Topic 5: Arithmetic Instructions

CSE 30: Computer Organization and Systems Programming
Summer Session II

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Overview

- Variables in Assembly: Registers
- Comments in Assembly
- Addition and Subtraction in Assembly
- Memory Access in Assembly

Assembly Language

- Basic job of a CPU: execute lots of *instructions*
- Instructions are the primitive operations that the CPU may execute.
- Different CPUs implement different sets of instructions. The set of instructions a particular CPU implements is an *Instruction Set Architecture (ISA)*
  - Examples: ARM, Intel 80x86, IBM/Motorola PowerPC (Macintosh), MIPS, Intel IA64, ...

Instruction Set Architectures

- Early trend was to add more and more instructions to new CPUs to do elaborate operations
  - VAX architecture had an instruction to multiply polynomials!
- RISC philosophy (Cocke IBM, Patterson, Hennessy, 1980s) –
  Reduced Instruction Set Computing
  - Keep the instruction set small and simple, makes it easier to build fast hardware.
  - Let software (compiler) do complicated operations by composing simpler ones.

Assembly Variables: Registers

- Unlike HLL like C or Java, assembly cannot use variables
  - Why not? Keep Hardware Simple
- Assembly Operands are registers
  - Limited number of special locations built directly into the hardware
  - Operations can only be performed on these!
- Benefit: Since registers are directly in hardware, they are very fast (faster than 1 billionth of a second)

Assembly Variables: Registers

- Drawback: Since registers are in hardware, there are a predetermined number of them
  - Solution: ARM code must be very carefully put together to efficiently use registers
- 16 registers in ARM
  - Why 16? Smaller is faster
- Each ARM register is 32 bits wide
  - Groups of 32 bits called a word in ARM
  - They are referred to as: r0-r14, PC and CPSR (actually 37 registers - additional registers have similar names for other modes)

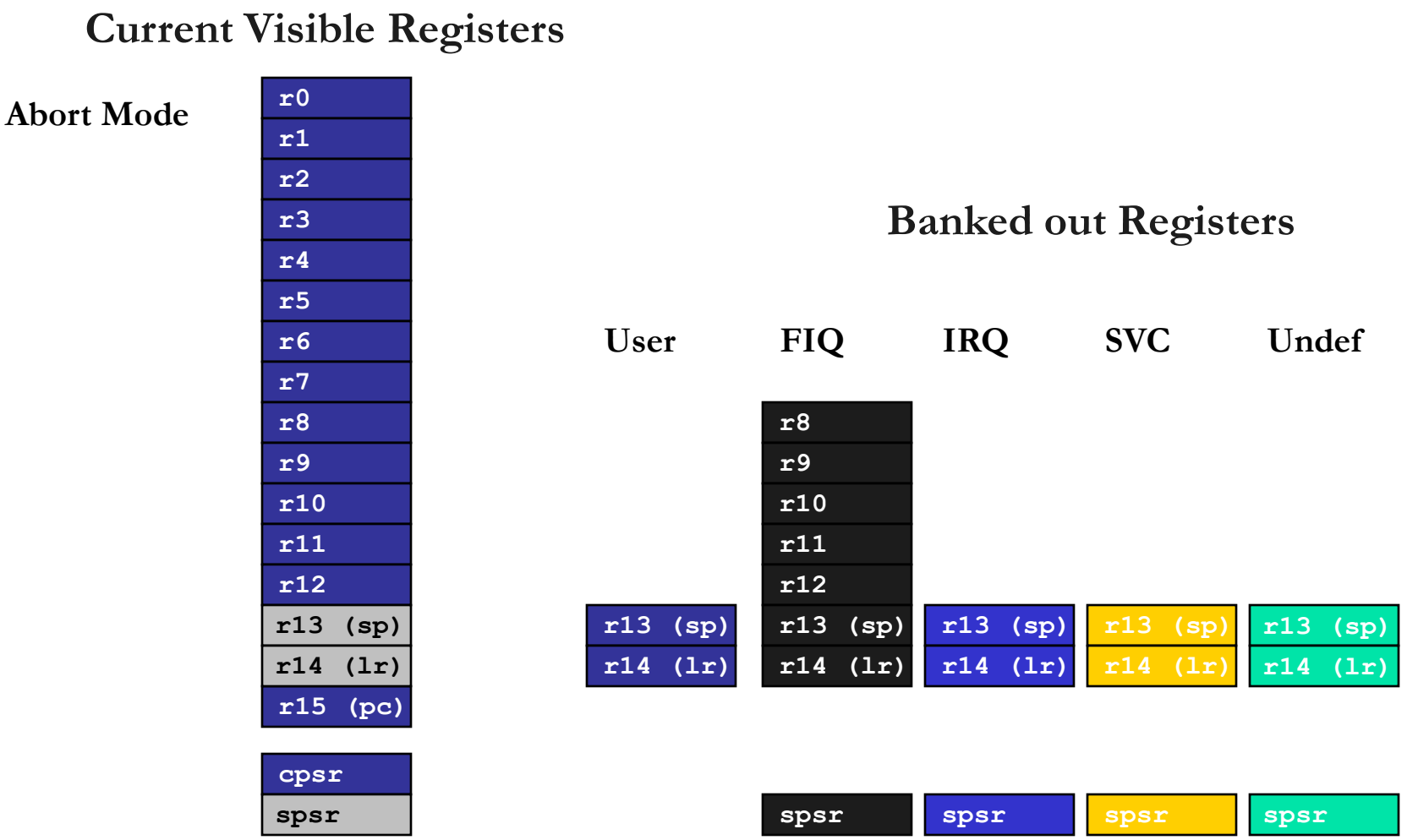
C, Java Variables vs. Registers

- In C (and most High Level Languages) variables declared first and given a type
  - Example:

```
int fahr, celsius;
char a, b, c, d, e;
```

- Each variable can ONLY represent a value of the type it was declared as (cannot mix and match `int` and `char` variables).
- In Assembly Language, the registers have no type; operation determines how register contents are treated

The ARM Register Set



Processor Modes

- The ARM has seven basic operating modes:
  - **User** : unprivileged mode under which most tasks run
  - **FIQ** : entered when a high priority (fast) interrupt is raised
  - **IRQ** : entered when a low priority (normal) interrupt is raised
  - **Supervisor** : entered on reset and when a Software Interrupt instruction is executed
  - **Abort** : used to handle memory access violations
  - **Undef** : used to handle undefined instructions
  - **System** : privileged mode using the same registers as user mode
- We will mainly use User mode. Other modes much less important for this class.
- For now, only worry about r0-r12 and treat these as registers that you can store any variable.

Comments in Assembly

- Another way to make your code more readable: comments!
- Semicolon (;) is used for ARM comments
  - anything from semicolon to end of line is a comment and will be ignored
- Note: Different from C
  - C comments have format /* comment */, so they can span many lines

Assembly Instructions

- In assembly language, each statement (called an Instruction), executes exactly one of a short list of simple commands
- Unlike in C (and most other High Level Languages), each line of assembly code contains at most 1 instruction
- Instructions are related to operations (=, +, -, *, /) in C or Java

ARM Addition and Subtraction

- Syntax of Instructions:

  1 2, 3, 4

  where:

  1) instruction by name

  2) operand getting result (“destination”)

  3) 1st operand for operation (“source1”)

  4) 2nd operand for operation (“source2”)

- Syntax is rigid (for the most part):
  - 1 operator, 3 operands
  - Why? Keep Hardware simple via regularity

Addition and Subtraction of Integers

- Addition in Assembly
  - Example: `ADD r0,r1,r2` (in ARM)

    Equivalent to: `a = b + c` (in C)

    where ARM registers `r0,r1,r2` are associated with C variables `a, b, c`
- Subtraction in Assembly
  - Example: `SUB r3, r4, r5` (in ARM)

    Equivalent to: `d = e - f` (in C)

    where ARM registers `r3,r4,r5` are associated with C variables `d, e, f`

Addition and Subtraction of Integers

- How do the following C statement?

```
a = b + c + d - e;
```

- Break into multiple instructions

```
ADD r0, r1, r2      ; a = b + c
ADD r0, r0, r3      ; a = a + d
SUB r0, $t0, r4     ; a = a - e
```

- Notice: A single line of C may break up into several lines of ARM.
- Notice: Everything after the semicolon on each line is ignored (comments)

Addition and Subtraction of Integers

- How do we do this?

```
f = (g + h) - (i + j);
```

- Use intermediate temporary register

```
ADD r0,r1,r2          ; f = g + h
ADD r5,r3,r4          ; temp = i + j
SUB r0,r0,r5          ; f =(g+h)-(i+j)
```

Immediates

- Immediates are numerical constants.
- They appear often in code, so there are ways to indicate their existence
- Add Immediate:

  `f = g + 10` (in C)

  `ADD r0,r1,#10` (in ARM)

  where ARM registers `r0,r1` are associated with C variables `f, g`
- Syntax similar to `add` instruction, except that last argument is a #number instead of a register.

Integer Multiplication

- Paper and pencil example (unsigned):

```
  Multiplicand  1000      8
   Multiplier  x1001      9
                 1000
                0000
               0000
             +1000
             01001000
```

  - m bits x n bits = m + n bit product

Multiplication

- In MIPS, we multiply registers, so:
  - 32-bit value x 32-bit value = 64-bit value

- Syntax of Multiplication (signed):
  - `MUL` register1, register2, register3

Multiplication

- Example:
  - in C: `a = b * c;`
  - in MIPS:
    - let b be r2; let c be r3; and let a be r0 and r1 (since it may be up to 64 bits)

```
MUL r0, r2, r3   ; b*c only 32 bits stored
```

Note: Often, we only care about the lower half of the product.

```
SMULL r0,r1,r2,r3 ; 64 bits in r0:r1
```

Multiply and Divide

- There are 2 classes of multiply - producing 32-bit and 64-bit results
- 32-bit versions on an ARM7TDMI will execute in 2 - 5 cycles

```
MUL r0, r1, r2          ; r0 = r1 * r2
MLA r0, r1, r2, r3      ; r0 = (r1 * r2) + r3
```

- 64-bit multiply instructions offer both signed and unsigned versions
  - For these instruction there are 2 destination registers

```
[U|S]MULL r4, r5, r2, r3      ; r5:r4 = r2 * r3
[U|S]MLAL r4, r5, r2, r3      ; r5:r4 = (r2 * r3) + r5:r4
```

- Most ARM cores do not offer integer divide instructions
  - Division operations will be performed by C library routines or inline shifts

Conclusion

- In MIPS Assembly Language:
  - Registers replace C variables
  - One Instruction (simple operation) per line
  - Simpler is Better
  - Smaller is Faster
- Instructions so far:

  `ADD, SUB, MUL, MULA, [U|S]MULL, [U|S]MLAL`
- Registers:

  Places for general variables: `r0-r12`