COMP 3221

Microprocessors and Embedded Systems

Lectures 27: Exceptions & Interrupts - I

http://www.cse.unsw.edu.au/~cs3221

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Overview

- Instruction Set Support for Exceptions
- Privileged vs User modes of operation.
- Handling a Single Interrupt

Review

- I/O gives computers their 5 senses
- I/O speed range is million to one
- Processor speed means must synchronize with I/O devices before use
- Polling works, but expensive
  - processor repeatedly queries devices
- Interrupts works, more complex

Definitions for Clarification

- **Exception**: signal marking that something “out of the ordinary” has happened and needs to be handled. Caused by internal and external sources
- **Interrupt**: Externally asynchronous exception (by I/Os)
- **Software Interrupt (SWI)**: User defined synchronous exception
- **Trap**: Processor’s diversion to a code to handle exception

Example of Exception Sources in ARM

- Externally generated interrupts
- An attempt by the processor to execute an undefined instruction
- Accessing privileged operating system functions via software interrupts (SWI).
  - `Print`
  - `Access Ethernet`

I/O Interrupt

- An I/O interrupt is like an undefined instruction exceptions except:
  - An I/O interrupt is “asynchronous”
  - More information needs to be conveyed
- An I/O interrupt is asynchronous with respect to instruction execution:
  - I/O interrupt is not associated with any instruction, but it can happen in the middle of any given instruction
  - I/O interrupt does not prevent any instruction from completion

Architecture Support for Exceptions

- Save the PC for return
  - But where?
- Where to go when Exception occurs?
- How to determine the Cause of exception?
- How to handle exceptions?

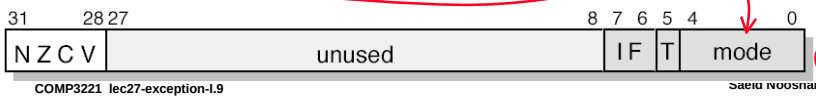
Exception Sources in ARM

- Reset: Occurs when the processor reset pin is asserted. (Signalling power-up)
- Undefined Instruction: Occurs if the processor, does not recognize the currently executing instruction.
- Software Interrupt (SWI): This is a user-defined intentional synchronous interrupt instruction.
- Prefetch Abort: Occurs when the processor attempts to execute an instruction that was not fetched, because the address was illegal.
- Data Abort: Occurs when a data transfer instruction attempts to load or store data at an illegal address.
- IRQ: Occurs when the processor external Interrupt ReQuest pin is asserted
- FIQ: Occurs when the processor external Fast Interrupt reQuest pin is asserted

ARM Modes of Operations

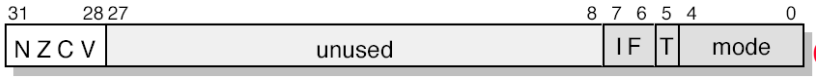
- 10000 **User** Normal user code — Non-Privileged Mode
- 10001 **FIQ** Processing fast interrupts
- 10010 **IRQ** Processing standard interrupts
- 10011 **SVC** Processing software interrupts (SWIs)
- 10111 **Abort** Processing memory faults
- 11011 **Undef** Handling undefined instruction traps
- 11111 **System** Running privileged operating system tasks

Privileged Modes



CPSR

CPSR Encoding for Operating Modes & Interrupts



CPSR

mode	Mode of Operation
T	ARM vs Thumb State (We only use ARM in COMP3221
F	FIQ Fast interrupts Disable bit
I	IRQ Normal interrupt Disable bit
NZCV	Condition Flags

Changing mode bits is only possible in privileged modes

User Mode vs Privileged Modes

- User Applications run in User Mode
- Privileged modes, used to
  - service interrupts
  - exceptions
  - access protected resources (via SWI Instruction)
- Privileged modes ➔ User mode OK
- User mode ➔ Privileged modes NOT OK
  - Only possible through Controlled mechanisms: SWI, Exceptions, Interrupts

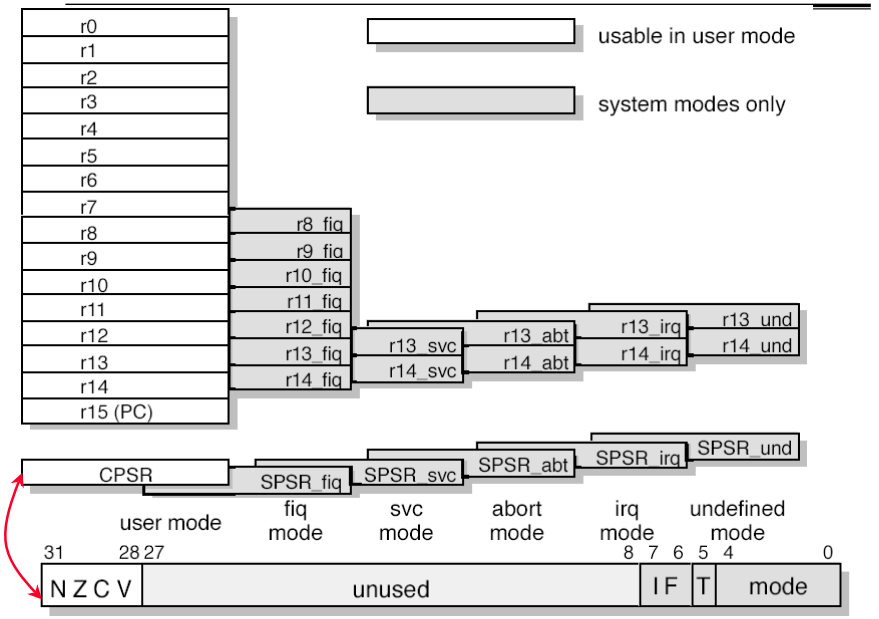
Rationale Privileged Modes

- Privileged modes protect system from getting trashed by user.
- Some Instructions can only be executed in privileged mode
- Example: User can't directly read/write information from disk I/Os.
- Why not allow direct access to non-disk I/O devices in user mode?
- Komodo on DSLMU runs in Privileged mode. Can access everything while running Komodo

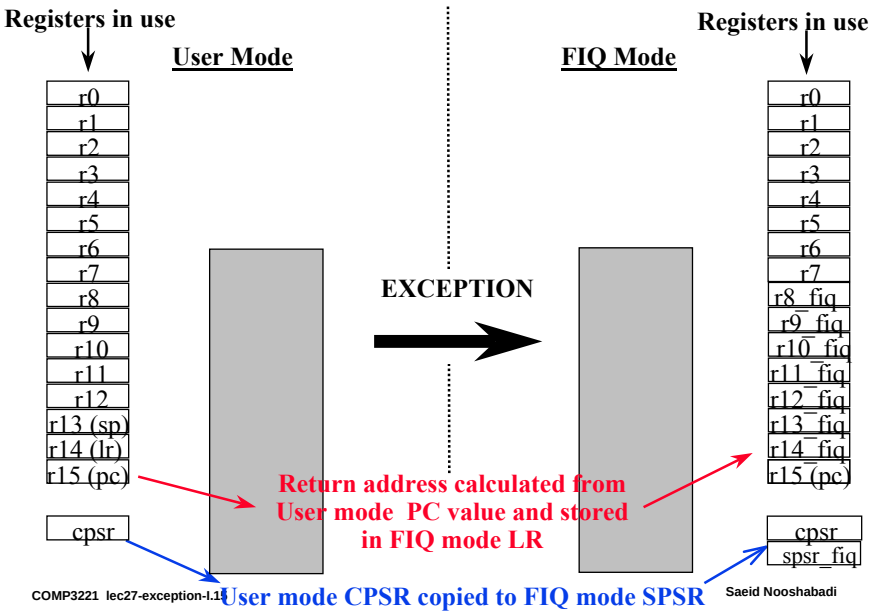
I/O Requires Privileged Modes

- Transmitter/receiver Status and Data words are in privileged data space; thus we must be in privileged mode to read or write them.
- Device drivers run in privileged mode.
- To access the I/O devices the user application has to make a Supervisor call to the OS via SWI instruction
- Komodo on DSLMU Allows access to I/O ports in User mode!
  - Security hole !

Support for ARM Modes of Operations



Switching between Modes (User to FIQ Mode)



Exception Handling Mechanism (#1/2)

- The processor's response to an exception
  - Copies the Current Program Status Register (CPSR) into the appropriate mode Saved Program Status Register(SPSR)
  - Sets the appropriate CPSR bits
    - Mode bits : set appropriately. maps in the appropriate banked registers for that mode.
    - I bit : to disable interrupts. IRQs are disabled once any other exception occurs
    - F bit: FIQs are also disabled when a FIQ occurs.
  - Stores the address of the return instruction (generally PC – 4) in LR_<mode>.
  - Sets the PC to the appropriate vector address.This forces the branch to the appropriate exception handler.

Exception Handling Mechanism (#2/2)

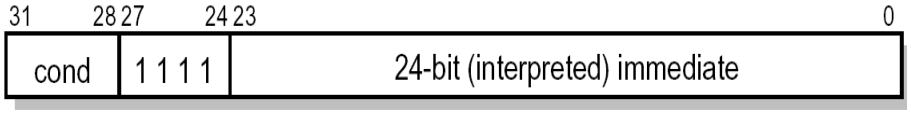
- Returning from an exception handler
  - Restore the CPSR from the SPSR_<mode>.
  - Restore the PC using the return address stored in LR_<mode>.
  - These can be achieved in a single instruction
    `movs pc, lr` or
    `subs pc, lr, #4`
  - Adding the S flag (update condition codes) to a data processing instruction when in a privileged mode with the PC as the destination register, also transfers the SPSR to CPSR
  - Same thing for Load Multiple instruction (using the ^ qualifier)
    `ldmfd sp! {r0-r12, pc}^`

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
- 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`

0x00000000	Reset
0x00000004	Undefined Instr
0x00000008	SWI
0x0000000C	Prefetch Abort
0x00000010	Data Abort
0x00000014	Reserved
0x00000018	IRQ
0x0000001C	FIQ

Software Interrupt (SWI)



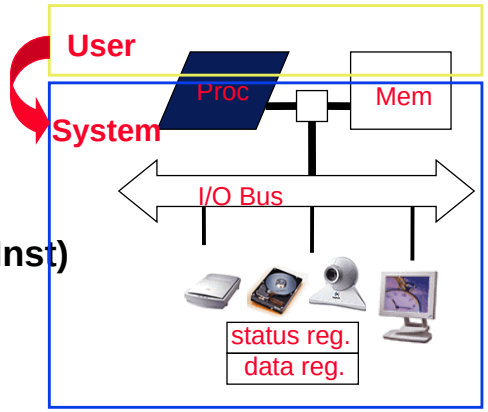
- In effect, a SWI is a user-defined instruction,
- A planned Exception from User Application to request privileged O/S services via SWI Supervisor call.
- It causes:
  - A switch to privileged Supervisor Mode.
  - A branch to an exception trap to the SWI exception vector (0x00000008)
  - a SWI exception handler to be called.
- The handler can then examine the comment field of the instruction to decide what operation has been requested.

SWI Invocation

- How does user invoke the OS?
  - `swi` instruction: invoke the OS code (Go to 0x00000008, change to privileged mode)
  - By software convention,number `xxx` in `swi xxx` has system service requested: OS performs request

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



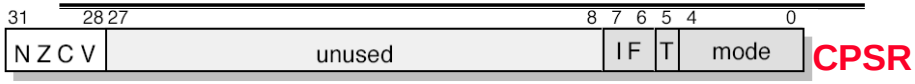
Reading Material

- Experiment 5 Documentation
- Steve Furber: ARM System On-Chip; 2nd Ed, Addison-Wesley, 2000, ISBN: 0-201-67519-6. Chapter 5.
- ARM Architecture Reference Manual 2nd Ed, Addison-Wesley, 2001, ISBN: 0-201-73719-1, Part A , Exceptions, chapter A2 Section 6

SWI Example under GNU Debugging tools

```
7;Print to console a single char in
 R0
 swi 0x0

;Read a single char from Kboard
 into R0
 swi 0x4

;Print nul-terminated string
 prt_str to the console
 ldr   r0,=prt_str
 swi   0x2

Swi 0x11 ; Terminate the program

.data
 prt_str: .asciz "Hello World:\n"
```


CPSR and SPSR Transfer Instructions

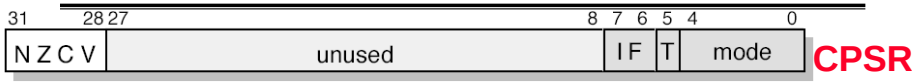


- MRS and MSR transfer content CPSR/SPSR to /from a general purpose register.
  - All of status register, or just the flags, can be transferred.
  - `mrs Rd, <psr> ; Rd ← <psr>`
  - `msr <psr>,Rm ; <psr> ← Rm`
  - `msr <psrf>,Rm ; <psrf> ← Rm`

  Where `<psr> = CPSR, CPSR_all, SPSR or SPSR_all`

  and `<psrf> = CPSR_flg or SPSR_flg`
- Also an immediate form
  - `msr <psrf>,#Imm32`
  - a 32-bit immediate, of which the 4 most significant bits are written to the flag bits.

Modifying CPSR



- Unused reserved bits, may be used in future, therefore:
  - they must be preserved when altering PSR
  - the value they return must not be relied upon when testing other bits.
- Thus read-modify-write strategy must be followed when modifying any PSR:
  - Transfer PSR to register using MRS
  - Modify relevant bits
  - Transfer updated value back to PSR using MSR
- Note:
  - In User Mode, all bits can be read but only the flag bits can be written to.

Questions Raised about Interrupts

- Which I/O device caused interrupt?
  - Needs to convey the identity of the device generating the interrupt
- Can avoid interrupts during the interrupt routine?
  - What if more important interrupt occurs while servicing this interrupt?
  - Allow interrupt routine to be entered again?
- Who keeps track of status of all the devices, handle errors, know where to put/supply the I/O data?

4 Responsibilities leading to OS

- The I/O system is shared by multiple programs using the processor
- Low-level control of I/O devices is complex because requires managing a set of concurrent events and because requirements for correct device control are often very detailed
- I/O systems often use interrupts to communicate information about I/O operations
- Would like I/O services for all user programs under safe control

4 Functions OS must provide

- OS guarantees that user's program accesses only the portions of I/O device to which user has rights (e.g., file access)
- OS provides abstractions for accessing devices by supplying routines that handle low-level device operations
- OS handles the interrupts generated by I/O devices (and other exceptions generated by a program)
- OS tries to provide equitable access to the shared I/O resources, as well as schedule accesses in order to enhance system performance

Things to Remember

- Privileged Mode v. 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, interrupt handler must:
  - service all interrupts (no drops)
  - service by priority
  - make all users believe that no interrupt has occurred