Overview

- Instruction Set Support for Exceptions
- Role of O/S in Handling Exceptions
- Prioritized Exceptions
- Re-entrant Exception Routine

Review: Support for ARM Modes of Operations

<table>
<thead>
<tr>
<th>Mode</th>
<th>r0</th>
<th>r1</th>
<th>r2</th>
<th>r3</th>
<th>r4</th>
<th>r5</th>
<th>r6</th>
<th>r7</th>
<th>r8</th>
<th>r9</th>
<th>r10</th>
<th>r11</th>
<th>r12</th>
<th>r13</th>
<th>r14</th>
<th>r15 (PC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>User</td>
<td>unusable in user mode</td>
<td>system modes only</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Review: Exception Handling and the Vector Table

- When an exception occurs, the core:
  - Copies CPSR into SPSR_<mode>
  - Sets appropriate CPSR bits
    - Interrupt disable flags if appropriate.
  - Maps in appropriate banked registers
  - Stores the “return address” in LR_<mode>
  - Sets PC to vector address

- Single instruction stored at these locations should be a branch to a handler
- To return, exception handler needs to:
  - Restore CPSR from SPSR_<mode>
  - Restore PC from LR_<mode> via `movs pc, lr` or `subs pc, lr, #4`
Review: Privileged vs User Mode

- Privileged Modes vs. User Mode: OS can provide security and fairness
- swi: provides a way for a programmer to avoid having to know details of each I/O device.
- To be acceptable, Exception handler must:
  - service all Exceptions (no drops)
  - service by priority
  - make all users believe that no Exception has occurred

Review: OS: I/O Requirements

- The OS must be able to prevent:
  - The user program from communicating with the I/O device directly
- If user programs could perform I/O directly:
  - No protection to the shared I/O resources
- 3 types of communication are required:
  - The OS must be able to give commands to the I/O devices
  - The I/O device notify OS when the I/O device has completed an operation or an error
  - Data transfers between memory and I/O device

Review: Crossing the System Boundary

- System loads user program into memory and 'gives' it use of the processor
- Switch back
  - swi
    - request service
    - I/O
  - exception (und. Inst)
  - Interrupt

Instruction Set Support for OS (#1/2)

- How to turn off interrupts during Exception routine?
- Bits in CPSR determines whether or not interrupts disabled:
  - Interrupt Request bit (I) (1 ⇒ disabled, 0 ⇒ enabled)
  - Once an exception occurs (I) bit sets to 1 automatically
  - Return from exception restores the original value
  - Fast Interrupt Request bit (F) only gets disabled if an fast Interrupt occurs

<table>
<thead>
<tr>
<th>31</th>
<th>28</th>
<th>27</th>
<th>unused</th>
<th>8</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>Z</td>
<td>C</td>
<td>V</td>
<td>IF</td>
<td>T</td>
<td>mode</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Instruction Set Support for OS (#2/2)

◦ How to prevent user program from turning off interrupts (forever)?
◦ **Interrupt Request bit (I)** and **Fast Interrupt Request bit (F)** bits can only be changed from the privileged modes.

Multiple Simultaneous Exceptions/Interrupts

◦ Problem: What if Data Abort exception and an I/O interrupt (printer ready, for example) come in both at the same time?
◦ Options:
  • drop any conflicting interrupts/exceptions: unrealistic, they may be important
  • simultaneously handle multiple interrupts exceptions: unrealistic, may not be able to synchronize them (such as with multiple I/O interrupts)
  • queue them for later handling: sounds good

Exceptions Prioritization in ARM

<table>
<thead>
<tr>
<th>Exception Type</th>
<th>Priority (1=High, 6=Low)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reset</td>
<td>1</td>
</tr>
<tr>
<td>Data Abort</td>
<td>2</td>
</tr>
<tr>
<td>Fast Interrupt (FIQ)</td>
<td>3</td>
</tr>
<tr>
<td>Interrupt (IRQ)</td>
<td>4</td>
</tr>
<tr>
<td>Prefetch Abort</td>
<td>5</td>
</tr>
<tr>
<td>Software Interrupt (SWI)</td>
<td>6</td>
</tr>
<tr>
<td>Undefined Instruction</td>
<td>6</td>
</tr>
</tbody>
</table>

FIQ Priority

◦ Placing the Data Abort exception above the FIQ exception in the priority list ensures that the Data Abort is actually registered before the FIQ is handled.
◦ The Data Abort handler is entered first but control is then passed immediately to the FIQ handler.
◦ Once the FIQ has been handled, control returns to the Data Abort Handler.
◦ This means that the data transfer error does not escape detection as it would if the FIQ were handled first.
Hardware support for FIQ

- Extra register set r12_fiq – r8_fiq in FIQ bank would mean that they don’t need to be saved.
- That means faster processing
- FIQ vector address at 0x00000000C is the last vector, and therefore can start executing immediately without a branch instruction

Preempting Exceptions by Interrupts

- Question: Suppose we’re dealing with a computer running a nuclear facility. What if we’re handling an Floating Point Divide by 0 Exception and a Nuclear Meltdown Imminent interrupt comes in?
- Answer: We need to categorize and allow some interrupts preempt other Exceptions so we can handle them in order of urgency: emergency vs. luxury.

ARM Support for Preempting Exceptions

- ARM Architecture Support to simplify software:
  - An Exception Process sets IRQ bits (disables it).
  - No further IRQ interrupt is possible
  - However, No exception can disable FIQ interrupt
- If an FIQ interrupt comes while servicing an exception
  - Take FIQ immediately
  - Return to interrupted exception code as soon as no more FIQ Interrupt
    - State information for the preempted exception are saved on banked registers and as well as some internal registers

Reading Material

- Experiment 5 Documentation
So Many Devices One FIQ/IRQ

- Two interrupt request signals FIQ and IRQ never enough for all of the I/O devices
- Need a mechanism to attach multiple devices to the same IRQ pin.
- Solution: Use Interrupt Controller to attach multiple devices to the same IRQ pin.

Interrupt Controller controls how multiple peripherals can interrupt the ARM processor. Essentially, the interrupt controller acts as a large AND-OR gate.

In the event of an IRQ a combination of hardware and software techniques are required to detect the sources of interrupt and provide a system of priority and queuing.

Interrupt Controller in DSLMU/Komodo

- IRQ Enable: Enables individual interrupts
- IRQ Status: Indicates raising interrupt.
- Prioritization: in software

DSLMU/Komodo IRQ Status/Enable Regs

<table>
<thead>
<tr>
<th>Bit</th>
<th>Mode</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>R/W</td>
<td>Push-button switch S2 on the Expansion Board</td>
</tr>
<tr>
<td>6</td>
<td>R/W</td>
<td>Push-button switch S3 on the Expansion Board</td>
</tr>
<tr>
<td>5</td>
<td>R/W</td>
<td>Serial port transmitter ready</td>
</tr>
<tr>
<td>4</td>
<td>R/W</td>
<td>Serial port receiver ready</td>
</tr>
<tr>
<td>3</td>
<td>—</td>
<td>(Reserved)</td>
</tr>
<tr>
<td>2</td>
<td>R/W</td>
<td>Xilinx Virtex-E interrupt request</td>
</tr>
<tr>
<td>1</td>
<td>R/W</td>
<td>Xilinx Spartan-XL interrupt request</td>
</tr>
<tr>
<td>0</td>
<td>R/W</td>
<td>Timer Compare interrupt request</td>
</tr>
</tbody>
</table>

IRQ status reg. address = 0x10000018
IRQ Enable reg. address = 0x1000001C

IRQ Interrupt Levels in ARM?

- What are they?
- It depends what the ARM chip is inside of: differ by app: GameBoy, Digital Set top Box, Digital Answering Machine, Digital Satellite Decoder, Pocket PC, Mobile Phone
- ARM architecture and Interrupt controller enables priorities for different I/O events
Improving Data Transfer Performance

• Thus far: OS give commands to I/O, I/O device notify OS when the I/O device completed operation or an error

• What about data transfer to I/O device?
  • Processor busy doing loads/stores between memory and I/O Data Register

• Ideal: specify the block of memory to be transferred, be notified on completion?
  • Direct Memory Access (DMA): a simple computer transfers a block of data to/from memory and I/O, interrupting upon done

Example: FIQ Code for DMA controller

• DMA code from Disk Device to Memory

  .data
  Count: .word 4096
  Start: .space 4096
  .text
  Initial: ldr a1, =Count
  ldr a1, [a1] ; No. chars
  ldr a2, =Start ; next char
  Wait: ldr a3, DiskControl
  tst a3,1 ; select Ready
  beq Wait ; spinwait
  ldrb a4, DiskData ; get byte
  strb a4, [a2], #1 ; transfer,
  subs a1, a1,#1 ; Count--
  bne Wait ; next char

• DMA “computer” in parallel with CPU

Re-entrant Interrupt Routine?

• Prioritization and queuing of interrupts attached to IRQ interrupt controller requires one interrupt preemting another interrupt (reentrant interrupts)

• All exceptions set IRQ disable interrupt bit (I)
  • FIQ can interrupt IRQ and other exceptions
  • FIQ sets FIQ disable interrupt bit (F) as well

• How allow one IRQ interrupt to interrupt another IRQ interrupt and and safely save registers?

• Interrupt service Routine needs to save:
  • Return address on lr_irq for the pre-empted IRQ handler on IRQ Mode Stack
  • all registers that it is going to use on IRQ Mode Stack
  • Reset the IRQ disable bit

• Same thing for FIQ

Pre-empting Other Exceptions by IRQ?

• All exceptions set IRQ disable interrupt bit (I)
  • FIQ can interrupt IRQ and other exceptions

• How allow IRQ interrupts to interrupt other exceptions (other than IRQ and FIQ exceptions)?

• Interrupt service Routine needs to save:
  • all registers that it is going to use on IRQ Mode Stack
  • Reset the IRQ disable bit
IRQ Controller Support for Queuing and Priority

- IRQ Controller Support to simplify software:
  - An Interrupt Process cannot be preempted by Exception at same or lower "level"
  - When an interrupt is handled, take the highest priority interrupt on the queue
  - If a higher priority interrupt comes in while servicing a lower priority one
    - Preempt the lower priority one and take the higher priority one
    - current priority value is pushed onto a first-in last-out stack and the current priority is updated to the higher priority.
    - Return to interrupted code as soon as no more Interrupts at a higher level
    - On return the current interrupt level is updated with the last stored interrupt level from the stack.

Things to Remember

- Privileged Mode v. User Mode: OS can provide security and fairness
- Exceptions prioritization in the case of multiple concurrent exceptions.
- Multiple devices can be connected to single IRQ interrupt via an Interrupt Controller.
- Re-entrant Interrupt: One interrupt preempting another interrupt.
  - Prioritization and queuing of interrupts in hardware or software is required for this to work.