Assignment 3
Computer Organization
Deadline: 11:55pm Tuesday, Dec 3, 2024

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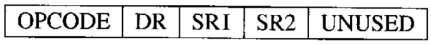
1. Suppose a 32-bit instruction takes the following format: (10 points)



DR: Destination Register; SR1 & SR2: Source Register 1&2

If there are 225 opcodes and 120 general purpose registers,

1) What is the minimum number of bits required to represent the OPCODE? Explain why. (2 points)
2) What is the minimum number of bits required to represent the Destination Register (DR)? Explain why. (2 points)
3) What is maximum number of UNUSED bits in the instruction encoding? Explain why. (2 points)
4) Suppose the address space contains 2^{16} memory locations and the addressability is 32 bits. How many bytes can the memory store in total? (2 points)
5) How many address lines are necessary? How many data lines are necessary (2 points)

1) 8, because $2^7 = 128 < 225 < 2^8 = 256$
2) 7, because $2^6 = 64 < 120 < 2^8 = 128$
3) 3, because $32\text{-}8\text{-}7\text{-}7\text{-}7 = 3$
4) 262144 Bytes, because $2^{16} \times 32\ bits = 2^{21}\ bits = 2^{18}\ Bytes = 262144\ Bytes$
5)
   a) Address lines: $\log_2 2^{16} = 16$
   b) Data lines: 32

2. The LC-3 does not have an opcode for the logical function OR. That is, there is no instruction in the LC-3 ISA that performs the OR operation. However, we can write a sequence of instructions to implement the OR operation. The four instruction sequence below performs the OR of the contents of register 1 and

register 2 and puts the result in register 3. Fill in the two missing instructions so that the four instruction sequence will do the job. (8 points)

(1): 1001 100 001 111111 // R4 = NOT R1

(2): 1001 101 010 111111 // R5 = NOT R2

(3): 0101 110 100 000 101 // R6 = R4 AND R5

(4): 1001 110 110 111111 // R6 = NOT R6

3. The PC contains x3010. The following memory locations contain values as shown: (10 points)

x3050:	x70A4
x70A2:	x70A3
x70A3:	xFFFF
x70A4:	x123B

The following three LC-3 instructions are then executed, causing a value to be loaded into R6.

```
Address X3010:  1110 0110 0011 1111

Address X3011:  0110 1000 1100 0000

Address X3012:  0110 1101 0000 0000
```

a) Explain what each instruction does. (6 points)
b) What is that value to be loaded into R6? (2 points)
c) We could replace the three-instruction sequence with a single instruction. What is it? Write the instruction in binary. (2 points)

a) **x3010: 1110 0110 0011 1111 // LEA R3 PC+0x3F**

PC + 0x3F = x3011 + x3F = x3050

LEA loads the effective address of a memory location into a register.

R3 now contains the value x3050.

x3011: 0110 1000 1100 0000 // LDR R4 R3+0

base address = value in R3 = x3050

Offset = 0

Address accessed = x3050 + 0 = x3050.

The value at memory address x3050 is x70A4.

R4 now contains x70A4.

x3012: 0110 1101 0000 0000 // LDR R6 R4+0

Base address = value in R4 = x70A4.

Offset = 0

Address accessed = x70A4 + 0 = x70A4.

The value at memory address x70A4 is x123B.

R6 now contains x123B.

b) The final value loaded into R6 is x123B.
c) 1010 110 00011 1111 // LDI R6 PC+0x3F

4. Suppose the following LC-3 program is loaded into memory starting at location x30FF: (12 points)

x30FF	1110 0010 0000 0001
x3100	0110 0100 0100 0010
x3101	1111 0000 0010 0101
x3102	0001 0100 0100 0001
x3103	0001 0100 1000 0010

a) Explain what each instruction does. (10 points)
b) If the program is executed, what is the value in R2 at the end of execution? (2 points)

a)

1. x30FF: 1110 0010 0000 0001 // LEA, R1, #1

set R1 to the address PC + 1

R1 = x3101

2. x3100: 0110 0100 0100 0010 // LDR, R2, R1, #2

   loads the value from value in address R1 + 2 to R2

   R1 + 2 = x3103

   R2 = 0001 0100 0100 0001 = x1482

3. x3101: 1111 0000 0010 0101 // TRAP x25

   Halt (stops execution)

4. x3102: 0001 0100 0100 0001 // ADD, R2, R1, R1

   R2 = R1 + R1 = x6202

5. x3103: 0001 0100 1000 0010 // ADD, R2, R2, R2

   R2 = R2 + R2 = xC404

b) The program halts after TRAP x25, so the instructions at x3102 and x3103 are not executed. The value in R2 is x1482.

5. 1) Construct the symbol table for the following LC-3 assembly language program. (10 points)

   2) Assemble it into binary machine code line by line by hand. (30 points)

   3) What does the program do? (10 points)

```
        .ORIG   x3000
        LD      R0,ASCII
        LD      R1,NEG
AGAIN   LDI     R2,DSR
        BRzp    AGAIN
        STI     R0,DDR
        ADD     R0,R0,#1
        ADD     R2,R0,R1
        BRnp    AGAIN
        HALT
ASCII   .FILL   x0041
NEG     .FILL   xFFB6    ; -x004A
DSR     .FILL   xFE04
DDR     .FILL   xFE06
        .END
```

1) Symbol Table:

Symbol	Address
AGAIN	x3002
ASCII	x3009
NEG	x300A
DSR	x300B
DDR	x300C

2)

Address	Label	Hex	Binary	Instruction
x3000		x2008	0010 0000 0000 1000	LD R0, ASCII
x3001		x2208	0010 0010 0000 1000	LD R1, NEG
x3002	AGAIN	xA408	1010 0100 0000 1000	LDI R2, DSR
x3003		x07FE	0000 0111 1111 1110	BRzp AGAIN
x3004		xB007	1011 0000 0000 0111	STI R0, DDR
x3005		x1021	0001 0000 0010 0001	ADD R0, R0, #1
x3006		x1401	0001 0100 0000 0001	ADD R2, R0, R1
x3007		x0BFA	0000 1011 1111 1010	BRnp AGAIN
x3008		xF025	1111 0000 0010 0101	HALT
x3009	ASCII	x0041	0000 0000 0100 0001	NOP
x300A	NEG	xFFB6	1111 1111 1011 0110	.FILL xFFB6
x300B	DSR	xFE04	1111 1110 0000 0100	.FILL xFE04
x300C	DDR	xFE06	1111 1110 0000 0110	.FILL xFE06

3) Print “ABCDEFGHI”