COMP 3221

Microprocessors and Embedded Systems

Lecture 10: C/Assembler Logical and Shift – II & Multiplication

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

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Overview

- Shift Operations
  - Field Insertion
- Multiplication Operations
  - Multiplication
  - Long Multiplication
  - Multiplication and accumulation
  - Signed and unsigned multiplications

Review: ARM Instructions So far

```
add
sub
mov
and
bic
orr
eor
```

Data Processing Instructions with shift and rotate

```
lsl, lsr, asr, ror
```


Review: Masking via Logical AND

- AND:Note that `and`ing a bit with 0 produces a 0 at the output while `and`ing a bit with 1 produces the original bit.
- This can be used to create a **mask**.
  - Example:

```
       1011 0110 1010 0100 0011 1101 1001 1010
Mask:  0000 0000 0000 0000 0000 0000 1111 1111
```

  - The result of `and`ing these two is:

```
       0000 0000 0000 0000 0000 0000 1001 1010
```

Review: Masking via Logical BIC

- BIC (AND NOT):Note that `bic`ing a bit with 1 produces a 0 at the output while `bic`ing a bit with 0 produces the original bit.
- This can be used to create a **mask**.
  - Example:

1011 0110 1010 0100 0011 1101 1001 1010

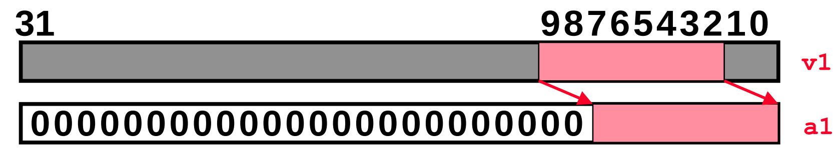
Mask: 0000 0000 0000 0000 0000 0000 1111 1111

  - The result of `bic`ing these two is:

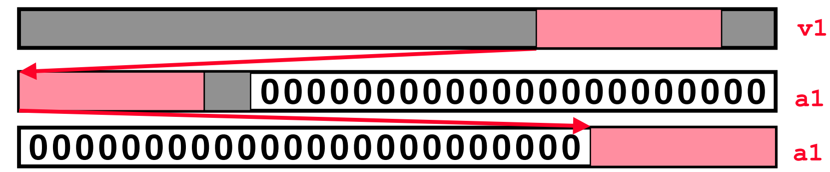
1011 0110 1010 0100 0011 1101 0000 0000

Extracting a field of bits (#1/2)

- Extract bit field from bit 9 (left bit no.) to bit 2 (size=8 bits) of register v1, place in rightmost part of register a1

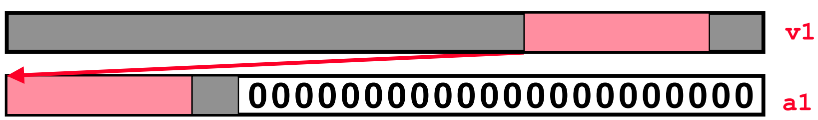


- Shift field as far left as possible (9 →31) and then as far right as possible (31→7)

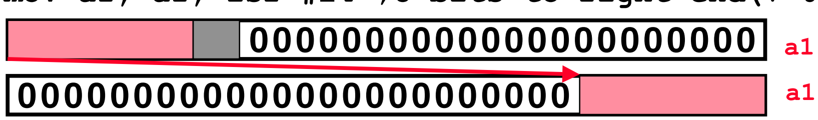


Extracting a field of bits (#2/2)

```
mov a1, v1, lsl #22 ;8 bits to left end (31-9)
```

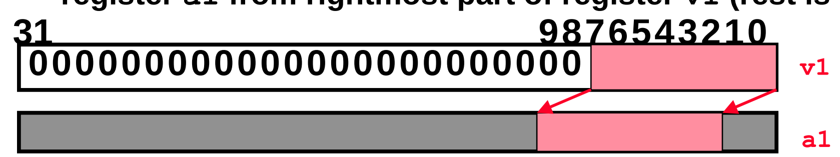



```
mov a1, a1, lsr #24 ;8 bits to right end(7-0)
```

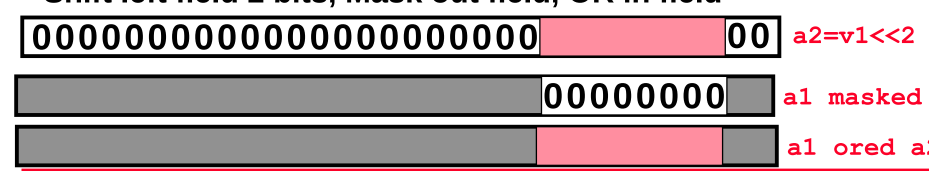


Inserting a field of bits

- Insert bit field into bit 9 (left bit no.) to bit 2 (size=8 bits) of register `a1` from rightmost part of register `v1` (rest is 0)



- Shift left field 2 bits, Mask out field, OR in field



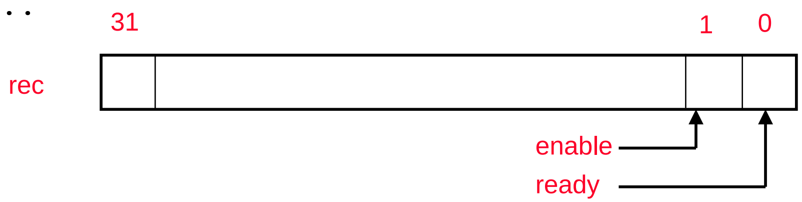

```
mov a2, v1, lsl #2 ; field left 2
bic a1, a1, #0x3FC ; mask out 9-2
                   ; 0x03FC = 0011 1111 1100
orr a1, a1, a2     ; OR in field
```

; `bic` stands for 'bit clear, where '1' in the second operand clears
; the corresponding bit in the first

Bit manipulation in C (#1/2)

- Convert C code to ARM ASM
- Bit Fields in C (Word as 32 bits vs int/unsigned!)

```
struct {
    unsigned int ready:  1; /* bit 0 */
    unsigned int enable: 1; /* bit 1 */
} rec;
rec.enable = 1;
rec.ready = 0;
printf("%d %d", rec.enable, rec.ready);
...
```



Brian Kernighan & Dennis Ritchie:
The C Programming Language, 2nd Ed., PP 150

Bit manipulation in C (#2/2)

```
struct {
     unsigned int ready:  1; /* bit 0 */
     unsigned int enable: 1; /* bit 1 */
 } rec; /* v1 */
 rec.enable = 1;
 rec.ready = 0;
 printf("%d %d", rec.enable, rec.ready);
```

```
 orr v1,v1, #0x2            ;1 in bit 1
 bic v1,v1  #1              ;0 in bit 0,
```

; `bic` stands for 'bit clear, where '1' in the second operand clears
; the corresponding bit in the first

```
 ldr a1, =LCO               ;printf format
 mov a2, v1, lsr #1        ;just bit 1
 and a2, a2,0x0001          ;mask down to 1
 and a3, v1, 0x0001        ;just bit 0
 bl     printf              ;call printf
```


Multiply by Power of 2 via Shift Left (#1/3)

- In decimal:
  - Multiplying by 10 is same as shifting left by 1:
    - $714_{10} \times 10_{10} = 7140_{10}$
    - $56_{10} \times 10_{10} = 560_{10}$
  - Multiplying by 100 is same as shifting left by 2:
    - $714_{10} \times 100_{10} = 71400_{10}$
    - $56_{10} \times 100_{10} = 5600_{10}$
  - Multiplying by 10^n is same as shifting left by n

Multiply by Power of 2 via Shift Left (#2/3)

- In binary:
  - Multiplying by 2 is same as shifting left by 1:
    - $11_2 \times 10_2 = 110_2$
    - $1010_2 \times 10_2 = 10100_2$
  - Multiplying by 4 is same as shifting left by 2:
    - $11_2 \times 100_2 = 1100_2$
    - $1010_2 \times 100_2 = 101000_2$
  - Multiplying by 2^n is same as shifting left by n

Multiply by Power of 2 via Shift Left (#3/3)

° Since shifting is so much faster than multiplication (you can imagine how complicated multiplication is), a good compiler usually notices when C code multiplies by a power of 2 and compiles it to a shift instruction:

`a *= 8;` (in C)

would compile to:

`mov   a0,a0,lsl #3` (in ARM)

Shift, Add and Subtract for Multiplication

Add and Subtract Examples:

```
f = 5*g              /* f = (4+1) x g */        (in C)
add v1,v2,v2 lsl #2  ; v1 = v2 + v2 *4  (in ARM)

f = 105 *g           /* f = (15 x 7) x g */  (in C)
                      /* f = (16 –1 ) x (8 – 1) x g */
rsb v1,v2,v2 lsl #4  ; v1 = -v2 + v2 *16  (in ARM)
                      ; f = (16-1)* g
rsb v1,v1,v1 lsl #3   ; v1 = -v1 + v1 *8  (in ARM)
                      ; f = (8-1)* f
```


Shift, Add and Subtract for Division

- ARM does not have division.
- Division A/B produces a quotient and a remainder.
- It should be done via sequence of subtraction and shifting (See Experiment 3)
- For B in A/B a constant value (eg 10) simpler technique via Shift, Add and Subtract is available (Will be discussed later)

Shift Right Arithmetic; Divide by 2???

° Shifting left by n is same as Multiplying by 2^n

° Shifting right by n bits would seem to be the same as dividing by 2^n

° Problem is signed integers

- Zero fill is wrong for negative numbers

° Shift Right Arithmetic (`asr`); sign extends (replicates sign bit);

° 1111 1111 1111 1000 = -8

° 1111 1111 1111 1100 = -4

° 1111 1111 1111 1110 = -2

° 1111 1111 1111 1111 = -1

Is asr really divide by 2?

- Divide +5 by 4 via `asr` 2; result should be 1

0000 0000 0000 0000 0000 0000 0000 0101

0000 0000 0000 0000 0000 0000 0000 0001

- = +1, so **does** work
- Divide -5 by 4 via `asr` 2; result should be -1

1111 1111 1111 1111 1111 1111 1111 1011

1111 1111 1111 1111 1111 1111 1111 1110

- = -2, not -1; Off by 1, so **doesn't always** work
- Rounds to $-\infty$

MULTIPLY (unsigned): Terms, Example

- Paper and pencil example (unsigned):

```
Multiplicand     1000
Multiplier       1001
                 ----
                 1000
                0000
               0000
              1000
              --------
Product       01001000
```

- m bits x n bits = m+n bit product
- 32-bit value x 32-bit value = 64-bit value

Multiplication Instructions

- The Basic ARM provides two multiplication instructions.
- Multiply
  - `mul     Rd, Rm, Rs   ; Rd = Rm * Rs`
- Multiply Accumulate - does addition for free
  - `mla     Rd, Rm, Rs,Rn ; Rd = (Rm * Rs) + Rn`
- (Lower precision multiply instructions simply throws top 32bits away)
- Restrictions on use:
  - Rd and Rm cannot be the same register
    - Can be avoided by swapping Rm and Rs around. This works because multiplication is commutative.
  - Cannot use PC.

  These will be picked up by the assembler if overlooked.
- Operands can be considered signed or unsigned
  - Up to user to interpret correctly.

Multiplication Example

- Example:
  - in C: `a = b * c;`
  - in ARM:
    - let `b` be `v1`; let `c` be `v2`; and let `a` be `v3` (It may be up to 64 bits)

```
mul v3, v2, v1 ;a = b*c
                  ; lower half of product into
                  ; v3. Upper half is thrown up
```

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

Multiplication and Accumulate Example

- One example of use of `mla` is for string to number conversion: eg

```
Convert string="123" to value=123
   value = 0
   loop = 0
   len = length of string
   Rd = value
   while loop <> len
   c = extract(string, len - loop,1)
   Rm = 10 ^ loop
   Rs =  ASC(c) - ASC ('0')
   mla Rd, Rm, Rs, Rd
   loop = loop + 1
   endwhile
```


Multiply-Long and Multiply-Accumulate Long

- Instructions are
  - MULL which gives RdHi,RdLo:=Rm*Rs
  - MLAL which gives RdHi,RdLo:=(Rm*Rs)+RdHi,RdLo
- However the full 64 bit of the result now matter (lower precision multiply instructions simply throws top 32 bits away)
  - Need to specify whether operands are signed or unsigned
- Therefore syntax of new instructions are:

```
• umull   RdLo,RdHi,Rm,Rs     ;RdHi,RdLo:=Rm*Rs
• umlal   RdLo,RdHi,Rm,Rs     ;RdHi,RdLo:=(Rm*Rs)+RdHi,RdLo
• smull   RdLo, RdHi, Rm, Rs  ;RdHi,RdLo:=Rm*Rs (Signed)
• smlal   RdLo, RdHi, Rm, Rs  ;RdHi,RdLo:=(Rm*Rs)+RdHi,RdLo
                                                  (Signed)
```

- Not generated by the compiler. (Needs Hand coding)

Division

- No Division Instruction in ARM
- Division has two be done in software through a sequence of shift/ subtract / add instruction.
  - General A/B implementation (See Experiment 3)
  - For B in A/B a constant value (eg 10) simpler technique via Shift, Add and Subtract is available (Will be discussed later)

Quiz

1. Specify instructions which will implement the following:

   a) a1 = 16 b) a2 = a1 * 4

   c) a1 = a2 / 16 (r1 signed 2's comp.) d) a2 = a3 * 7

2. What will the following instructions do?

   a) `add a1, a2, a2, lsl #2` b) `rsb a3, a2, #0`

3. What does the following instruction sequence do?

```
add a1, a2, a2, lsl #1
sub a1, a1, a2, lsl #4
add a1, a1, a2, lsl #7
```

Quiz Solution (#1/2)

1. Specify instructions which will implement the following:

a) a1 = 16 `mov a1, #16`

b) a2 = a1 * 4 `mov a2, a1, lsl #2`

c) a1 = a2 / 16 (r1 signed 2's comp.) `mov a1, a2, asr #4`

d) a2 = a3 * 7 rsb `a2, a3, a3, lsl #3`

a2 = a3* (8-1)

whereas `sub a2, a3, a3, lsl #3` would give a3* -7

2. What will the following instructions do?

a) `add a1, a2, a2, lsl #2`

a1= a2+ (a2 * 4) ie a1:=a2*5

b) `rsb a3, a2, #0`

° r2=0-r1 ie r2:= -r1

Quiz Solution (#2/2)

3. What does the following instruction sequence do?

```
add a1, a2, a2, lsl #1
sub a1, a1, a2, lsl #4
add a1, a1, a2, lsl #7
```

```
a1 = a2 + (a2 * 2) = a2 * 3
a1 = a1 - (a2 * 16)= (a2 * 3) - (a2 * 16) = a2 * -13
a1 = a1 + (a2 * 128) =  (a2 * -13) + (a2 * 128)
                     = r1 * 115
                     i.e.  a1 = a2 * 115
```


COMP3221 Reading Materials (Week #4)

- Week #4: Steve Furber: ARM System On-Chip; 2nd Ed, Addison-Wesley, 2000, ISBN: 0-201-67519-6. We use chapters 3 and 5
- ARM Architecture Reference Manual –On CD ROM

"And in Conclusion…"

- New Instructions:

```
mul
mla
umull
umlal
smull
smlal
```