I/O Management
Intro
Chapter 5

I/O Devices

• There exists a large variety of I/O devices:
  – Many of the with different properties
  – They seem to require different interfaces to
    manipulate and manage them
    • We don’t want a new interface for every device
    • Diverse, but similar interfaces leads to code
duplication
• Challenge:
  – Uniform and efficient approach to I/O

Categories of I/O Devices (by usage)

• Human readable
  – Used to communicate with the user
  – Printers, Video Display, Keyboard, Mouse
• Machine readable
  – Used to communicate with electronic equipment
  – Disk and tape drives, Sensors, Controllers, Actuators
• Communication
  – Used to communicate with remote devices
  – Ethernet, Modems, Wireless

Differences that Impact I/O Device Handling

• Data rate
  – May be differences of several orders of magnitude between the data transfer rates

Sample Data Rates

<table>
<thead>
<tr>
<th>Device</th>
<th>Data rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keyboard</td>
<td>50 bytes</td>
</tr>
<tr>
<td>Mouse</td>
<td>100 bytes</td>
</tr>
<tr>
<td>Galactic monitor</td>
<td>1.6 kbps</td>
</tr>
<tr>
<td>Telephone Raised</td>
<td>2.8 kbps</td>
</tr>
<tr>
<td>Dual SDF files</td>
<td>16384 bytes</td>
</tr>
<tr>
<td>Laser printer</td>
<td>4096 bytes</td>
</tr>
<tr>
<td>Ethernet</td>
<td>10 Mbps</td>
</tr>
<tr>
<td>USB (Universal Serial Bus)</td>
<td>1.5 Mbps</td>
</tr>
<tr>
<td>Digital camera</td>
<td>1 Mbps</td>
</tr>
<tr>
<td>FAX</td>
<td>14.4 kbps</td>
</tr>
<tr>
<td>Modem</td>
<td>33.6 kbps</td>
</tr>
<tr>
<td>Fast Ethernet</td>
<td>12.8 Mbps</td>
</tr>
<tr>
<td>ATA 4.2 disk</td>
<td>16.8 Mbps</td>
</tr>
<tr>
<td>Virtex (Xilinx Spartan)</td>
<td>33.6 Mbps</td>
</tr>
<tr>
<td>ISA card</td>
<td>6.4 Mbps</td>
</tr>
<tr>
<td>SOCKET 18/42 network</td>
<td>76.8 Mbps</td>
</tr>
<tr>
<td>SCSI 44/80 2 disk</td>
<td>80 Mbps</td>
</tr>
<tr>
<td>Gigabit Ethernet</td>
<td>1000 Mbps</td>
</tr>
<tr>
<td>Ethernet</td>
<td>1 Gbps</td>
</tr>
<tr>
<td>Sun Gigabit Ethernet SX</td>
<td>20 Gbps</td>
</tr>
</tbody>
</table>

Differences that Impact I/O Device Handling

• Application
  – Disk used to store files requires file-management software
    • May provide feature specific to function, e.g. non-volatile RAM.
  – 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 that Impact I/O Device Handling

- 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

Accessing I/O Controllers

- Separate I/O and memory space
  - I/O controller registers appear as I/O ports
  - Accessed with special I/O instructions
- Memory-mapped I/O
  - Controller registers appear as memory
  - Use normal load/store instructions to access
- Hybrid
  - x86 has both ports and memory mapped I/O

Bus Architectures

(a) A single-bus architecture
(b) A dual-bus memory architecture

Interrupts Revisited

- Devices connected to an Interrupt Controller via lines on an I/O bus (e.g. PCI)
- Interrupt Controller signals interrupt to CPU and is eventually acknowledged.
- Exact details are architecture specific.

Direct Memory Access

- Takes control of the bus from the CPU to transfer data to and from memory over the system bus
- Reduced number of interrupts occur
  - No expensive context switches

DMA

- Cycle stealing is used to transfer data on the system bus
  - The instruction cycle is suspended so data can be transferred
  - The CPU pauses one bus cycle
  - CPU Cache can hopefully avoid such pauses by hide DMA bus transactions
  - Cycle stealing causes the CPU to execute more slowly
  - Still more efficient than CPU doing transfer itself
DMA
- Commonly burst-mode is used
  - CPU uses several consecutive cycles to load entire cache line
  - DMA writes (or reads) a similar sized burst
  - Reason: More efficient (less cycles overall) to transfer a sequence of words than a word at a time.
    - No bus arbitration, read/write setup, or addressing cycles.
- Number of required busy cycles can be cut by
  - Path between DMA module and I/O module that does not include the system bus
- Also called polling, or busy waiting
  - I/O module (controller) performs the action, not the processor
  - Sets appropriate bits in the I/O status register
  - No interrupts occur
  - Processor checks status until operation is complete
    - Wastes CPU cycles

Interrupt-Driven I/O
- Processor is interrupted when I/O module (controller) ready to exchange data
- Processor is free to do other work
- No needless waiting
- Consumes a lot of processor time because every word read or written passes through the processor

Direct Memory Access
- Transfers a block of data directly to or from memory
- An interrupt is sent when the task is complete
- The processor is only involved at the beginning and end of the transfer

The Process to Perform DMA Transfer

Evolution of the I/O Function
- Processor directly controls a peripheral device
  - Example: CPU controls a flip-flop to implement a serial line
Evolution of the I/O Function

- Controller or I/O module is added
  - Processor uses programmed I/O without interrupts
  - Processor does not need to handle details of external devices
  - Example: A Universal Asynchronous Receiver Transmitter
    - CPU simply reads and writes bytes to I/O controller
    - I/O controller responsible for managing the signaling

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

Evolution of the I/O Function

- 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 has a separate processor
  - Example: SCSI controller
    - Controller CPU executes SCSI program code out of main memory

Evolution of the I/O Function

- I/O processor
  - I/O module has its own local memory, internal bus, etc.
  - It's a computer in its own right
  - Example: Myrinet Multi-gigabit Network Controller