CS/ECE 252: INTRODUCTION TO COMPUTER ENGINEERING

UNIVERSITY OF WISCONSIN—MADISON

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Midterm 3
In Class (50 minutes)
Note: This was originally given as an optional supplemental test after Midterm 3; for future reference it is more appropriately regarded simply as Midterm 3.

NO: BOOK(S), NOTE(S), CALCULATORS OF ANY SORT.

This exam has 10 pages, including a blank page. Plan your time carefully, since some problems are longer than others. You must turn in all pages.

A listing of the **LC-3 instruction set** is given at the end of this booklet for your convenience.

LAST NAME: _____

FIRST NAME:_____

SECTION: _____

ID # _____

Question	Maximum Points	Points
1	6	
2	6	
3	5	
4	7	
5	7	
6	6	
Total	37	

Problem 1. (6 points)

This program adds up ten numbers, leaving the sum in R1. The numbers are found in memory starting at location x3100. There is **one** error in this program. **Circle** the bad instruction, and write the corrected instruction (in binary) below.

```
x3000 0101  001  001  1  00000   Clear R1

x3001 1110  010  011111110     R2 ← x3100

x3002 0101  011  011  1  00000   Clear R3

x3003 0001  011  011  1  01010   R3 ← 10

x3004 0000  100  000000100     Branch if done

x3005 0110  100  010  000000    R4 ← M[R2]

x3006 0001  001  001  000  100   R1 ← R1 + R4

x3007 0001  011  011  1  11111   Decrement loop count

x3008 0000  111  111111011     Branch Loop

x3009 1111  0000  0010  0101    HALT
```

Corrected Instruction:

As we said in class, there are really *two* errors in this program. Extra credit if you fix both of them; a maximum of 3 extra points if you accurately and completely fix both.

Error #1: The loop iterates 11 times, not 10. This can be fixed in one of three ways:

a. Change the first branch to BRz or BRnz, instead of BRn.
   x3004 0000 110 000000100
b. Put a 9 in R3 instead of a 10:
   x3003 0001 011 011 1 01001
c. (Not quite as neat) Change the second branch to only branch back on positive
   x3008 0000 001 111111011

Error #2: R2, the data pointer, never gets incremented. Insert the following instruction after either x3005 or x3006 (though not after x3007):

0001 010 010 1 00001

Problem 2. (6 Points)

Some of the following instructions are "no-operation"; that is, they do not change the value of any of the eight general-purpose registers or the PC. (For this problem, don't worry about the condition codes.)

Check the box next to each no-operation instruction.

☐ `0101 000 000 100000 And` No, clears R0

☐ `0101 000 000 000000 And` Yes, ANDs R0 with itself which doesn't change it

☐ `0001 000 000 100000 Add` Yes, adds zero

☐ `0001 000 000 000000 Add` No, doubles R0

☐ `1110 000 000000000 LEA` No, copies PC into R0

☐ `0110 000 000 000000 LDR` No, does a load into R0

☐ `0000 000 000000000 Branch` Yes, never branches

☐ `0000 111 000000000 Branch` Yes, branches but doesn't add anything to PC

Problem 3. (5 points)

a. Suppose you wish to test whether or not bit 3 is set in register R0. (That is, you wish to set the condition codes so that you can do a conditional branch.)
Write the **instruction or instructions** below, in binary, for the test. (You do not need to include the branch itself). Assume the data is already in R0.

Use an AND instruction to test a bit. It doesn't matter what the destination register is as long as it's a register you don't mind overwriting:

```
0101 001 000 1 01000
                ^
               (That is bit 3)
```

b. Suppose you need to do the same thing, except test for bit 12. You do **not** need to write the binary, but state how many instructions are needed and describe what they are.

Bit 12 is beyond what you can set in the immediate field. You need to load a register with a word that just has bit 12 set (x1000), then do the AND. There are several ways to put x1000 into a register. The easiest is to load it:

```
    LD R1,BitTwelve
    AND R1,R1,R0
    . . .
    etc
BitTwelve .FILL x1000
```

If you want to be creative, you could create x1000 by putting x0008 into a register and then shifting it left (adding to itself) nine times; this would take about seven instructions including the AND. (There is no point into doing this in real life.)

Another approach is to shift R0 left three times (add to itself 3 times). Then you don't even need the AND; just branch on the 'n' bit. This is only three instructions.

Problem 4. (7 points)

Most computers have an XOR instruction, but the LC-3, alas, does not. But recall that XOR (Exclusive OR) means "one or the other but not both"; we can write a program to do that operation as ((A or B) and not (A and B)). It is started below; finish it. Include **both** binary and comments. Assume the operands are in R2 and R3, and leave the result in R7.

```
1001 100 010 111111      R4 ← NOT R2

1001 101 011 111111      R5 ← NOT R3

0101 110 100 000 101     R6 ← R4 AND R5
```

```
1001 110 110 111111      R6 <- NOT R6   (which is R2 OR R3)
_____________________  ____________________________________

0101 000 010 000 011     R0 <- R2 AND R3
_____________________  ____________________________________

1001 000 000 111111      R0 <- NOT R0   = (NOT (R2 AND R3))
_____________________  ____________________________________

0101 111 000 000 110     R7 <- R0 AND R6   = (R2 OR R3) AND NOT (R2 AND R3)
_____________________  ____________________________________
```

Problem 5. (7 points)

What ends up in the registers after these instructions are executed?

```
x3000 0010 010 000001111    LD   R2 <- M[x3010]

x3001 1110 011 000001111    LEA  R3 <- x3011

x3002 1010 100 000001111    LDI  R4 <- M[M[x3012]]

x3003 0110 000 011 000010   LDR  R0 <- M[R3+2] = M[x3013]

x3004 0110 001 010 000010   LDR  R1 <- M[R2+2] = M[x3016]

x3005 1111 0000 0010 0101   HALT

. . .
. . . These are data, not instructions:

x3010 0011 0000 0001 0100   x3014

x3011 0011 0000 0001 1111   x301f

x3012 0011 0000 0001 0101   x3015

x3013 0000 0000 0010 0100   x0026

x3014 0011 0000 0001 0110   x3016

x3015 0000 0000 1001 0001   x0091

x3016 0011 0000 0010 0000   x3020
```

R0 _____x0026

R1 _____x3020

R2 _____x3014

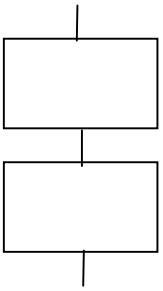
R3 _____x3011

R4 _____x0091

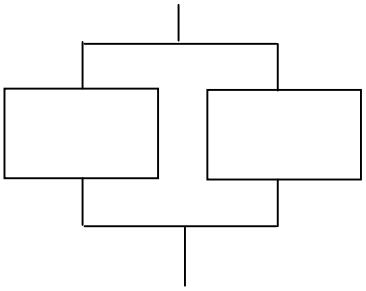
A number of people added wrong for the first three instructions. They converted 1111 to a decimal 15, then proceeded to add HEX 15 to the PC. This resulted in the wrong answer for all five registers. If it was clear to me that you understood the instructions and did everything right except this one thing, I gave back some points. If you got a zero and feel you fall into that category, come see the instructor or a TA.

Problem 6. (6 points)
Which of these constructs are the ones we studied for *systematic decomposition*? List the letters corresponding to each one that applies: A, E, F (Don't forget that all such decompositions have exactly one path in at the top and one out at the bottom, so they can replace a rectangular box.

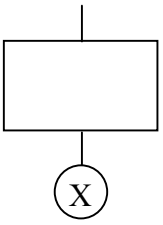
a. Sequential



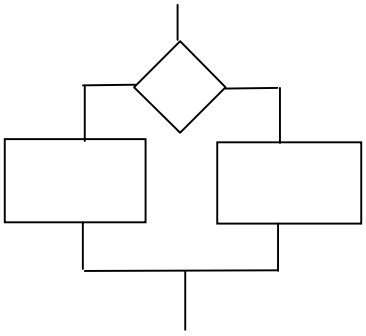
d. Parallel



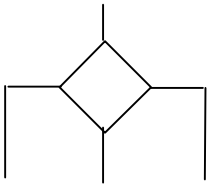
b. Halting



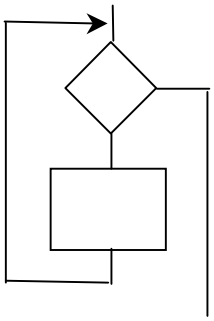
e. Conditional



c. Multi-way Conditional



f. Iterative



Scratch paper