I/O Management and Disk Scheduling
Categories of I/O Devices

• Human readable
  – Used to communicate with the user
  – Printers
  – Video display terminals
    • Display
    • Keyboard
    • Mouse
Categories of I/O Devices

• Machine readable
  – Used to communicate with electronic equipment
  – Disk and tape drives
  – Sensors
  – Controllers
  – Actuators
Categories of I/O Devices

- Communication
  - Used to communicate with remote devices
  - Digital line drivers
  - Modems
Differences in I/O Devices

• Data rate
  – May be differences of several orders of magnitude between the data transfer rates
Figure info is a bit dated, e.g. “what’s a floppy” :-)

Figure 11.1 Typical I/O Device Data Rates
Differences in I/O Devices

• Application
  – Disk used to store files requires file management software
  – Disk used to store virtual memory pages needs special hardware and software to support it
  – Terminal used by system administrator may have a higher priority
Differences in I/O Devices

• Complexity of control
• Unit of transfer
  – Data may be transferred as a stream of bytes for a terminal or in larger blocks for a disk
• Data representation
  – Encoding schemes
• Error conditions
  – Devices respond to errors differently
Performing I/O

• Programmed I/O
  – Process is busy-waiting for the operation to complete

• Interrupt-driven I/O
  – I/O command is issued
  – Processor continues executing instructions
  – I/O module sends an interrupt when done
Performing I/O

- Direct Memory Access (DMA)
  - DMA module controls exchange of data between main memory and the I/O device
  - Processor interrupted only after entire block has been transferred
## Relationship Among Techniques

<table>
<thead>
<tr>
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<th>No Interrupts</th>
<th>Use of Interrupts</th>
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<tr>
<td>I/O-to-memory transfer</td>
<td>Programmed I/O</td>
<td>Interrupt-driven I/O</td>
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<td>through processor</td>
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<td>Direct I/O-to-memory</td>
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<td>Direct memory access (DMA)</td>
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Evolution of the I/O Function

- Processor directly controls a peripheral device
- Controller of I/O module is added
  - Processor uses programmed I/O without interrupts
  - Processor does not need to handle details of external devices
Evolution of the I/O Function

• Controller or I/O module with interrupts
  – Processor does not spend time waiting for an I/O operation to be performed

• Direct Memory Access
  – Blocks of data are moved into memory without involving the processor
  – Processor involved at beginning and end only
Evolution of the I/O Function

• I/O module is a separate processor
  – CPU directs I/O processor to execute program in main memory

• I/O processor
  – I/O module now has its own local memory
  – It’s a computer in its own right
Direct Memory Access

- Processor delegates I/O operation to the DMA module
- DMA module transfers data directly to or from memory
- When complete DMA module sends an interrupt signal to the processor
Figure 11.2  Typical DMA Block Diagram
DMA Configurations

(a) Single-bus, detached DMA

(b) Single-bus, Integrated DMA-I/O
DMA Configurations

Figure 11.3 Alternative DMA Configurations
Operating System Design

Issues

• Efficiency
  – Most I/O devices extremely slow compared to main memory
  – Use of multiprogramming allows for some processes to be waiting on I/O while another process executes
  – I/O cannot keep up with processor speed
  – Swapping is used to bring in additional *Ready Processes*, which is an I/O operation
Operating System Design

Issues

• Generality
  – Desirable to handle all I/O devices in a uniform manner
  – Hide most of the details of device I/O in lower-level routines so that processes and upper levels see devices in general terms such as read, write, open, close, lock, unlock
Figure 11.4  A Model of I/O Organization
I/O Buffering

• Reasons for buffering
  – Processes must wait for I/O to complete before proceeding
  – Certain pages must remain in main memory during I/O
I/O Buffering

- **Block-oriented**
  - Information is stored in fixed sized blocks
  - Transfers are made a block at a time
  - Used for disks and tapes

- **Stream-oriented**
  - Transfer information as a stream of bytes
  - Used for terminals, printers, communication ports, mouse and other pointing devices, and most other devices that are not secondary storage
Single Buffer

- Operating system assigns a buffer in main memory for an I/O request
- Block-oriented
  - Input transfers made to buffer
  - Block moved to user space when needed
  - Another block is moved into the buffer
    - “Read ahead”
Single Buffer

• Block-oriented (cont.)
  – User process can process one block of data while next block is read in
  – Swapping can occur since input is taking place in system memory, not user memory
  – Operating system keeps track of assignment of system buffers to user processes
Single Buffer

• Stream-oriented
  – e.g. terminal
    • Used a line at time
    • User input from a terminal is one line at a time with carriage return signaling the end of the line
    • Output to the terminal is one line at a time
  – e.g. network I/O
    • NIC (network interface card)
    • protocol stack
I/O Buffering

(a) No buffering

(b) Single buffering
Double Buffer

- Use two system buffers instead of one
- A process can transfer data to or from one buffer while the operating system empties or fills the other buffer
Circular Buffer

- More than two buffers are used
- Each individual buffer is one unit in a circular buffer
- Used when I/O operation must keep up with process

(d) Circular buffering