Homework 7

Graded

Student

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Total Points

100 / 100 pts

Question 1

Overview — 0 / 0 pts

✔ **+ 0 pts** Correct

+ 0 pts Incorrect

Question 2

User I/0 — **5** / 5 pts

2.1 .stringz — 2 / 2 pts

✔ **+ 2 pts** Correct (12)

+ 0 pts Incorrect

2.2 (no title) — 3 / 3 pts

✔ **+ 3 pts** Correct (GETC)

+ 0 pts Incorrect

Question 3

Subroutine Basics **21** / 21 pts

3.1 **BR vs. JMP** **3** / 3 pts

- ✔ **+ 1 pt** Correctly explains functionality of **BR**
- ✔ **+ 1 pt** Correctly explains functionality of **JMP**
- ✔ **+ 1 pt** Describes a **valid/correct** instance where one would use **BR** over **JMP**

+ 0 pts Incorrect

3.2 **JSR vs. JSRR** **3** / 3 pts

- ✔ **+ 1 pt** Explains the functionality of **JSR**
- ✔ **+ 1 pt** Explains the functionality of **JSRR**
- ✔ **+ 1 pt** Describes a **valid/correct** instance to use one instruction over the other

+ 0 pts Incorrect

3.3 **RET** **4** / 4 pts

- ✔ **+ 4 pts** Correct (JMP R7)

+ 0 pts Incorrect

3.4 **JSR** **6** / 6 pts

- ✔ **+ 6 pts** Correct - uses one of the following strategies:

```
(1)
LEA RX, FOO
JSRR RX

(2)
LEA R7, 1
BR FOO
```

+ 3 pts Partially correct - does one of the following:
(1) Attempts to use LEA + JSRR strategy, but implements incorrectly
(2) Attempts to use LEA + BR strategy, but implements incorrecctly

+ 0 pts Incorrect

3.5 **Caller and Callee** **5** / 5 pts

- ✔ **+ 2 pts** Selects FOO as the caller
- ✔ **+ 3 pts** Provides valid explanation (ex. since foo calls bar, foo must be the caller)

+ 0 pts Incorrect

Question 4

Subroutine Tracing **18** / 18 pts

4.1 **(no title)** **6** / 6 pts

✔ **+ 6 pts** Correct (-7)

+ 0 pts Incorrect

4.2 **(no title)** **6** / 6 pts

✔ **+ 6 pts** Correct (-2)

+ 0 pts Incorrect

4.3 **(no title)** **6** / 6 pts

✔ **+ 6 pts** Correct (0x3005)

+ 0 pts Incorrect

Question 5

Subroutine Fill-in-the-Blanks **18** / 18 pts

5.1 **(no title)** **6** / 6 pts

✔ **+ 6 pts** Correct (ADD R1, R1, 1)

+ 0 pts Incorrect

5.2 **(no title)** **6** / 6 pts

✔ **+ 6 pts** Correct (LDR R3, R3, 0)

+ 0 pts Incorrect

5.3 **(no title)** **6** / 6 pts

+ 0 pts Incorrect

✔ **+ 6 pts** Correct
(1) ADD R1, R1, -1
(2) AND R1, RX, 0

Question 6

The Stack **8** / 8 pts

6.1 **Stack and Return Addresses** **4** / 4 pts

✔ **+ 4 pts** Correct - calling multiple subroutines would clobber R7

+ 2 pts Partially correct - example: (losing system state but no explicit mention of R7 and/or losing return address)

+ 0 pts Incorrect

6.2 **(no title)** **4** / 4 pts

✔ **+ 4 pts** Correct (ADD R6, R6, 3)

+ 0 pts Incorrect

Question 7

I/O and the Trap Vector Table **30** / 30 pts

7.1 **(no title)** **3** / 3 pts

✔ **+ 3 pts** Correct (true)

+ 0 pts Incorrect

7.2 **(no title)** **3** / 3 pts

✔ **+ 3 pts** Correct (false)

+ 0 pts Incorrect

7.3 **(no title)** **3** / 3 pts

✔ **+ 3 pts** Correct (false)

+ 0 pts Incorrect

7.4 **(no title)** **3** / 3 pts

✔ **+ 3 pts** Correct (as a memory location)

+ 0 pts Incorrect

7.5 **(no title)** **3** / 3 pts

✔ **+ 3 pts** Correct (the address of the trap service subroutines)

+ 0 pts Incorrect

7.6 **(no title)** **15** / 15 pts

✔ **+ 3 pts** (1) Code section 1 correct:

LDI RX, KBSRADDR (RX any register except R1)

✔ **+ 3 pts** (2) Code section 2 correct:

LDI R0, KBDRADDR

✔ **+ 5 pts** (3) Correct explanation of code:

stores characters starting from R1/BUFFER and terminates when 'z' is pressed

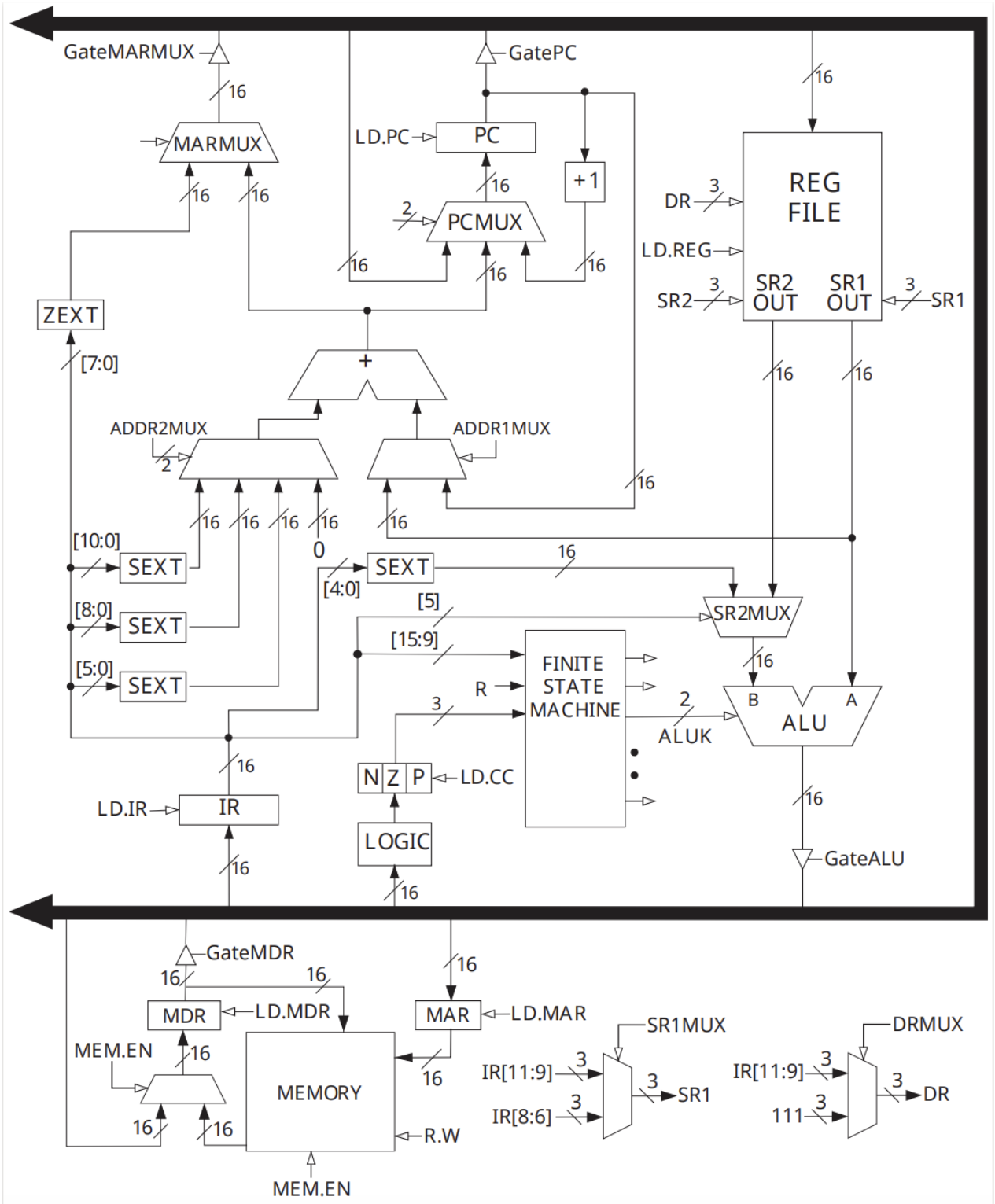
✔ **+ 4 pts** (4) Correct explanation of stop condition changes:

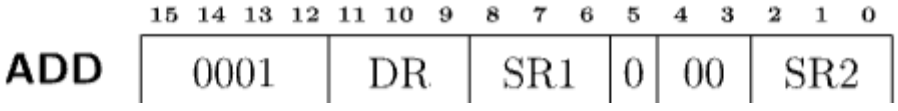
would need to check against the ASCII value of 'Z' (optional: 0x5A) in addition to 'z' which we already have)

+ 0 pts Incorrect

Q1 Overview

0 Points





ADD

0001	DR	SR1	1	imm5

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
AND	0101			DR			SR1				0	00		SR2		
AND	0101			DR			SR1				1	imm5				

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NOT	1001			DR			SR				111111					

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BR	0000				N	Z	P	PCoffset9								

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
JMP	1100				000			BaseR			000000					
JSR	0100				1	PCoffset11										
JSRR	0100				0	00		BaseR			000000					

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LD	0010			DR				PCoffset9								
LDI	1010			DR				PCoffset9								
LDR	0110			DR				BaseR			offset6					
LEA	1110			DR				PCoffset9								

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ST	0011			SR				PCoffset9								
STI	1011			SR				PCoffset9								
STR	0111			SR				BaseR			offset6					

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TRAP	1111				0000				trapvect8							

This homework is worth a total of 100 points.

We have provided LC-3 datapath and instruction set here, but LC-3 reference materials can **also be found in Canvas > Files**.

This question (`Q1`) cannot be answered. It's used for formatting instructions. Do not worry about Gradescope saying you haven't answered one question. It's this one!

Please complete the following problems. The collaboration policy for the course still applies. Refer to the syllabus for details regarding this policy.

Please answer these questions without copying the provided assembly code into LC-3 Tools. Why? You WILL NOT have access to LC-3 Tools for the quizzes.

Q2 User I/0

5 Points

Q2.1 .stringz

2 Points

How many memory locations does the pseudo-op `.stringz "Hello World"` allocate in memory?

- ○ 10
- ○ 11
- ○ 9
- ◉ 12

Q2.2
3 Points

Choose the correct TRAP instruction that receives some user input and sets R7 to contain the value 1 if it is the character 'A' and 0 otherwise.

```
.orig x3000
        ;; TODO: Your code here
        AND R7, R7, 0
        LD R1, CHAR
        NOT R1, R1
        ADD R1, R1, 1
        ADD R2, R1, R0
        BRnp END
        ADD R7, R7, 1
END     HALT

CHAR .fill x41 ;; ASCII 'A'

.end
```

- ○ PUTS
- ◉ GETC
- ○ OUT
- ○ HALT

Q3 Subroutine Basics
21 Points

Q3.1 BR vs. JMP
3 Points

What is the difference between `BR` and `JMP`?

Explain the functionality of each instruction and describe **one** instance where you would use `BR` over `JMP`.

Both BR and JMP are control instructions as they write into the PC (program counter). They both change the value of PC to a different address, affecting the order of execution. BR can only change the address by 256 values before or after, but can change based on the condition codes (NZP). Unlike BR, which changes the order of execution conditionally, JMP always jumps (unconditional). JMP can change the PC by a value stored in a base register using 16 bits, so the range of jumping is higher. You would use BR over JMP when checking an if statement and branching appropriately based on whether the condition was met.

Q3.2 JSR vs. JSRR
3 Points

What is the difference between `JSR` and `JSRR`?

Explain each of the instructions and describe **one** instance where you would use one over the other.

JSR stores the value of PC* into R7 and then changes the value of the PC by the offset11. This function is useful when calling subroutines because you can always jump back to the address after the call and continue execution by using the address stored in R7 (initial PC*). JSRR does the same thing as JSR but would be used in situations where the subroutine is defined at an address that is farther than 1024 values away from the PC value. The address written to the PC is instead taken from a base register that holds 16 bits.

Q3.3 RET
4 Points

Which one of the following is equivalent to `RET`?

- (●) JMP R7
- ( ) LEA R0
- ( ) JSRR R7
- ( ) BRnzp R7

Q3.4 JSR
6 Points

Consider the code snippet below:

```
.orig x3000
    AND R0, R0, 0
    JSR FOO ;REPLACE THIS LINE
    PUTS
    HALT

FOO
    ;CODE FOR FOO
    RET
.end
```

Let's say I want to replace `JSR FOO` (line 3 in the code above) with other LC-3 instructions.

Write **exactly two** LC-3 instructions that preserve the functionality of `JSR FOO` but do **not** use the `JSR` instruction.

```
LEA R7, #1     ; save eff. address in R7 (PC*)
BR FOO         ; branch to FOO
```

Q3.5 Caller and Callee
5 Points

Consider the code snippet below that has two functions, `foo` and `bar`:

```
1   .orig x3000
2
3   FOO
4           LEA R0, PROMPT
5           PUTS
6           GETC
7           JSR BAR
8           ADD R1, R1, 0
9           BRn ELSE
10          LEA R0, WIN
11          PUTS
12          BR DONE
13  ELSE    LEA R0, LOSE
14          PUTS
15  DONE    HALT
16
17  BAR
18          LD R2, CHAR
19          NOT R2, R2
20          ADD R1, R1, 1
21          ADD R1, R1, R0
22          RET
23
24  PROMPT  .stringz "Enter a character and win some money: "
25  WIN     .stringz "You won $10,000,000 dollars!\n"
26  LOSE    .stringz "You didn't win any money :(\n"
27
28  CHAR .fill x51
29
30  .end
31
```

Which function is the **caller**?

- (●) FOO
- ( ) BAR
- ( ) neither

Justify your answer in three sentences or less.

FOO contains the instruction JSR BAR. This means we are jumping to BAR from FOO and once BAR is finished executing the RET instruction takes us back to FOO. Hence, FOO is the caller and BAR is being called.

Q4 Subroutine Tracing
18 Points

Given the following LC-3 Assembly code, answer the questions below

```
.orig x3000
        AND R0, R0, 0
        ADD R0, R0, 7
        JSR FOO
        ADD R0, R1, R0
        AND R1, R1, 0
        HALT
.end

.orig x300F
FOO     NOT R0, R0
        ADD R0, R0, 1
        LD R1, MYLABEL
        ADD R7, R7, R1
        NOT R1, R1
        ADD R1, R1, 1
        RET

MYLABEL .fill x0002
.end
```

Q4.1
6 Points

What is the value in **R0** (as a decimal number) after the program is finished running?

-7

Q4.2
6 Points

What is the value in **R1** (as a decimal number) after the program is finished running?

-2

Q4.3
6 Points

What is the value of **R7** (as a hexadecimal number) after the program is finished running?

Use the prefix `0x` in your answer.

0x3005

Q5 Subroutine Fill-in-the-Blanks

18 Points

Consider the following pseudocode translated into LC-3 Assembly code.

Pseudocode:

```
String str = "aibohphobia";
boolean isPalindrome = true
int length = 0;
while (str[length] != '\0') {
    length++;
}
int left = 0
int right = length - 1
while(left < right) {
    if (str[left] != str[right]) {
        isPalindrome = false;
        break;
    }
    left++;
    right--;
}
mem[mem[ANSWERADDR]] = isPalindrome;
```

LC-3 Assembly Code:

```
AND R1, R1, 0    ;;R1 = isPalindrome = 0 = false
;CODE SECTION 1  - we need to set isPalindrome to true
AND R2, R2, 0    ;;R2 = length = 0

WHILE
ADD R3, R2, R0   ;R3 = length + starting address of string
;CODE SECTION 2  - we want R3 = str[length]
BRz ENDWHILE
ADD R2, R2, 1   ;;R2 = length++
BR WHILE


ENDWHILE
AND R3, R3, 0   ;;R3 = left = 0
ADD R4, R2, -1  ;;R4 = right = length - 1

LOOP
NOT R5, R4
ADD R5, R5, 1   ;;R5 = -right
ADD R5, R3, R5  ;;R5 = left - right
BRzp END

ADD R5, R0, R3
LDR R5, R5, 0    ;;R5 = str[left]

ADD R6, R0, R4
LDR R6, R6, 0
NOT R6, R6
ADD R6, R6, 1   ;;R6 = -str[right]

ADD R5, R5, R6  ;;str[left] - str[right]
BRz EQUAL
;;CODE SECTION 3 - set isPalindrome to false
BR END

EQUAL
ADD R3, R3, 1  ;;R3 = left++
ADD R4, R4, -1  ;;R4 = right--
BR LOOP

END
HALT
```

Notes/Assumptions:

- the **address** of the first letter of the string has **ALREADY** been placed in **R0**
- a value of **1 is true**, and a value of **0 is false**
- the `.orig` and `.end` tags are not pictured, assume the program functions as expected

Given the pseudocode and the commented LC-3 Assembly code above, you will fill in the missing lines of code: `CODE SECTION 1`, `CODE SECTION 2`, **and** `CODE SECTION 3`.

Q5.1
6 Points

Code Section 1:

```
ADD R1, R1, 1
```

Q5.2
6 Points

Code Section 2:

```
LDR R3, R3, 0
```

Q5.3
6 Points

Code Section 3:

```
AND R1, R1, 0
```

Q6 The Stack
8 Points

Q6.1 Stack and Return Addresses
4 Points

What is the purpose behind storing the return address on the stack if we already have a register (`R7`) dedicated to holding the return address?

Using a stack to store memory addresses allows us to make it recursive as we can have multiple jump locations. For example, if we call a subroutine within a subroutine, we cannot return all the way back to the main code as R7 now stores the address too the most recent JSR/JSRR instruction, i.e. the address in R7 would be overwritten. Having a stack allows us to keep a track of previous addresses. R6 acts as a stack pointer keeping track of the address to jump to.

Q6.2
4 Points

Write exactly 1 LC-3 instruction that pops 3 elements off the stack without restoring values into any registers. You may assume popping will not not move `R6` beyond the boundaries of the stack memory region.

```
ADD R6, R6, 3     ; pops 3 from stack
```

Q7 I/O and the Trap Vector Table

30 Points

Answer the questions below concerning I/O and the Trap Vector Table.

Q7.1

3 Points

The LC-3 Traps are synchronous.

- (●) True
- ( ) False

Q7.2

3 Points

The LC-3 I/O with interrupts are synchronous.

- ( ) True
- (●) False

Q7.3

3 Points

In the polling approach to I/O, the programmer repeatedly checks the **data** register for I/O.

- ( ) True
- (●) False

Q7.4
3 Points

How does the LC-3 allow you to access device registers?

- ○ As a general purpose register
- ○ As read-only memory in the FSM
- ○ As a datapath register (ex. PC, IR)
- ◉ As a memory location

Q7.5
3 Points

What does the trap vector table hold?

- ○ The code for trap service subroutines
- ○ An instruction that invokes the specific behavior of traps
- ◉ The addresses of the trap service subroutines

Q7.6
15 Points

Consider the code provided below:

```
.orig x3000
        LEA R1, BUFFER
START
        ;;CODE SECTION 1

        BRzp START

        ;;CODE SECTION 2

        STR R0, R1, 0

        LD R2, TERMINATOR
        NOT R2, R2
        ADD R2, R2, 1

        ADD R0, R0, R2
        BRz END
        ADD R1, R1, 1
        BR START

END
        HALT

KBSRADDR    .fill xFE00
KBDRADDR    .fill xFE02
TERMINATOR  .fill x7A
BUFFER      .blkw 100
.end
```

The goal of this program is to read characters from the keyboard and stop after meeting a certain condition. You will insert the missing code at `CODE SECTION 1` and `CODE SECTION 2`.

They should each be **one line of code**.

Code Section 1:

```
LDI R0, KBSRADDR
```

Code Section 2:

```
LDI R0, KBDRADDR
```

Briefly explain what the code above does, **aside** from the fact that it should read characters from the keyboard.

The code uses BUFFER to block out a chunk of memory for keyboard input. It stores what is read in R0 and is placed in memory at an address starting at BUFFER. It then continues to take in characters until the terminator character (lowercase z) is entered. It does this by checking if the character has an ascii value of x7A. If it finds 'z', the program terminates. If not, we increment R1 which accesses the next address in the BUFFER block.

Now, let's say we want our **stop condition** for the program to **no longer be case sensitive**. Describe what changes we would need to make to our program above.

We will create a new label, TERMINATOR2, that stores x5A (ASCII value for 'Z'). We will negate it using NOT and ADD and store it in temporary register R3. After checking for 'z' we will create another check for 'Z' (ADD R0 and R3). We will then check for this value to be 0 using BRz. If it is 0, branch to END. If neither case is met, we continue as is by incrementing R1 and unconditional branch.