



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





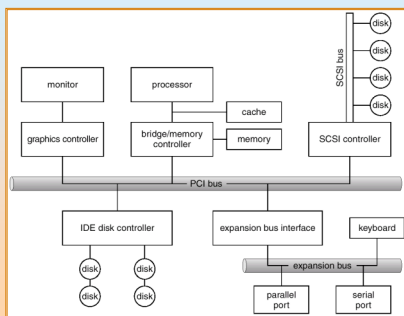
I/O Hardware

- 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





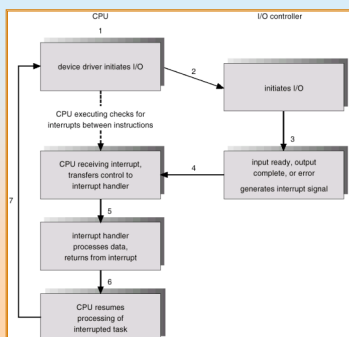
Interrupts

- 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 unmaskable
- 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

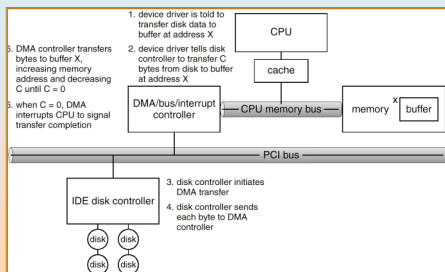


Direct Memory Access

- 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





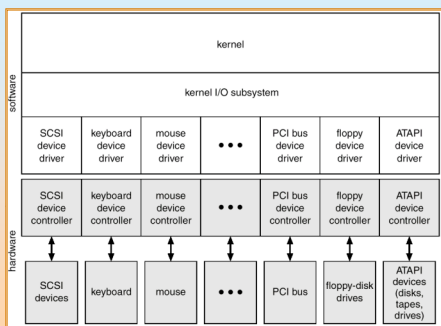
Application I/O Interface

- 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 shareable	tape keyboard
device speed	latency seek time transfer rate delay between operations	
I/O direction	read only write only readDwrite	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/9//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
- If programmable interval time 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





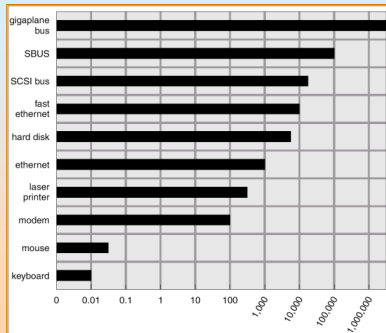
Kernel I/O Subsystem

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





Sun Enterprise 6000 Device-Transfer Rates kbits/second



Operating System Concepts with Java

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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

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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

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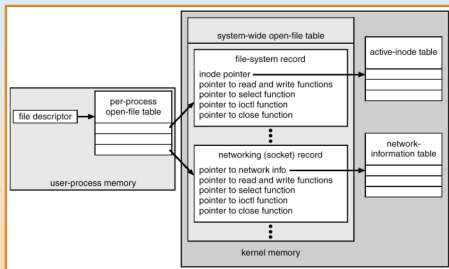
Kernel Data Structures

- 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





UNIX I/O Kernel Structure





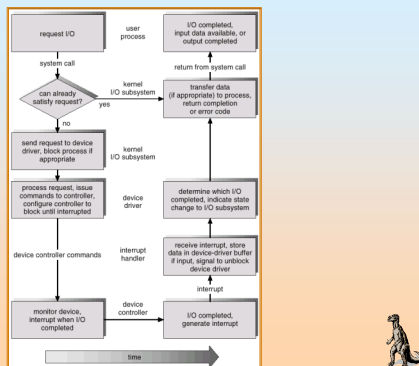
I/O Requests to Hardware Operations

- 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



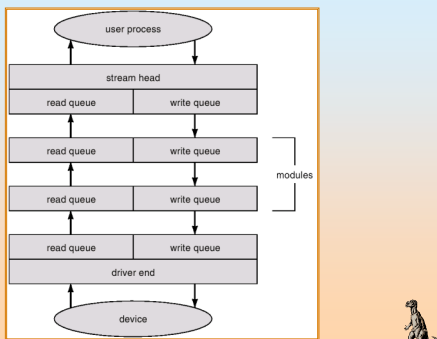


STREAMS

- **STREAM** – a full-duplex communication channel between a user-level process and a device
- A STREAM consists of:
 - STREAM head interfaces with the user process
 - driver end interfaces with the device
 - zero or more STREAM modules between them.
- Each module contains a **read queue** and a **write queue**
- Message passing is used to communicate between queues



The STREAMS Structure





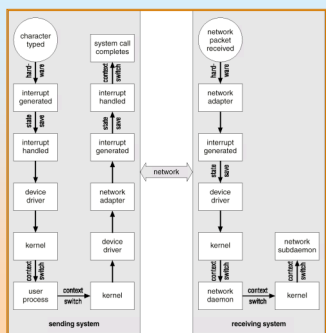
Performance

- 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





Device-Functionality Progression

