Chapter 4
ARM Arithmetic and Logic Instructions Exercises ANS

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Review

Summary of Carry and Overflow Flags

Bit	Name	Meaning after add or sub
N	negative	result is negative
Z	zero	result is zero
V	overflow	signed overflow
C	carry	unsigned overflow

Carry flag C = 1 upon an **unsigned** addition if the answer is wrong (true result > 2^n-1)

Carry flag C = 0 (Borrow flag = 1) upon an unsigned subtraction if the answer is wrong (true result < 0)

Overflow flag V =1 upon a **signed** addition if the answer is wrong (true result > 2^{n-1}-1 or true result < -2^{n-1})

CPSR (Current Program Status Register)

Review

References

- Lecture 2: Carry flag for unsigned addition and subtraction
  - https://www.youtube.com/watch?v=MxGW2WurKuM&list=PLRJhV4hUhlymmp5CCeIFPyxbknsdcXCc8&index=2
- Lecture 3: Overflow flag for signed addition and subtraction
  - https://www.youtube.com/watch?v=BIn6iyYIGio&list=PLRJhV4hUhlymmp5CCeIFPyxbknsdcXCc8&index=3

Flags ANDS

- What are value of r2, and NZCV flags after execution, assuming all flags are initially 0.

```
LDR r0, =0xFFFFFFF00
LDR r1, =0x00000001
ANDS r2, r1, r0, LSL #1
```

Flags ANDS ANS

- What are value of r2, and NZCV flags after execution, assuming all flags are initially 0.

```
LDR r0, =0xFFFFFF00
LDR r1, =0x00000001
ANDS r2, r1, r0, LSL #1
```

- ANS: r2 = 0x00000000
- NZCV = 0110

- Left shift (LSL #1) moves the bits in r0 left by 1 bit. The bitwise AND is then computed: r2 = r1 & (r0 << 1).
- N (Negative flag): Set to 0 because result r2 = 0x00000000, which is not negative.
- Z (Zero flag): Set to 1 because the result is zero (r2 = 0).
- C (Carry flag): Set to 1. The carry flag is updated based on the last bit shifted out during the left shift operation on r0. Since the left shift of 0xFFFFFF00 by 1 bit causes a '1' to be shifted out, the carry flag is set to 1.
- V (Overflow flag): Unchanged by AND operation.

Flags ADDS

- What are value of r2, and NZCV flags after execution, assuming all flags are initially 0.

```
LDR r0, =0xFFFFFF00
LDR r1, =0x00000001
ADDS r2, r1, r0, LSL #1
```

Flags ADDS ANS

- What are value of r2, and NZCV flags after execution, assuming all flags are initially 0.

```
LDR r0, =0xFFFFFF00
LDR r1, =0x00000001
ADDS r2, r1, r0, LSL #1
```

- ANS: r2 = 0xFFFFFE01
- NZCV = 1000
  - Left shift (LSL #1) moves the bits in r0 left by 1 bit, so r0 = 0xFFFFFE00. The ADDS is then computed: r2 = r1 + (r0 << 1) = 0xFFFFFE01
  - N (Negative): Since result r2 = 0xFFFFFE01 when interpreted as signed 32-bit (two's complement) is negative (most significant bit is 1), N = 1.
  - Z (Zero): Result is not zero, Z = 0.
  - C (Carry): Carry is set if there is an unsigned overflow. Here carry flag C = 0.
  - V (Overflow): Overflow is set if there is a signed overflow. Here:
    - $r1$ is positive; $r0 << 1$ is negative since high bit is set; 2 operands have different signs, no overflow, so V = 0.
    - Recall "Overflow cannot occur when adding 2 operands with different signs or when subtracting 2 operands with the same sign."

Flags

r0	0xffffffff
r1	0x00000001
r2	0x00000003
r3	0xfffffff0

- Suppose registers have the following values:
- What are value of r4, and NZCV flags after execution, assuming all flags are initially 0. (Each instruction runs individually.)
- (a) ADD r4, r0, r2, ASR #3
- (b) ADDS r4, r0, r1
- (c) LSRS r4, r0, #1
- (d) ANDS r4, r0, r3
- (e) CMP r2, #3

Flags ANS

r0	0xffffffff
r1	0x00000001
r2	0x00000003
r3	0xfffffff0

- (a) ADD r4, r0, r2, ASR #3
  - First, r2 ASR #3: 0x00000003 >> 3 = 0x00000000 (arithmetic shift preserves sign)
  - Then: r4 = r0 + 0 = 0xffffffff + 0 = 0xffffffff
  - Result: r4 = 0xffffffff, NZCV = 0000 (ADD doesn't affect flags)
- (b) ADDS r4, r0, r1
  - r4 = 0xffffffff + 0x00000001 = 0x00000000 (truncated to 32-bit)
  - N = 0 (result bit 31 = 0, not negative)
  - Z = 1 (result is zero)
  - C = 1 (carry out from bit 31: 0xffffffff + 1 produces carry)
  - V = 0 (no signed overflow: -1 + 1 = 0, valid in 32-bit signed range)
  - Result: r4 = 0x00000000, NZCV = 0110
- (c) LSRS r4, r0, #1
  - Logical shift right with flag update: 0xffffffff >> 1 = 0x7fffffff
  - N = 0 (result bit 31 = 0)
  - Z = 0 (result is not zero)
  - C = 1 (last bit shifted out was 1)
  - V = 0 (logical shifts don't affect overflow flag)
  - Result: r4 = 0x7fffffff, NZCV = 0010

Flags ANS

r0	0xffffffff
r1	0x00000001
r2	0x00000003
r3	0xfffffff0

- (d) ANDS r4, r0, r3
  - Bitwise AND with flag update: 0xffffffff & 0xfffffff0 = 0xfffffff0
  - N = 1 (result bit 31 = 1, negative)
  - Z = 0 (result is not zero)
  - C = 0 (logical operations clear carry flag)
  - V = 0 (logical operations don't affect overflow)
  - Result: r4 = 0xfffffff0, NZCV = 1000
- (e) CMP r2, #3
  - Compare operation: r2 - 3 = 3 - 3 = 0 (result not stored, only flags updated)
  - N = 0 (subtraction result is 0, bit 31 = 0)
  - Z = 1 (subtraction result is 0)
  - C = 1 (no borrow: 3 ≥ 3, so C = 1 = not borrow)
  - V = 0 (no signed overflow in 3 - 3)
  - Result: NZCV = 0110

Review

Barrel Shifter: Explanations

- LSL (logical shift left): shifts left, fills zeros on the right; C gets the last bit shifted out of bit 31. This is multiply by 2^n for non-overflowing values.
- LSR (logical shift right): shifts right, fills zeros on the left; C gets the last bit shifted out of bit 0. This is unsigned division by 2^n.
- ASR (arithmetic shift right): shifts right, fills the sign bit on the left to preserving the sign; C gets the last bit shifted out of bit 0. This is signed division by 2^n with sign extension
- ROR (rotate right): rotates bits right with wraparound; bits leaving bit 0 re-enter at bit 31, and C receives the bit that wrapped. This is a pure rotation without data loss.
- RRX (rotate right extended): rotates right by one through the carry flag, treating C as a 33rd bit; new bit 31 comes from old C, and C receives old bit 0.

Arithmetic with Shifts

- Assuimg 32-bit registers:
- Q1:
  - LDR r0, =0x00000007
  - MOV r0, r0, LSL 7
- Q2:
  - LDR r0, =0x00000400
  - MOV r0, r0, LSR 2
- Q3:
  - LDR r0, =0xFFFFC000
  - MOV r0, r0, LSR 2
- Q4:
  - LDR r0, =0xFFFFC000
  - MOV r0, r0, ASR 2
- Q5:
  - LDR r0, =0x00000007
  - MOV r0, r0, ROR 2

Q1 ANS

- Q1:
  - LDR r0, =0x00000007
  - MOV r0, r0, LSL 7
- ANS:
  - Original r0 = 0000 0000 0000 0000 0000 0000 0000 0111
  - After LSL 7, r0 = 0000 0000 0000 0000 0000 0011 1000 0000 = 0x0380 (896 in decimal)
  - In decimal: 7 × 2^7 = 7 × 128 = 896 (Not required for exam)

Q2 ANS

- Q2:
  - LDR r0, =0x00000400
  - MOV r0, r0, LSR 2
- ANS:
  - Original r0 = 0000 0000 0000 0000 0000 0100 0000 0000
  - After LSR 2, r0 = 0000 0000 0000 0000 0000 0001 0000 0000 = 0x00000100 (256 in decimal)
  - In decimal: $1024 \div 2^2 = 256$ (Not required for exam)

Q3 ANS

- Q3:
  - LDR r0, =0xFFFFC000
  - MOV r0, r0, LSR 2
- ANS:
  - Original r0 = 1111 1111 1111 1111 1111 1100 0000 0000
  - After LSR 2, r0 = 0011 1111 1111 1111 1111 1111 0000 0000 = 0x3FFFF000
  - In decimal: 4,294,951,424 ÷ 4 = 1,073,737,728 (Not required for exam)

Q4 ANS

- Q3:
  - LDR r0, =0xFFFFC000
  - MOV r0, r0, ASR 2
- ANS:
  - Original r0 = 1111 1111 1111 1111 1111 1100 0000 0000
  - After ASR 2, r0 = 1111 1111 1111 1111 1111 1111 0000 0000 = 0xFFFFFF00 (-256 in decimal)
  - In decimal: -16384 ÷ 2^2 = -4096 (Not required for exam)

Q5 ANS

- Q4:
  - LDR r0, =0x00000007
  - MOV r0, r0, ROR 2
- ANS:
  - Original r0 = 0000 0000 0000 0000 0000 0000 0000 0111
  - After ROR r0 = 1100 0000 0000 0000 0000 0000 0000 0001 = 0xC0000001

Assembly Programming

- Write ARMv7 assembly for pseudocode
  - r1 = (r0 >> 4) & 15

Assembly Programming ANS

- Write ARMv7 assembly for pseudocode
  - r1 = (r0 >> 4) & 15
- ANS:
  - MOV r1, r0, LSR #4
  - AND r1, r1, #15