From last lecture

- We looked at the multi-cycle control scheme in detail
- Multi-cycle control can be implemented using FSM
- FSM is composed of some combinational logic and memory element
Today’s topics

- Exceptions
  - Reset
  - Interrupt
  - Exceptions

Terminology

- Exception
  - a condition causing the processor to escape from its normal control flow, to a pre-defined location (to deal with the condition)
  - Types
    - Reset (external)
    - Interrupt (external)
    - Exception (internal)
    - Software interrupt (internal)

- The exception mechanism plays a critical role in building a computer system
  - OS implementation
  - Time sharing system
  - Supporting a new instruction on an existing architecture
Exception types

- **Reset**
  - External (asynchronous to internal processing)
  - Puts the processor into a known, initial state
  - Jump to “reset vector” address

- **Interrupt**
  - External (asynchronous to internal processing)
  - Saves the current program counter and status register in special registers
  - Jump to “interrupt vector” address

- **Exception**
  - Internal (associated with some instruction; e.g., divide by 0)
  - Saves the current program counter and status register in special registers
  - Jump to “exception vector” address

- **Software interrupt**
  - Internal (associated with a special instruction called “software interrupt”)
  - Used to call system functions
  - Used to emulate a special instruction
  - Used to support debugging software/hardware

Interrupt & reset
Reset exception

- When you boot your machine;

- Internally, power-on generates a pulse (typically 1→0→1)
  - Then this "low" pulse is stretched by some logic to the point when
    - Several valid clocks have been generated and fed into the processor
    - Power level is stabilized
  - All the critical registers inside a processor will be initialized to a known value when this "reset pulse" is applied
  - After the pulse is applied, the processor, at its initial state, jumps to a pre-defined location (typically 0)

- Then, another jump instruction is usually executed
  - Now, jump to a location where boot code is
  - Boot code runs, initializes all other hardware, starts the operating system

Reset processing

On a reset, Jump to “0”

Usually, the reset vector is stored in ROM or Flash!
Interrupt processing

- There are many interrupt sources
  - I/O devices
    - Keyboards
    - Mouse
    - UART (Universal Asynchronous Receiver-Transmitter)
    - Flash card controller (e.g., SmartMedia, memory stick, MMC, SD, CF, …)
  - DMA (Direct Memory Access)
  - Other peripheral devices
    - Timers
    - Watchdog timer
  - From outside the CPU
- These devices raise “interrupt” so that the CPU can stop what it has been doing and start paying attention to them
  - CPU saves the current PC and status automatically
  - Interrupt handler saves registers on stack
  - After interrupt is handled, interrupt handler restores the previous state and return to the previous job

Exception processing

- Here, “exception” means an internally-generated interrupt condition
  - E.g., Divide-by-Zero, undefined instruction
- On detecting these events, the processor saves the current PC and the state, and jumps to an exception handler by jumping to a vector
- Exception handler
  - Saves registers
  - Figures out why exception occurred
  - Does some appropriate actions
  - Restores registers
  - Returns to execute the original instruction
- Software interrupt can be thought of as a type of exception
  - To implement some system call
Exception vector

<table>
<thead>
<tr>
<th>Address</th>
<th>Exception</th>
<th>Mode on entry</th>
<th>I state on entry</th>
<th>F state on entry</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x00000000</td>
<td>Reset</td>
<td>Supervisor</td>
<td>Set</td>
<td>Set</td>
</tr>
<tr>
<td>0x00000004</td>
<td>Undefined instruction</td>
<td>Undefined</td>
<td>Set</td>
<td>Unchanged</td>
</tr>
<tr>
<td>0x00000088</td>
<td>Software interrupt</td>
<td>Supervisor</td>
<td>Set</td>
<td>Unchanged</td>
</tr>
<tr>
<td>0x0000008C</td>
<td>Prefetch Abort</td>
<td>Abort</td>
<td>Set</td>
<td>Unchanged</td>
</tr>
</tbody>
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</thead>
<tbody>
<tr>
<td>0x00000010</td>
<td>Data Abort</td>
<td>Abort</td>
<td>Set</td>
<td>Unchanged</td>
</tr>
<tr>
<td>0x00000014</td>
<td>Reserved</td>
<td>Reserved</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0x00000018</td>
<td>IRQ</td>
<td>IRQ</td>
<td>Set</td>
<td>Unchanged</td>
</tr>
<tr>
<td>0x0000001C</td>
<td>FIQ</td>
<td>FIQ</td>
<td>Set</td>
<td>Set</td>
</tr>
</tbody>
</table>

(Taken from ARM7 Technical Reference Manual)

Processor support

- Refer to Chapter 5.6

- Necessary functions
  - On detecting an interrupt or exception
    - Processor saves the associated PC in a special register
    - Processor saves the current state (status register) in a special register
    - Processor jumps to a pre-defined vector address
  - Instructions
    - To return to the exception-causing location
    - To manipulate special registers
  - Processor modes
    - Normal mode – user programs run in this mode
    - Privileged mode – interrupt handlers and operating system codes run in this mode
    - Processor switches from normal mode to privileged mode on exceptions/interrupts
To summarize…

- Exceptions and interrupts are an important part of any processor.
- Modern operating system heavily depends on the hardware support for exceptions.
- Interrupt mechanism allows efficient use of CPU cycles by getting hold of it only when it is necessary.
- Implementing this interrupt mechanism usually is complicated and requires a lot of validation efforts in a processor design cycle.