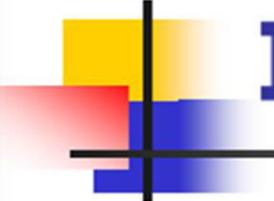


Interrupt structure – Vector interrupt table, Interrupt service routines





Introducing ARM

■ ARM register set

- ARM processor has 37 32-bit registers.
- 31 registers are general purpose registers.
- 6 registers are control registers
- Registers are named from R0 to R16 with some registers banked in different modes
- R13 is the stack pointer **SP** (Banked)
- R14 is subroutine link register **LR** (Banked)
- R15 is program counter **PC**
- R16 is current program status register **CPSR** (Banked)



Introducing ARM

■ Modes of operation

- ARM processor has 7 modes of operation.
- Switching between modes can be done manually through modifying the mode bits in the CPSR register.
- Most application programs execute in user mode
- Non user modes (called privileged modes) are entered to serve interrupts or exceptions
- The system mode is special mode for accessing protected resources. It don't use registers used by exception hanlders, so it can't be corrupted by any exception handler error!!!



Introducing ARM

■ Modes of operation

Switching between these modes requires saving/loading register values

Processor Mode	Description
User (<i>usr</i>)	Normal program execution mode
FIQ (<i>fiq</i>)	Fast data processing mode
IRQ (<i>irq</i>)	For general purpose interrupts
Supervisor (<i>svc</i>)	A protected mode for the operating system
Abort (<i>abt</i>)	When data or instruction fetch is aborted
Undefined (<i>und</i>)	For undefined instructions
System (<i>sys</i>)	Privileged mode for OS Tasks

Introducing ARM

■ ARM register set

More banked registers, so context switching is faster

ARM state general registers and program counter					
System and User	FIQ	Supervisor	Abort	IRQ	Undefined
r0	r0	r0	r0	r0	r0
r1	r1	r1	r1	r1	r1
r2	r2	r2	r2	r2	r2
r3	r3	r3	r3	r3	r3
r4	r4	r4	r4	r4	r4
r5	r5	r5	r5	r5	r5
r6	r6	r6	r6	r6	r6
r7	r7	r7	r7	r7	r7
r8	r8_fiq	r8	r8	r8	r8
r9	r9_fiq	r9	r9	r9	r9
r10	r10_fiq	r10	r10	r10	r10
r11	r11_fiq	r11	r11	r11	r11
r12	r12_fiq	r12	r12	r12	r12
r13	r13_fiq	r13_svc	r13_abt	r13_irq	r13_und
r14	r14_fiq	r14_svc	r14_abt	r14_irq	r14_und
r15	r15 (PC)	r15 (PC)	r15 (PC)	r15 (PC)	r15 (PC)

ARM state program status registers



△ = banked register



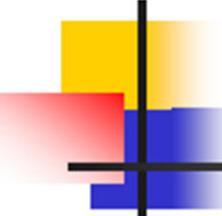
Exceptions

■ What is an exception?

An exception is any condition that needs to halt normal execution of the instructions

■ Examples

- Resetting ARM core
- Failure of fetching instructions
- HWI
- SWI



Exceptions

■ Exceptions and modes

Each exception causes the ARM core to enter a specific mode.

Exception	Mode	Purpose
Fast Interrupt Request	FIQ	Fast interrupt handling
Interrupt Request	IRQ	Normal interrupt handling
SWI and RESET	SVC	Protected mode for OS
Pre-fetch or data abort	ABT	Memory protection handling
Undefined Instruction	UND	SW emulation of HW coprocessors



When Exception Occurs...

- ✓ Exception causes mode change and
 - Saves the cpsr to the spsr of the exception mode
 - Saves the pc to the lr of the exception mode
 - Sets the cpsr to the exception mode
 - Sets pc to the address of the exception handler



Exceptions

■ Vector table

It is a table of addresses that the ARM core branches to when an exception is raised and there is always branching instructions that direct the core to the ISR.

At this place in memory, we find a branching instruction

`ldr pc, [pc, #_IRQ_handler_offset]`



Address	Exception	Mode on entry
0x00000000	Reset	Supervisor
0x00000004	Undefined instruction	Undefined
0x00000008	Software interrupt	Supervisor
0x0000000C	Abort (prefetch)	Abort
0x00000010	Abort (data)	Abort
0x00000014	Reserved	Reserved
0x00000018	IRQ	IRQ
0x0000001C	FIQ	FIQ

Exceptions

■ Exception priorities

decide which of the currently raised exceptions is more important

Both are caused by an instruction entering the execution stage of the ARM instruction pipeline

Decide if the exception handler itself can be interrupted during execution or not?

Exception	Priority	I bit	F bit
Reset	1	1	1
Data Abort	2	1	-
FIQ	3	1	1
IRQ	4	1	-
Prefetch abort	5	1	-
SWI	6	1	-
Undefined instruction	6	1	-



Exception Handlers

✓ Reset handler

- Initializes the system, setting up stack pointers, memory, external interrupt sources before enabling IRQ or FIQ
- Code should be designed to avoid further triggering of exceptions

✓ Data Abort

- Occurs when memory controller indicates that an invalid memory address has been accessed
- An FIQ exception can be raised within data abort handler



Exception Handlers (contd.)

FIQ

- Occurs when an external peripheral generates the FIQ input signal
- Core disables both FIQ and IRQ interrupts

IRQ

- Occurs when an external device generates the IRQ input signal
- IRQ handler will be entered if neither an FIQ exception or Data abort exception occurs
- On entry IRQ exception is disabled and should remain disabled for the handler if not enabled by the handler



Exception Handlers (contd.)

✓ Prefetch Abort

- Occurs when an attempt to fetch an instruction results in memory fault
- FIQ exception can be serviced

✓ Undefined Instruction

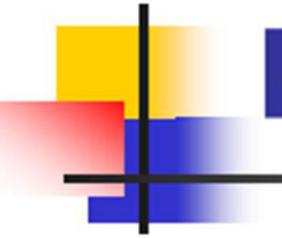
- Occurs when an instruction is not in the ARM or Thumb instruction

✓ SWI and undefined instruction have the same level of priority because they cannot occur together



Returning from Exception Handler

- ✓ Exception handler must not corrupt lr
- ✓ After servicing is complete, return to normal execution occurs
 - By moving the correct value of link register r14 into pc
 - By restoring cpsr from spsr



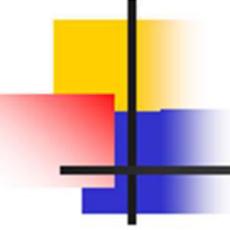
Exceptions

■ Entering exception handler

1. Save the address of the next instruction in the appropriate Link Register ***LR***.
2. Copy ***CPSR*** to the ***SPSR*** of new mode.
3. Change the mode by modifying bits in ***CPSR***.
4. Fetch next instruction from the vector table.

■ Leaving exception handler

1. Move the Link Register ***LR*** (minus an offset) to the ***PC***.
2. Copy ***SPSR*** back to ***CPSR***, this will automatically changes the mode back to the previous one.
3. Clear the interrupt disable flags (if they were set).



Exceptions

■ Link Register Offset

This register is used to return the **PC** to the appropriate place in the interrupted task since this is not always the old **PC** value. It is modified depending on the type of exception.

The **PC** has advanced beyond the instruction causing the exception. Upon exit of the prefetch abort exception handler, software must re-load the PC back one instruction from the **PC** saved at the time of the exception.

Exception	Returning Address
Reset	None
Data Abort	LR-8
FIQ, IRQ, prefetch Abort	LR-4
SWI, Undefined Instruction	LR



Interrupts

■ Assigning interrupts

It is up to the system designer who can decide which HW peripheral can produce which interrupt.

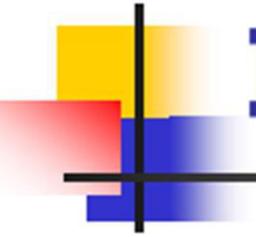
But system designers have adopted a standard design for assigning interrupts:

- SWI are used to call privileged OS routines.
- IRQ are assigned to general purpose interrupts like periodic timers.
- FIQ is reserved for one single interrupt source that requires fast response time.



Interrupt Assignment

- ✓ An interrupt controller connects multiple external interrupts to either FIQ or IRQ
- ✓ IRQ are normally assigned to general purpose interrupts
 - Example: periodic timer interrupt to force a context switch
- ✓ FIQ is reserved for an interrupt source which requires fast response time



Interrupts

■ Interrupt latency

It is the interval of time from an external interrupt signal being raised to the first fetch of an instruction of the ISR of the raised interrupt signal.

System architects try to achieve two main goals:

- To handle multiple interrupts simultaneously.
- To minimize the interrupt latency.

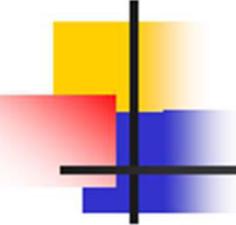
And this can be done by 2 methods:

- allow nested interrupt handling
- give priorities to different interrupt sources



Interrupt Latency

- ➊ Hardware and software latency
- ➋ Software methods to reduce latency
 - Nested handler which allows further interrupts to occur even when servicing an existing interrupt by re-enabling the interrupts inside service routine
 - Program interrupt controller to ignore interrupts of same or lower priority
 - Higher priority interrupts will have lower average latency



Interrupts

■ Enabling and disabling Interrupt

This is done by modifying the **CPSR**, this is done using only 3 ARM instruction:

MRS To read *CPSR*
MSR To store in *CPSR*
BIC Bit clear instruction
ORR OR instruction

Enabling an IRQ/FIQ
Interrupt:

```
MRS r1, cpsr  
BIC r1, r1, #0x80/0x40  
MSR cpsr_c, r1
```

Disabling an IRQ/FIQ
Interrupt:

```
MRS r1, cpsr  
ORR r1, r1, #0x80/0x40  
MSR cpsr_c, r1
```



Interrupts

■ Interrupt stack

Stacks are needed extensively for context switching between different modes when interrupts are raised.

The design of the exception stack depends on two factors:

- OS Requirements.
- Target hardware.

A good stack design tries to avoid stack overflow because it cause instability in embedded systems.



Stack Organization

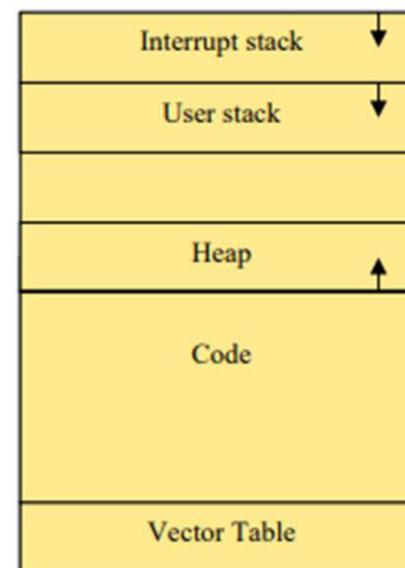
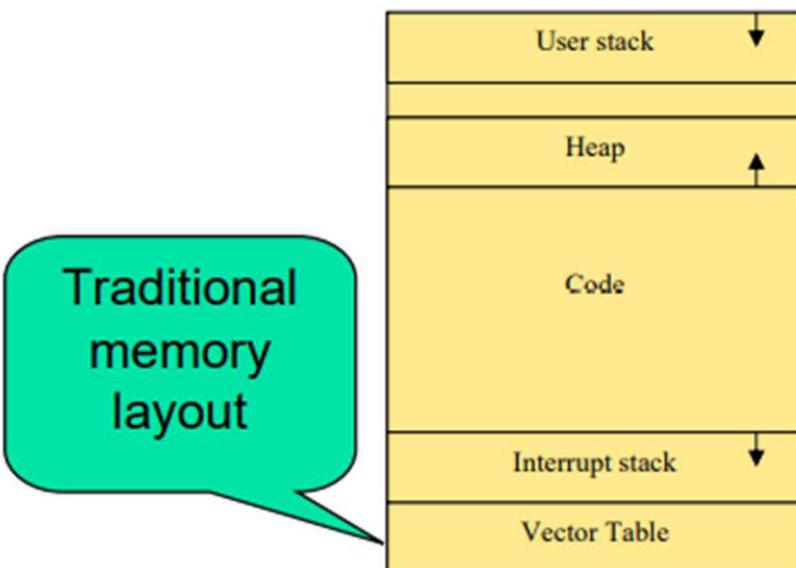
- ✓ For each processor mode stack has to be set up
 - To be done every time processor is reset
 - Change to each mode by storing CPSR bit pattern and initialise SP
- ✓ Design decisions
 - Location and mode (descending stack is common)
 - Size
 - Nested interrupt handler requires larger stack

Interrupts

■ Interrupt stack

Two design decisions need to be made for the stacks:

- The location
- The size



The benefit of this layout is that the vector table remains untouched if a stack overflow occurred!!



Interrupt handling schemes

■ Prioritized simple interrupt handling

- associate a priority level with a particular interrupt source.
- Handling prioritization can be done by means of software or hardware.
- When an interrupt signal is raised, a fixed amount of comparisons is done.
 - So the interrupt latency is deterministic.
 - But this could be considered a disadvantage!!



THANK YOU