ECE199JL Final Exam, Fall 2012

Tuesday 18 December

Name and UIUC Net ID:

- **Be sure that your exam booklet has 13 pages.**
- **Write your name at the top of each page.**
- **This is a closed book exam.**
- **We have included a scratch sheet and two LC-3 reference pages.**
- **Appendix A of the textbook is available to you on request.**
- **You are allowed FOUR** 8.5×11**" sheets of notes.**
- **Absolutely no interaction between students is allowed.**
- **Show all of your work.**
- **Challenge questions are marked with ***.**
- **Don't panic, and good luck!**

"I think there is a world market for maybe five computers."
—Thomas Watson (Chairman of IBM), 1943

Problem 1	10 points	______________
Problem 2	15 points	______________
Problem 3	15 points	______________
Problem 4	15 points	______________
Problem 5	25 points	______________
Problem 6	10 points	______________
Problem 7	10 points	______________
Total	100 points	______________

Problem 1 (10 points): Representations

Part A (3 points): Explain why an N-bit signed magnitude representation allows you to represent only $2^N - 1$ different numbers.

Part B (4 points): Two N-bit 2's complement numbers, A and B, are added to find their sum S, as shown to the right.

$$\begin{array}{r} A_{N-1}A_{N-2}\ldots A_2A_1A_0 \\ +\ B_{N-1}B_{N-2}\ldots B_2B_1B_0 \\ \hline S_{N-1}\,S_{N-2}\ldots S_2\,S_1\,S_0 \end{array}$$

Write a Boolean expression for the overflow condition for the addition in terms of the variables shown.

Part C (3 points): As you know, addition of two IEEE single-precision floating-point numbers is not associative. In other words, for some values of A, B, and C,

$$(A + B) + C \neq A + (B + C)$$

Give an example of values for A, B, and C for which this lack of associativity holds (*write decimal numbers or scientific notation—you need not translate to the binary representation for IEEE floating-point!*).

A ______________________

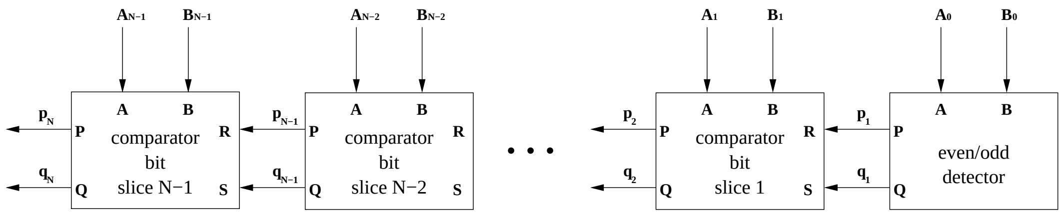
B ______________________

C ______________________

Problem 2 (15 points): Logic

The block diagram below illustrates a specialized N-bit unsigned comparator. The comparator operates on two unsigned numbers, A and B, to produce outputs P_N and Q_N with meanings defined in the table to the right.

P_N	Q_N	Meaning
0	0	$A < B$ and both A and B are odd
0	1	$A \geq B$ and both A and B are odd
1	0	$A < B$ and (A and B are not both odd)
1	1	$A \geq B$ and (A and B are not both odd)

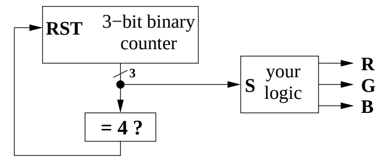


Part A (5 points): Design the even/odd detector. Show all work, including drawing a gate-level diagram implementing outputs P and Q in terms of inputs A and B.

Part B (10 points): Design the general bit slice for this comparator. Show all work, including drawing a gate-level diagram implementing outputs P and Q in terms of inputs A, B, R, and S.

Problem 3 (15 points): Finite State Machines

Part A (5 points): Professor Lumetta promised Professor Cangellaris to design a holiday light display for the new ECE building, but Lumetta has been too busy writing exam problems!

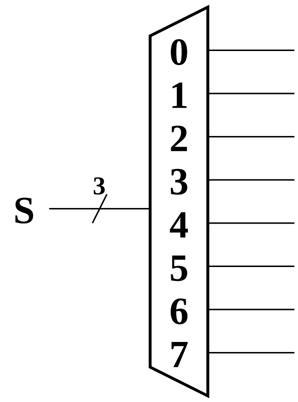


The design to the right shows what he needs: combinational logic that translates the output of a binary counter (counts upward) into RGB signals according to the following repeating sequence in the table below.

The RST input to the counter forces it back to 000 in the following cycle.

Design the logic needed to compute the RGB signals given the state $S_2S_1S_0$ of the counter. Use a few gates along with the decoder shown to the right to implement the functions R, G, and B as described by the table above.

color	RGB
RED	100
YELLOW	110
GREEN	010
BLUE	001
PURPLE	101



Part B (10 points): Draw an abstract transition diagram for a sequence recognizer that identifies the following sequences: 110, 0110, and 1100. In particular, the output R of the sequencer should be 1 whenever the input B has seen any of those three sequences in the last cycles.

Use as few states as possible, explain the meaning of your states, and be sure to specify the starting state.

Note that your diagram states should be labeled with names and output bit, but not with internal state bits (**you do not need to pick a representation**), but the arcs should be labeled with input combinations.

Problem 4*** (15 points): Machine Code Analysis

An LC-3 program is located in memory location x3000 to x3007.

The program starts executing at x3000. If we keep track of all values loaded into the MAR as the program executes, we obtain the sequence shown to the right. Such a sequence of values is referred to as a trace.

Fill in the table below with the bits stored in locations x3000 to x3007, then translate the bits to assembly code (fill in the blanks at the bottom of the page).

Some of the bits in the table have been filled in already—use these to deduce the values of the others such that the resulting program leads to the MAR trace shown to the right.

You will need some additional information:
- All registers contain x0000 when the program starts.
- Data stored in location x4FF8 and x5000 are x2012.
- HALT is TRAP x25.

MAR trace	
first value in MAR	x3000
second value in MAR	x3007
third value in MAR	x3001
. . .	x3003
	x3007
	x5000
	x3004
	x4FF8
	x3005
	x3006
	x3002

x3000	0	0	1	0	0	0	0									
x3001					1	0	0	0	0	0	0	0	0	0	0	1
x3002	1	1	1	1	0	0	0	0	0	0	1	0	0	1	0	1
x3003					0	0	1									
x3004	0	1	1	0	0	1	0									
x3005	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	1
x3006					0	0	0									
x3007																

Translate the bits to LC-3 assembly code (not RTL) with numeric operands. Do not use labels.

`x3000` ______________________________

`x3001` ______________________________

`x3002` ______________________________

`x3003` ______________________________

`x3004` ______________________________

`x3005` ______________________________

`x3006` ______________________________

`x3007` ______________________________

Problem 5 (25 points): Assembly Code

Part A (5 points): The LC-3 assembler produces the symbol table below when assembling the code shown to the right. Fill in the blank entries.

```
// Symbol table
// Scope level 0:
// Symbol Name       Address
// ----------------  ------------
//
// MAIN              ____________________
// LD1               x3001
// ST1               x3006
// LD2               x3007
// ST2               x300C
// INIT              x300F
//
// FOO               ____________________
// CALC              x301B
// NEXT              x3020
// DONE              x3024
// RETN              x302A
// OP1               x302B
// OP2               x302C
// EXT               x302D
// FLAG              x302E
//
// NAME              ____________________
//
// SIGN              ____________________
//
// MASK              ____________________
```

```
          .ORIG     x3000

MAIN      AND       R3,R3,#0
LD1       LD        R1,OP1
          LD        R4,SIGN
          AND       R5,R1,R4
          BRz       ST1
          JSR       FOO
ST1       ADD       R2,R1,#0
LD2       LD        R1,OP2
          LD        R4,SIGN
          AND       R5,R1,R4
          BRz       ST2
          JSR       FOO
ST2       ADD       R1,R1,#0
          AND       R3,R3,#1
          ST        R3,FLAG
INIT      AND       R4,R4,#0
          AND       R5,R5,#0
          ADD       R5,R5,#1
          AND       R6,R6,#0
          JSR       CALC
          HALT

FOO       ADD       R3,R3,#1
          LD        R4,EXT
          ADD       R1,R1,R4
          NOT       R1,R1
          ADD       R1,R1,#1
          RET
CALC      ADD       R3,R4,#-6
          BRzp      DONE
          AND       R3,R5,R2
          BRz       NEXT
          ADD       R6,R1,R6
NEXT      ADD       R5,R5,R5
          ADD       R1,R1,R1
          ADD       R4,R4,#1
          BRnzp     CALC
DONE      LD        R3,FLAG
          BRz       RETN
          NOT       R6,R6
          ADD       R6,R6,#1
          LD        R4,MASK
          AND       R6,R6,R4
RETN      RET

OP1       .FILL     x000B
OP2       .FILL     x0007
EXT       .FILL     xFF00
FLAG      .BLKW     #1
NAME      .STRINGZ  "Read this"
SIGN      .FILL     x0080
MASK      .FILL     x4FFF

          .END
```

Problem 5, continued:

Part B (10 points): The following LC-3 program determines whether or not two strings match (that is, whether or not they have identical contents). The first string starts at memory location x4000, and the second string starts at memory location x5000. Both strings are in the .STRINGZ format. If the two strings are the same, the program terminates with a 1 in R6. If the two strings are different, the program terminates with a 0 in R6. Write one LC-3 assembly instruction into each blank to complete the program. *You should not need to define any new labels.*

```
          .ORIG   x3000
          LD      R1, STRING1
          JSR     LENGTH

          ________________________________________ ; part A
          LD      R1, STRING2
          JSR     LENGTH

          ________________________________________ ; part B
          NOT     R4, R4
          ADD     R4, R4, #1
          ADD     R4, R4, R3
          BRnp    NO

          LD      R1, STRING1
          LD      R2, STRING2
CONTINUE  LDR     R3, R1, #0
          LDR     R4, R2, #0

          ________________________________________ ; part C
          NOT     R4, R4
          ADD     R4, R4, #1
          ADD     R4, R4, R3
          BRnp    NO

          ________________________________________ ; part D

          ________________________________________ ; part E
          BRnzp CONTINUE

YES       AND R6, R6, #0
          ADD R6, R6, #1
          BRnzp DONE

NO        AND R6, R6, #0
DONE      HALT

          ; a subroutine
LENGTH    AND     R0, R0, #0
COUNT     LDR     R5, R1, #0
          BRz     RETURN
          ADD     R0, R0, #1
          ADD     R1, R1, #1
          BRnzp   COUNT
RETURN    RET

STRING1   .FILL x4000
STRING2   .FILL x5000
          .END
```

Problem 5, continued:

Part C (10 points): Write a program in LC-3 assembly language that computes $RESULT = |A - 4|$. The $|\cdot|$ notation means "absolute value." Your program must have the following characteristics:

- The program must start at memory address x2800.
- The values A and $RESULT$ must be placed at the two memory addresses that immediately follow the last instruction in the program. These two addresses must be labeled `A` and `RESULT`, respectively.
- The value A must be initialized to 3.
- The program must produce the correct result for any initial value of A in the range [-1000,1000].
- The program must load the value of A, and store the correct $RESULT$, from/to the labeled memory locations.
- The program must execute HALT upon completion of this task.
- Appropriately comment your program so that the grader can understand your intent.

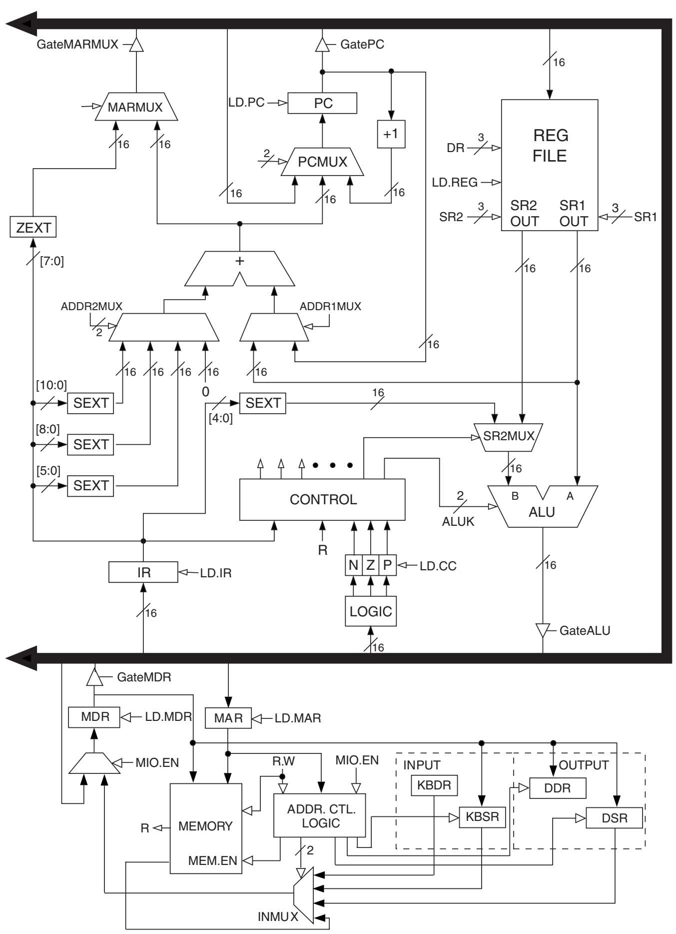
Problem 6 (10 points): LC-3 Implementation

Attached to the back of this exam is a copy of the LC-3 state machine (reproduced from the textbook). *Tear it off for use with this problem.*

Fill in the table below with the appropriate state numbers from that diagram for the ordered sequence of states that are active during the processing of an LC-3 LDR instruction. **Note: you may not need all rows of the table below.**

Next, for each state, indicate whether each control signal is active (1) or inactive (0). For your convenience, the LC-3 datapath is reproduced below (again from the textbook). **DO NOT LEAVE BLANK ENTRIES.**

State #	Gate.PC	LD.PC	LD.IR	LD.CC	LD.MAR	LD.MDR	GateMDR
18							
33							
35							
32							



Problem 7 (10 points): Critical Paths and Control Unit Design

Part A (3 points): Explain why the critical path through a tree-structured adder such as a Kogge-Stone adder is typically shorter than the critical path through a ripple carry adder.

Part B (4 points): Explain how a memory can be used to implement N Boolean logic functions on M variables. Be specific about the size of memory needed. (*You may want to draw a picture.*)

Part C (3 points): What is a microinstruction?

This page provided as scratch paper. If you need us to look at this page when grading, indicate this need **on the page of the corresponding problem** (not here!).

NOTES: RTL corresponds to execution (after fetch!); JSRR not shown

ADD

0001	DR	SR1	0	00	SR2

ADD DR, SR1, SR2

DR ← SR1 + SR2, Setcc

ADD

0001	DR	SR1	1	imm5

ADD DR, SR1, *imm5*

DR ← SR1 + SEXT(imm5), Setcc

AND

0101	DR	SR1	0	00	SR2

AND DR, SR1, SR2

DR ← SR1 AND SR2, Setcc

AND

0101	DR	SR1	1	imm5

AND DR, SR1, *imm5*

DR ← SR1 AND SEXT(imm5), Setcc

BR

0000	n	z	p	PCoffset9

BR{nzp} *PCoffset9*

((n AND N) OR (z AND Z) OR (p AND P)):
PC ← PC + SEXT(PCoffset9)

JMP

1100	000	BaseR	000000

JMP BaseR

PC ← BaseR

JSR

0100	1	PCoffset11

JSR *PCoffset11*

R7 ← PC, PC ← PC + SEXT(PCoffset11)

TRAP

1111	0000	trapvect8

TRAP *trapvect8*

R7 ← PC, PC ← M[ZEXT(trapvect8)]

LD

0010	DR	PCoffset9

LD DR, *PCoffset9*

DR ← M[PC + SEXT(PCoffset9)], Setcc

LDI

1010	DR	PCoffset9

LDI DR, *PCoffset9*

DR ← M[M[PC + SEXT(PCoffset9)]], Setcc

LDR

0110	DR	BaseR	offset6

LDR DR, BaseR, *offset6*

DR ← M[BaseR + SEXT(offset6)], Setcc

LEA

1110	DR	PCoffset9

LEA DR, *PCoffset9*

DR ← PC + SEXT(PCoffset9), Setcc

NOT

1001	DR	SR	111111

NOT DR, SR

DR ← NOT SR, Setcc

ST

0011	SR	PCoffset9

ST SR, *PCoffset9*

M[PC + SEXT(PCoffset9)] ← SR

STI

1011	SR	PCoffset9

STI SR, *PCoffset9*

M[M[PC + SEXT(PCoffset9)]] ← SR

STR

0111	SR	BaseR	offset6

STR SR, BaseR, *offset6*

M[BaseR + SEXT(offset6)] ← SR

For use with Problem 6.