Module 12: I/O Systems

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

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

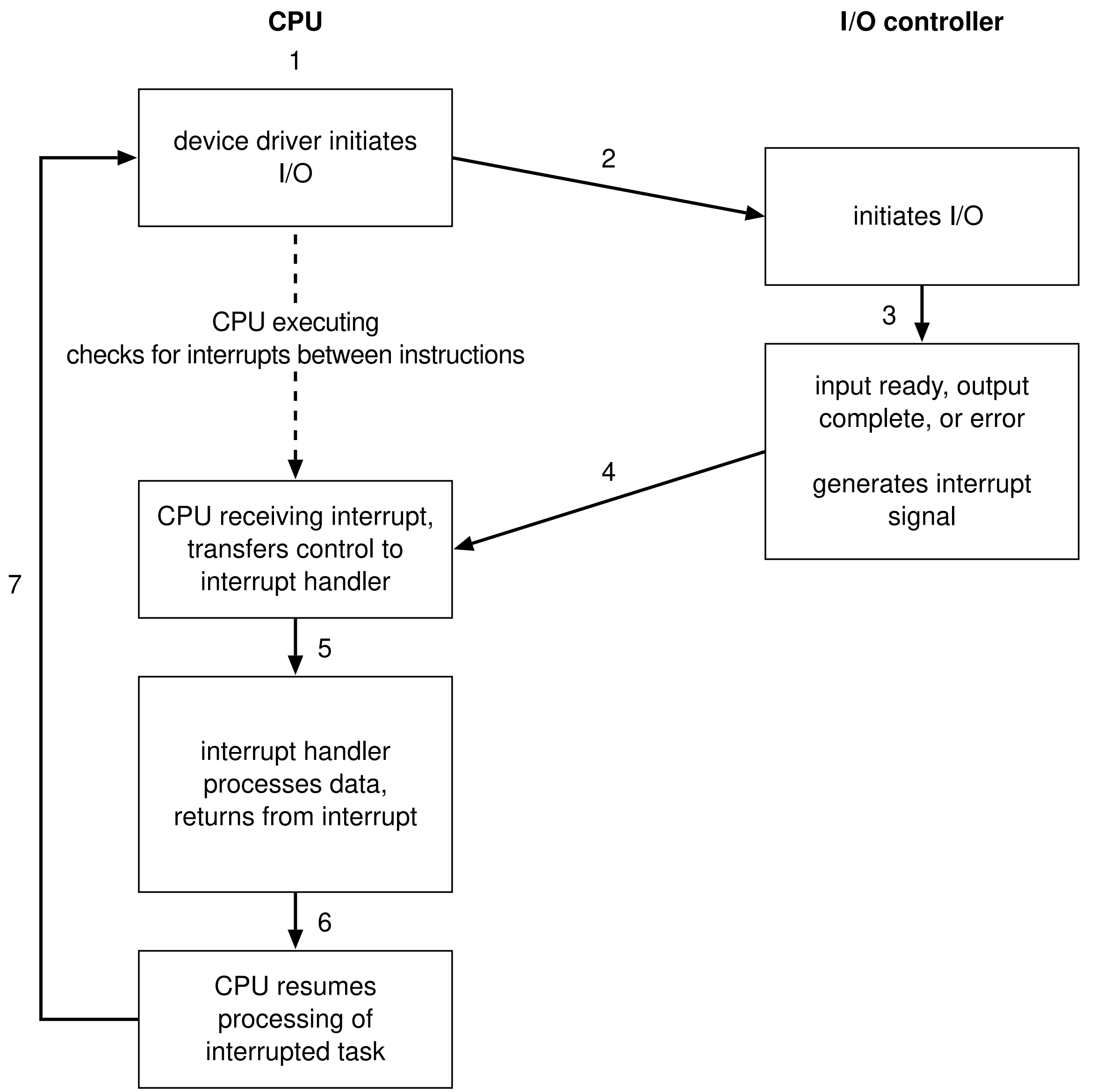
Polling

- 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 unmaskable
- Interrupt mechanism also used for exceptions

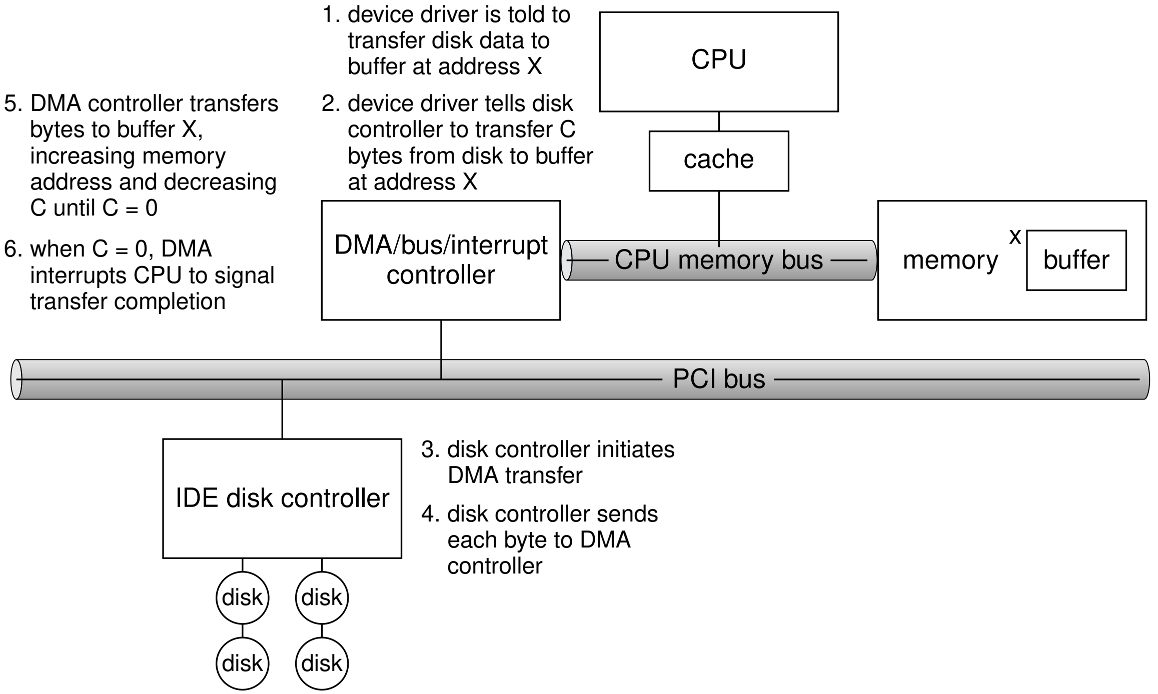
Interrupt-drive I/O Cycle



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
  - Synchronous or asynchronous
  - Sharable or dedicated
  - Speed of operation
  - read-write, read only, or write only

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 include socket interface
  - Separates network protocol from network operations
  - Includes `select` functionality
- Approaches vary widely (pipes, FIFOs, streams, queues, mailboxes)

Clocks and Timers

- Provide current time, elapsed time, timer
- it 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

Kernel I/O Subsystem

- Scheduling
  - Some I/O request ordering via per-device queue
  - Some OSs try fairness
- Buffering - store data in memory while transfering between devices
  - To cope with device speed mismatch
  - To cope with device transfer size mismatch
  - To maintain ”copy semantics”

Kernel I/O Subsystem

- Caching - fast memory holding copy of data
  - Always just a copy
  - Key to performance
- Spooling - 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 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

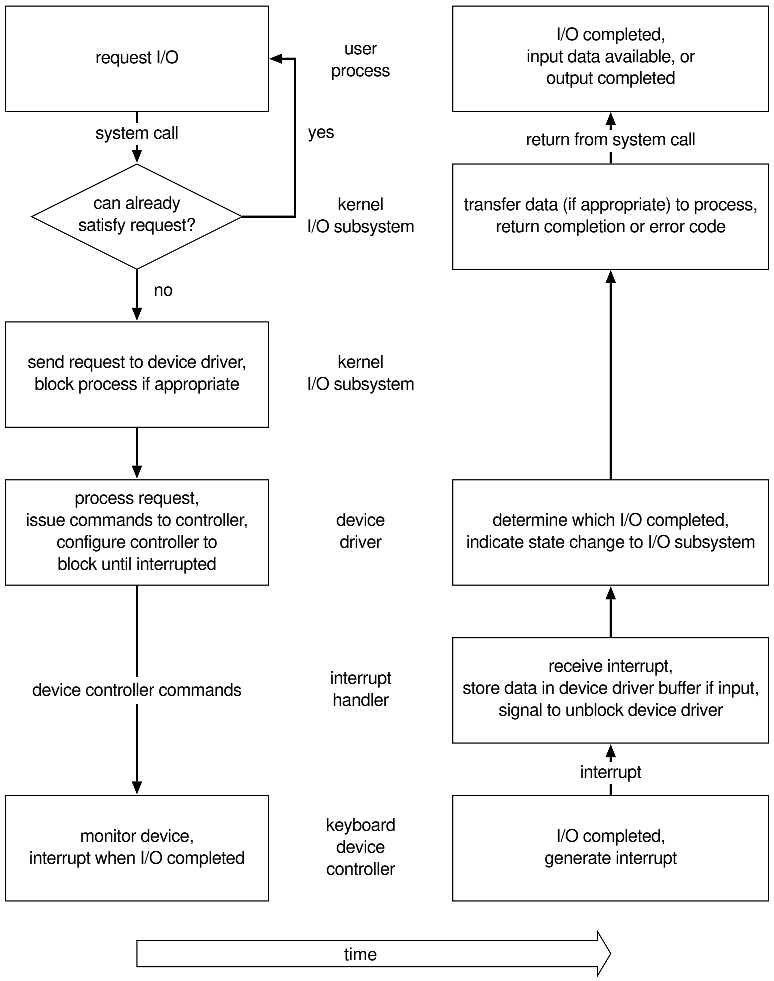
Kernel Data Structures

- Kernel keeps state info for I/O components, including open file tables, network connections, character device state
- Many, many complex data structures to track buffers, memory allocation, ”dirty” blocks
- Some use object-oriented methods and message passing to implement I/O

I/O Requests to Hardware Operations

- Consider reading a file from disk for a process
  - Determine device holding file
  - Translate name to device representation
  - Physically read data from disk into buffer
  - Make data available to requesting process
  - Return control to process

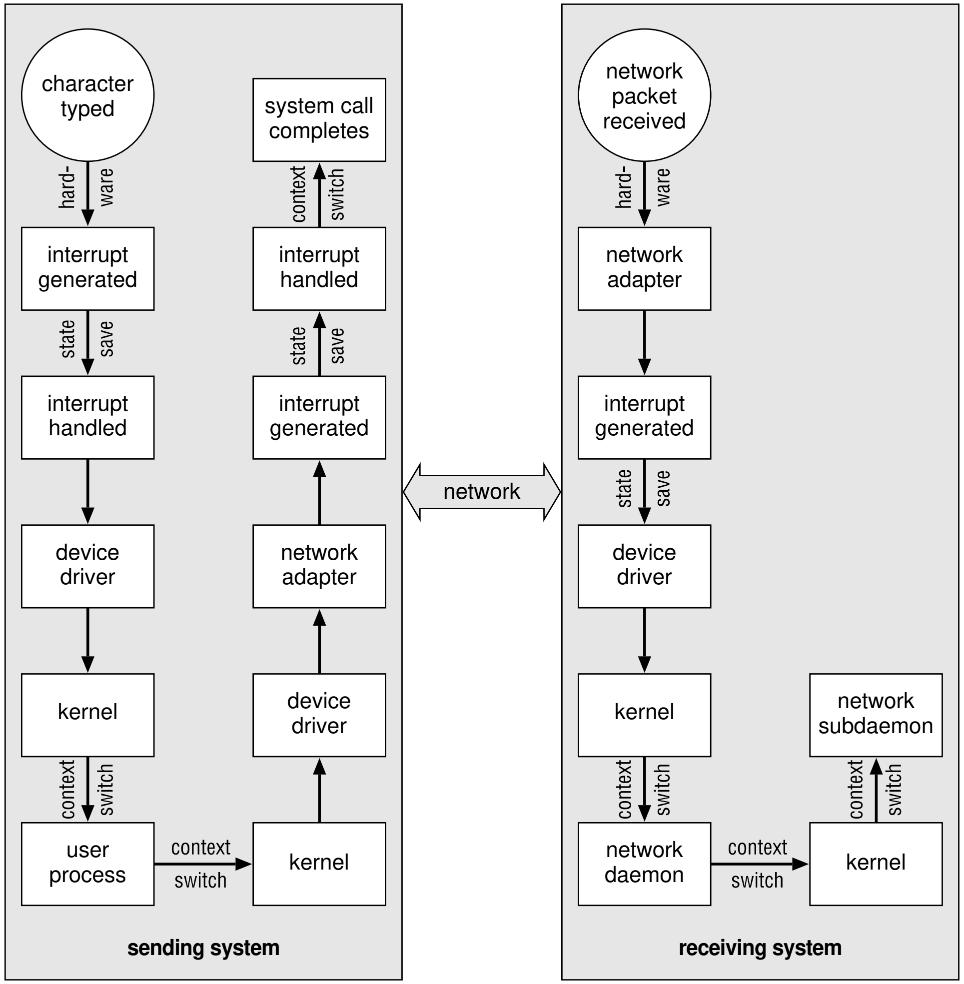
Life Cycle of an I/O Request



Performance

- I/O a major factor in system performance
  - Demands CPU to execute device driver, kernel I/O code
  - Context switches due to interrupts
  - Data copying
  - Network traffic especially stressful

Intercomputer communications



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