TCSS371 - Machine Organization
Assignment 3 - Von Neumann Model and Instructions
20 Points

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Purpose: This homework will test your understanding of Von Neumann Model and LC3 Instructions that we covered in lecture from Chapters 4 and 5 of the textbook

Student Learning Outcomes: The following student-learning outcomes are addressed in this assignment:

- translate between assembly instructions and machine code
- explain the instruction execution cycle

1. (Show your work) Suppose a **32-bit** instruction takes the following format:

OPCODE	DR	SR1	SR2	UNUSED

If there are 8 opcodes and 10 registers,

a. What is the minimum number of bits required to represent the OPCODE?
b. What is the minimum number of bits required to represent the Destination Register (DR)?
c. What is maximum number of UNUSED bits in the instruction encoding?

NOTE: Explain your answers and/or show your work for full credit. Answers with no explanation or work shown will not get full credit.

2. The LC-3 does not have a multiply instruction. You will write a **machine code (1s and 0s)** program to allow for multiplication of two numbers. Your program will include the features listed below in steps a through d. It's best to complete each step and test before moving to the next step. Test to make sure that the program works in LC3. *No credit if you write code in assembly.* Your machine code file name must be **Multiply.bin**

Check a ✓ a. Load register R3 with the number stored in memory location x3100. Load register R4 with the number stored in memory location x3101. ***The provided starter code already places data in these two memory locations.***

b. Write machine code to multiply the contents of R3 with the contents of R4. The result must be stored in R5. In other words, R5 <- R3 * R4. ✓

c. Modify the program to also store the result at memory location x3102. ✓

d. Modify the program to also set the contents of register R6 based on the final result stored in R5.
If R5 is greater than 0, R6 must be set to 1
If R5 is less than 0, R6 must be set to -1
If R5 is equal to 0, R6 must be set to 0

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Opcode	DR	SR1	SR2	Unused

32 bits total represent the instruction.

8 opcodes
10 registers

a) $\lceil \log_2(8) \rceil = 3$, exact value is 3
The minimum amount of bits to represent the opcodes is 3 bits. This is the minimum because none of the unused bits are required to form the bits of the opcode and $\log_2$(opcodes) rounded to the ceiling is equal to the amount of bits necessary to represent the opcodes. $2^3 = 8$, so 3 is the minimum amount of bits required, $2^2 + 2^1 + 2^0 = 7$

b) $\lceil \log_2(10) \rceil = 4$, exact value ≈ 3.321928094887

There are 10 registers, to find minimum amount of bits to represent the registers, we take $\log_2$(registers) and round to its ceiling giving us 4 in this case. The amount of bits required for any of our registers, DR, SR1, SR2 are equal.
DR is represented by at minimum 4-bits
$2^4 = 16$, $2^3 = 8$, $2^2 = 4$, $2^1 = 2$, $2^0 = 1$ 2^4 bits is the minimum for representing 10 registers.

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C.

Total bits = 32 bits $= T$
Minimum opcote bits = 3 = op
minimum DR Bits = 4 = r_1
Minimum SR1 Bits = 4 = r_2
Minimum SR2 Bits = 4 = r_3

$$T - (Op + r_1 + r_2 + r_3) = \text{Unused}$$

$$32 - (3 + 4 + 4 + 4) = 17$$

$\boxed{\text{UNUSED} = 17\text{-bits,}}$ this is the maximum possible Amount of unused bits since all registers and opcodes are using the minimum amount of bits to calculate 17 unused bits.