Department of Electrical and Computer Engineering

The University of Texas at Austin

EE 306, Fall 2021
Problem Set 6
Due: Not to be turned in
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Note: This problem set is unusually long, and is not to be turned in. We have put it together and handed it out to give you some challenging examples to help you prepare for the final exam.

1. Jane Computer (Bob's adoring wife), not to be outdone by her husband, decided to rewrite the TRAP x22 handler at a different place in memory. Consider her implementation below. If a user writes a program that uses this TRAP handler to output an array of characters, how many times is the ADD instruction at the location with label A executed? Assume that the user only calls this "new" TRAP x22 once. Is it ok to call TRAP x21 within this "new" Trap routine? Explain why or why not in 20 words or fewer.

```
; TRAP handler
; Outputs ASCII characters stored in consecutive memory locations.
; R0 points to the first ASCII character before the new TRAP x22 is called.
; The null character (x00) provides a sentinel that terminates the output sequence.

        .ORIG x020F
START   LDR R1, R0, #0
        BRz DONE
        ST R0, SAVER0
        ADD R0, R1, #0
        TRAP x21
        LD R0, SAVER0
A       ADD R0, R0, #1
        BRnzp START
DONE    RTI
```

```
SAVER0    .BLKW #1
          .END
```

2. (Adapted from 9.16)
    a. How many TRAP service routines can be implemented in the LC-3? Why?
    b. Why must a RTI instruction be used to return from a TRAP routine? Why won't a BRnzp (unconditional BR) instruction work instead?
    c. How many accesses to memory are made during the processing of a TRAP instruction?

3. (Adapted from 8.15)
    a. What does the following LC-3 program do?

```
          .ORIG  x3000
          LD R3 , A
          STI R3, KBSR
AGAIN     LD R0,B
          TRAP X21
          BRnzp AGAIN
A         .FILL X4000
B         .FILL X0032
KBSR      .FILL XFE00
          .END
```

    b. If someone strikes a key, the program will be interrupted and the keyboard interrupt service routine will be executed as shown below. What does the keyboard interrupt service routine do?

```
           .ORIG X1000
          LDI R0,KBDR
          TRAP X21
          TRAP X21
          RTI
KBDR      .FILL XFE02
          .END
```

    c. Finally, suppose the program of part a started executing, and someone sitting at the keyboard struck a key. What would you see on the screen?

4. (9.34) What does the following LC-3 program do?

```
            .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
DSR         .FILL xFE04
DDR         .FILL xFE06
            .END
```

5. (Adapted from 10.1)
   What are the defining characteristics of a stack? Give two implementations of a stack and describe their differences.

6. Consider the following LC-3 assembly language program. Assuming that the memory locations DATA get filled before the program executes, what is the relationship between the final values at DATA and the initial values at DATA?

```
            .ORIG   x3000
LEA         R0, DATA
            AND     R1, R1, #0
            ADD     R1, R1, #9
LOOP1       ADD     R2, R0, #0
            ADD     R3, R1, #0
LOOP2       JSR     SUB1
            ADD     R4, R4, #0
            BRzp    LABEL
            JSR     SUB2
LABEL       ADD     R2, R2, #1
            ADD     R3, R3, #-1
```

```
            BRp     LOOP2
            ADD     R1, R1, #-1
            BRp     LOOP1
            HALT
DATA        .BLKW   #10
SUB1        LDR     R5, R2, #0
            NOT     R5, R5
            ADD     R5, R5, #1
            LDR     R6, R2, #1
            ADD     R4, R5, R6
            RET
SUB2        LDR     R4, R2, #0
            LDR     R5, R2, #1
            STR     R4, R2, #1
            STR     R5, R2, #0
            RET
            .END
```

7. During the initiation of the interrupt service routine, the N, Z, and P condition codes are saved on the stack. By means of a simple example show how incorrect results would be generated if the condition codes were not saved. Also, clearly describe the steps required for properly handling an interrupt.

8. The program below counts the number of zeros in a 16-bit word. Fill in the missing blanks below to make it work.

```
             .ORIG x3000
            AND   R0, R0, #0
            LD    R1, SIXTEEN
            LD    R2, WORD
A           BRn   B
             _________________
B            _________________
            BRz   C
            _________________
            BR    A          ; note: BR = BRnzp
C           ST    R0, RESULT
            HALT
```

```
SIXTEEN    .FILL #16
WORD       .BLKW #1
RESULT     .BLKW #1

           .END
```

After you have the correct answer above, what one instruction can you change (without adding any instructions) that will make the program count the number of ones instead?

9. Fill in the missing blanks so that the subroutine below implements a stack multiply. That is it pops the top two elements off the stack, multiplies them, and pushes the result back on the stack. You can assume that the two numbers will be non-negative integers (greater than or equal to zero) and that their product will not produce an overflow. Also assume that the stack has been properly initialized, the PUSH and POP subroutines have been written for you and work just as described in class, and that the stack will not overflow or underflow.

   Note: All blanks must be filled for the program to operate correctly.

```
MUL        ________________
           ST  R0, SAVER0
           ST  R1, SAVER1
           ST  R2, SAVER2
           ST  R5, SAVER5
           AND R2, R2, #0
           JSR POP
           ADD R1, R0, #0
           JSR POP
           ADD R1, R1, #0
           ________________

AGAIN      ADD R2, R2, R0
           ________________
           BRp AGAIN
DONE       ADD R0, R2, #0
           JSR PUSH
           ________________
           LD R0, SAVER0
```

```
            LD R1, SAVER1
            LD R2, SAVER2
            LD R5, SAVER5
            RET
```

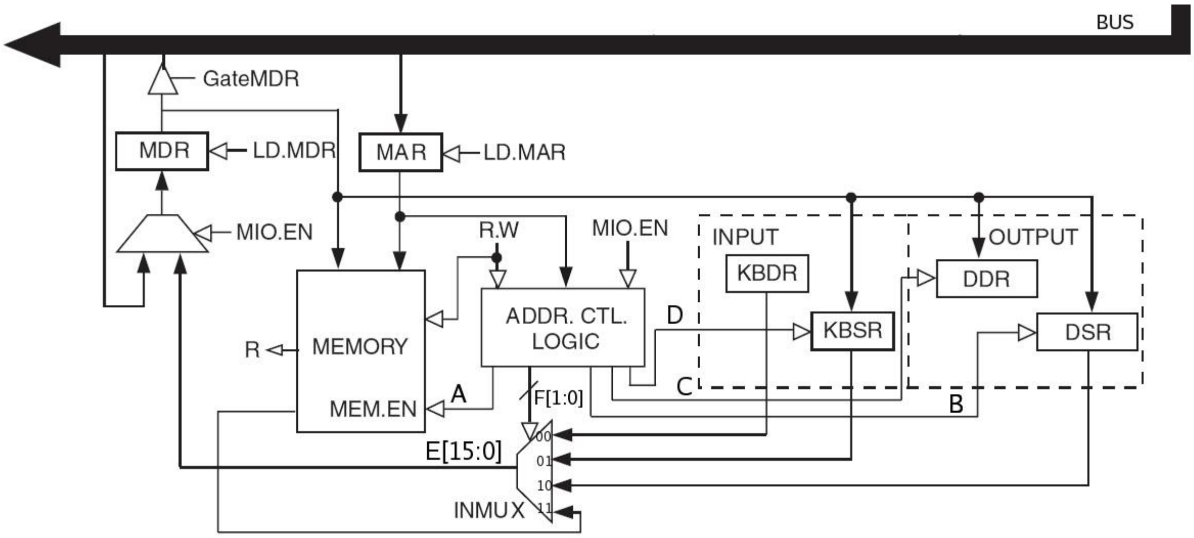
10. The program below calculates the closest integer greater than or equal to the square root of the number stored in NUM, and prints it to the screen. That is, if the number stored in NUM is 25, "5" will be printed to the screen. If the number stored in NUM is 26, "6" will be printed to the screen. Fill in the blanks below to make the program work.

    Note: Assume that the value stored at NUM will be between 0 an 81.

```
            .ORIG x3000
            AND R2, R2, #0
            LD R3, NUM
            BRz OUTPUT
            NOT R3, R3
            ADD R3, R3, #1
OUTLOOP     ADD R2, R2, #1
            _______________
            AND R1, R1, #0
INLOOP      ADD R1, R1, R2
            ADD R0, R0, #-1
            BRp INLOOP
            _______________
            BRn OUTLOOP
OUTPUT      LD R0, ZERO
            _______________
            TRAP x21
            HALT
NUM         .BLKW 1
ZERO        .FILL x30
            .END
```

11. The figure below shows the part of the LC-3 data path that deals with memory and I/O. Note the signals labeled A through F. A is the memory enable signal, if it is 1 memory is enabled, if it is 0, memory is disabled. B, C, and D are the load enable signals for the Device Registers. If the load enable signal is 1, the register

is loaded with a value, otherwise it is not. E is the 16-bit output of INMUX, and F is the 2-bit select line for INMUX.



The initial values of some of the processor registers and the I/O registers, and some memory locations are as follows:

R0 = x0000	KBSR = x8000	M[x3009] = xFE00
PC = x3000	KBDR = x0061	M[x300A] = xFE02
	DSR = x8000	M[x300B] = xFE04
	DDR = x0031	M[x300C] = xFE06

During the entire instruction cycle, memory is accessed between one and three times (why?). The following table lists two consecutive instructions to be executed on the LC-3. Complete the table with the values that each signal or register takes right after each of the memory accesses performed by the instruction. If an instruction does not require three memory accesses, draw a line accross the unused accesses. To help you get started, we have filled some of the values for you.

PC	Instruction	Access	MAR	A	B	C	D	E[15:0]	F[1]	F[0]	MDR
x3000	LD R0, x9	1	x3000					x2009			
		2									
		3									
x3001	LDR R0, R0, #0	1									
		2									
		3									

12. Note: This problem is NOT easy. In fact, it took me a while to solve it, and I am supposed to be an expert on 306 material. So, if you are struggling to pass this course, I suggest you ignore it. On the other hand, if you are a hot shot and think no problem is beyond you, then by all means go for it. We put it on the problem set to keep some of the hot shots out of mischief. We would not put it on the final, because we think it is too difficult to put on the exam.

    A programmer wrote this program to do something useful. He, however, forgot to comment his code, and now can't remember what the program is supposed to do. Your job is to save him the trouble and figure it out for him. In 20 words or fewer tell us what valuable information the program below provides about the value stored in memory location INPUT. Assume that there is a non-zero value at location INPUT before the program is executed.

    HINT: When testing different values of INPUT pay attention to their bit patterns. How does the bit pattern correspond to the RESULT?

```
        .ORIG x3000
        LD R0, INPUT
        AND R3, R3, #0
        LEA R6, MASKS
        LD R1, COUNT
LOOP    LDR R2, R6, #0
        ADD R3, R3, R3
        AND R5, R0, R2
        BRz SKIP
```

```
              ADD R3, R3, #1
              ADD R0, R5, #0
SKIP          ADD R6, R6, #1
              ADD R1, R1, #-1
              BRp LOOP
              ST R3, RESULT
              HALT
COUNT         .FILL #4
MASKS         .FILL 0xFF00
              .FILL 0xF0F0
              .FILL 0xCCCC
              .FILL 0xAAAA
INPUT         .BLKW 1
RESULT        .BLKW 1
              .END
```

13. Figure out what the following program does.

```
              .ORIG X3000
              LEA R2, C
              LDR R1, R2, #0
              LDI R6, C
              LDR R5, R1, #-3
              ST R5, C
              LDR R5, R1, #-4
              LDR R0, R2, #1
              JSRR R5
              AND R3, R3, #0
              ADD R3, R3, #7
              LEA R4, B
A             STR R4, R1, #0
              ADD R4, R4, #2
              ADD R1, R1, #1
              ADD R3, R3, #-1
              BRP A
              HALT
B             ADD R2, R2, #1
              LDR R0, R2, #0
              JSRR R5
              TRAP X29
```

```
            ADD R2, R2, #15
            ADD R0, R2, #3
            LD R5, C
            TRAP X2B
            ADD R2, R2, #5
            LDR R0, R2, #0
            JSRR R5
            TRAP X27
            JSRR R5
            JSRR R6
C           .FILL X25
            .STRINGZ "EE306 and tests are awesome"
            .END
```

14. (Adapted from 9.53)

Suppose we want to introduce two extra interrupts to the LC-3: INTA and INTB. INTA has priority 2 and an interrupt vector of x50. INTB has priority 4 and an interrupt vector of x60.

Recall that the priority is specified in bits [10:8] of the PSR. In fact, the full PSR specification is:

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PSR:	Pr	0	0	0	0	Priority			0	0	0	0	0	N	Z	P

where PSR[15] = 0 (Supervisor mode), 1 (User mode).
PSR[14:11] = 0000
PSR[10:8] = priority, 0 (lowest) to 7 (highest).
PSR[7:3] = 00000
PSR[2:0] = condition codes for N,Z,P

We want to provide some flexibility for developers to add their own INTA and INTB service routines, so we currently left them blank as shown below:

INTA service routine:

```
.ORIG x1000
RTI
.END
```

INTB service routine:

```
.ORIG x2000
RTI
.END
```

a. In order to support INTA and INTB, the interrupt vector table must have entries. Show the addresses of these entries and the contents of those memory locations.

Memory Address	**Content**

b. Show how the content of PSR changes after the following user program starts executing at priority 0 and right before the HALT instruction.

```
        .ORIG x3000
        LD    R0, NUM
        INTA occurs
        AND  R1, R1, # 0
        ADD  R1, R1, # 5
        INTB occurs
        ADD  R2, R0, R1
        HALT
NUM     .FILL xFFF1
```

Changes	**PSR Content**
Initial	1 0000 000 00000 010