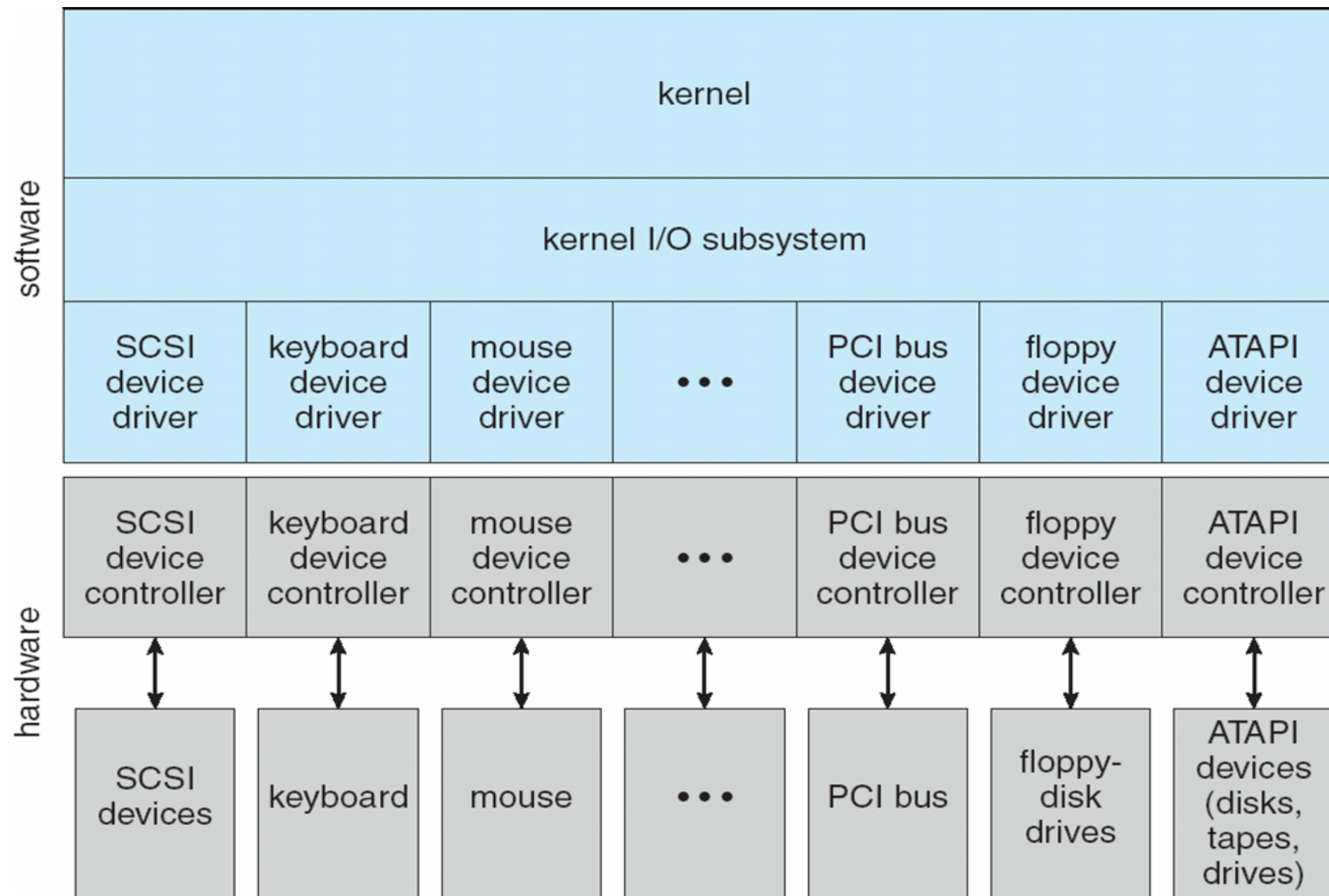
Six Step Process to Perform DMA Transfer



Application I/O Interface

- **It is useful for the operating system to be able to treat devices in a standard, uniform way**
 - Too many different types of devices for OS designers to handle each individually
 - Devices types are grouped and the OS provides a standard interface to those groups
- **Device drivers specific to each device implement one of the standard interfaces provided by the OS**
- **Device-driver layer hides differences among I/O controllers from kernel**
- **New devices using already-implemented protocols to communicate need no extra work**
- **Each OS has its own I/O subsystem structures and device driver frameworks**
- **Devices vary in many dimensions**
 - Character-stream or block transfer
 - Sequential or random-access
 - Synchronous or asynchronous transfers (or both)
 - Sharable or dedicated (can it be used concurrently by multiples threads/processes?)
 - 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 |

Characteristics of I/O Devices (Cont.)

- **Subtleties of devices handled by device drivers**
- **Broadly I/O devices can be grouped by the OS into:**
 - Block I/O
 - Character I/O (Stream)
 - Memory-mapped file access
 - Network sockets

Block and Character Devices

- **Block devices include disk drives**
 - Commands include `read`, `write`, `seek`
 - Raw I/O, direct I/O, or file-system access
 - Memory-mapped file access possible
 - DMA
- **Character devices include keyboards, mice, serial ports**
 - Commands include `get`, `put`
 - Libraries layered on top allow additional functionality

Network Devices

- **Different enough from block and character devices to have its own interface**
- **Unix and Windows NT/9x/2000 include socket interface**
 - Commands include **open**, **close**, **send**, **receive**
 - Separates network protocol from network operation

Clocks and Timers

- **Provide current time, elapsed time, timer**
- **Programmable interval timer used for timings, periodic interrupts**
 - Determining when a time-slice for a thread is complete
 - Periodically flushing disk buffers