6.190 Quiz Review Session

Practice quiz from Fall 2022 (First Quarter)

Problem 1

Binary Arithmetic

A. What is 0x68 ^ (0x9C | 0x5A)? Provide your result in both unsigned 8-bit binary and unsigned 8-bit hexadecimal.

- `0x9C = 0b1001_1100`
- `0x5A = 0b0101_1010`
- `(0x9C | 0x5A) = 0b1101_1110 = 0xDE`

- `0xDE = 0b1101_1110`
- `0x68 = 0b0110_1000`
- `0x68 ^ 0xDE =` **`0b1011_0110 = 0xB6`**

XOR		
a	b	out
0	0	0
0	1	1
1	0	1
1	1	0

OR		
a	b	out
0	0	0
0	1	1
1	0	1
1	1	1

B. What is the result of ((0b001 > 0b101) && 0b100) == 0b001)? Assume all numbers are unsigned. Provide your result in decimal.

- 0b001 = 1
- 0b100 = 4
- 0b101 = 5
- 1 > 5 is False (0)
- (0 && 4) = 0
- (0 == 1) = **0**

C. (4 points): What are 14 and 31 in 8-bit 2’s complement notation? What is –31 in 8-bit 2’s complement notation? Show how to compute 14–31 using 2’s complement addition. What is the result in 8-bit 2’s complement notation?

- 14 = **0b0000_1110**
- 31 = **0b0001_1111**
- -31 = **0b1110_0001**

- 0b0000_1110
- 0b1110_0001
- **0b1110_1111** = -(0b0001_0001) = -17

D. How many bits are required to encode decimal values ranging from -128 to 127 in two's complement representation? How many bits are required to encode decimal values ranging from 0 to 127 in unsigned binary representation? Provide your answer in decimal.

- Two's complement range: $[-2^{n-1}, 2^{n-1}-1]$
- Unsigned range: $[0, 2^{n}-1]$
- Where n is the number of bits

Two's complement

- $127 = 2^{n-1}-1$
- $128 = 2^{n-1}$
- $\log_2 128 = n-1$
- $7 = n-1$
- **$8 = n$**

Unsigned

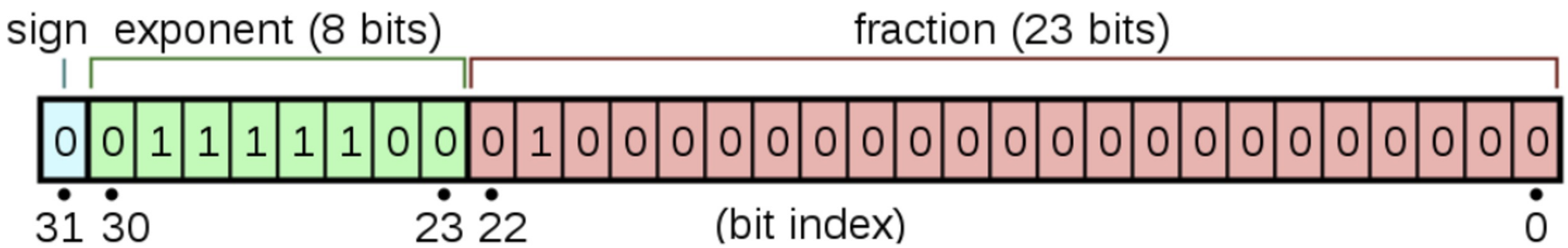
- $127 = 2^{n}-1$
- $128 = 2^{n}$
- $\log_2 128 = n$
- **$7 = n$**

E. (2 points) What is the result of the logical right shift `0b11011010` >> 2 in 2's complement notation? What is the result of the arithmetic right shift `0b11011010` >> 2 in 2's complement notation? Provide your answer in binary

- Logical: shift in zeros
- Arithmetic: shift in value of MSB
  - To preserve the sign of the value

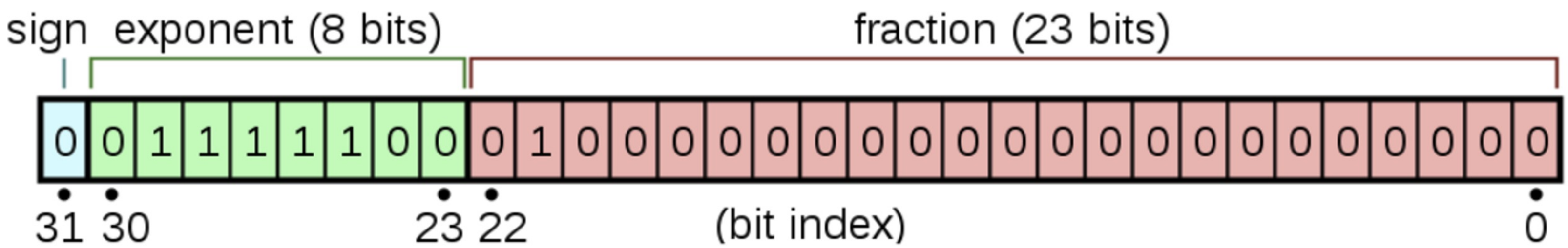
- Logical: `0b1101_1010 >> 2` `= 0b0011_0110`
- Arithmetic: `0b1101_1010 >> 2` `= 0b1111_0110`

G. What is the decimal equivalent of the 32-bit floating point number 0x41080000? The format of 32-bit floating point encoding is shown below. Show your work



$$\texttt{Value} = (-1)^{\text{sign}} \cdot 2^{\text{exp}-127} \cdot \left(1 + \sum_{i=1}^{23} b_{23-i} 2^{-i}\right)$$

G. What is the decimal equivalent of the 32-bit floating point number 0x41080000? The format of 32-bit floating point encoding is shown below. Show your work



$$\texttt{Value} = (-1)^{\text{sign}} \cdot 2^{\text{exp}-127} \cdot \left(1 + \sum_{i=1}^{23} b_{23-i} 2^{-i}\right)$$

0x41080000 = 0100_0001_0000_1000_0000_0000_0000_0000

$(-1)^0 * 2^{130 - 127} * (1 + 2^{-4}) = 2^3 * 1.0625 =$ **8.5**

Problem 2

What If

```c
// Given a string, flip the case of each alphabetical character.
void flip_case(char *x) {
   while (*x != 0) {
       if (is_uppercase(*x)) {
           *x += 'a' - 'A';  // e.g., 'G' becomes 'g'
       } else if (is_lowercase(*x)) {
           *x += 'A' - 'a';  // e.g., 'g' becomes 'G'
       }
       x++; // <- For part A and B
   }
}
```

A. Which candidates are equivalent to x++; in the above program?

Candidate	CIRCLE ONE:
`&x = &x + 1;`	
`*(&x) = x + 1;`	
`x = (char *)((uint32_t)x + 4);`	

```
&x = &x + 1;
```

A. Which candidates are equivalent to x++; in the above program?

Candidate	CIRCLE ONE:
`&x = &x + 1;`	YES NO
`*(&x) = x + 1;`	
`x = (char *)((uint32_t)x + 4);`	

Address of x Increment by 1

```
&x = &x + 1;
```

Address of x

Address of X = Address of X + 1

Doesn't work!
X is a pointer! Incrementing the address of the pointer is not the same thing as incrementing the pointer!

A. Which candidates are equivalent to x++; in the above program?

Candidate	CIRCLE ONE:
`&x = &x + 1;`	YES NO
`*(&x) = x + 1;`	
`x = (char *)((uint32_t)x + 4);`	

```
*(&x) = x + 1;
```

A. Which candidates are equivalent to x++; in the above program?

Candidate	CIRCLE ONE:	
`&x = &x + 1;`	YES	NO
`*(&x) = x + 1;`	YES	NO
`x = (char *)((uint32_t)x + 4);`		

increment x by one

```
*(&x) = x + 1;
```

same thing as x

*(&x) = x

Works just fine!
Obtaining the address of x, and then dereferencing that is just the same thing as writing down x.

A. Which candidates are equivalent to x++; in the above program?

Candidate	CIRCLE ONE:	
`&x = &x + 1;`	YES	NO
`*(&x) = x + 1;`	YES	NO
`x = (char *)((uint32_t)x + 4);`		

```
x = (char *)((uint32_t)x + 4);
```

A. Which candidates are equivalent to x++; in the above program?

Candidate	CIRCLE ONE:	
`&x = &x + 1;`	YES	NO
`*(&x) = x + 1;`	YES	NO
`x = (char *)((uint32_t)x + 4);`	YES	NO

Cast address into 32-bit number

```
x = (char *)((uint32_t)x + 4);
```

Cast back into a char pointer

Add 4 bytes to it

Doesn't work!
The idea was good but the execution wasn't. Chars are 1 byte wide, so we should have added 1 instead of 4.

B. Suppose we are instead to replace x++; in the implementation of flip_case with f(&x); and implement f as follows.

```
void f(__1__ x) {
    __2__++;
}
```

Blank 1:	Blank 2:

Things to note:

- Argument to function f() is a reference to x, since we pass in &x (the address of x).
- X is a char pointer (char *).

B. Suppose we are instead to replace x++; in the implementation of flip_case with f(&x); and implement f as follows.

```
void f(__1__ x) {
    __2__++;
}
```

Blank 1:	Blank 2:
char**	

Make the argument type a reference to a char*!

A pointer to a char pointer!

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```
void f(__1__ x) {
    __2__++;
}
```

Blank 1:	Blank 2:
`char**`	`(*x)`

Make the argument type a reference to a char*!
A pointer to a char pointer!

Increment x, not the pointer to x!
Dereference x before incrementing, but be careful of operator precedence. (++ occurs before *).

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void f(__1__ x) {
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`char**`	`(*x)`

Make the argument type a reference to a char*!
A pointer to a char pointer!

Increment x, not the pointer to x!
Dereference x before incrementing, but be careful of operator precedence. (++ occurs before *).

C. For each expression, determine the string that the program on the previous page would print if we were to replace ??? with that expression. If the code would not compile, write "WON'T COMPILE". If the exact output cannot be determined, write "CAN'T TELL".

Expression	Answer
`p`	
`str + 2`	
`(*q) + 8`	
`&(*(&p))[4] - 1`	

C. For each expression, determine the string that the program on the previous page would print if we were to replace ??? with that expression. If the code would not compile, write “WON’T COMPILE”. If the exact output cannot be determined, write “CAN’T TELL”.

```
int main() {
    char str[] = "ababABAB";
    char *p = str;   // char * that points to str
    char **q = &p;   // char ** that points to p
    flip_case(???); // <- REPLACE HERE
    printf("%s\n", str);
    return 0;
}
```

C. For each expression, determine the string that the program on the previous page would print if we were to replace ??? with that expression. If the code would not compile, write "WON'T COMPILE". If the exact output cannot be determined, write "CAN'T TELL".

Expression	**Answer**
`p`	ABABabab
`str + 2`	
`(*q) + 8`	
`&(*(&p))[4] - 1`	

Passing p should just flip the case of "ababABAB".

C. For each expression, determine the string that the program on the previous page would print if we were to replace ??? with that expression. If the code would not compile, write "WON'T COMPILE". If the exact output cannot be determined, write "CAN'T TELL".

Expression	Answer
`p`	ABABabab
`str + 2`	abABabab
`(*q) + 8`	
`&(*(&p))[4] - 1`	

Passing str+2 should just flip the case of the last 6 chars of str. Offsetting by 2 skips the first 2 chars.

C. For each expression, determine the string that the program on the previous page would print if we were to replace ??? with that expression. If the code would not compile, write "WON'T COMPILE". If the exact output cannot be determined, write "CAN'T TELL".

Expression	**Answer**
`p`	ABABabab
`str + 2`	abABabab
`(*q) + 8`	ababABAB
`&(*(&p))[4] - 1`	

Passing (*q) + 8 should avoid flipping anything. We've skipped all 8 chars. (*q) is the same as str, and offsetting by 8 moves the str up to the null char.

C. For each expression, determine the string that the program on the previous page would print if we were to replace ??? with that expression. If the code would not compile, write “WON’T COMPILE”. If the exact output cannot be determined, write “CAN’T TELL”.

Expression	Answer
`p`	ABABabab
`str + 2`	abABabab
`(*q) + 8`	ababABAB
`&(*(&p))[4] - 1`	abaBabab

***(&p) is just p again. &(p)[4] offsets p by four, and subtracting one brings the offset to 3. This skips the first three characters when flipping.**

Problem 3

C structs

Problem 3. C structs (13 points)

When communicating with our RISC-V microcontroller, we usually did so through the serial monitor embedded in our IDE. A struct called `SerialBuffer` is defined below to represent our controller's serial communication buffer, which is responsible for handling incoming Serial messages.

```
struct SerialBuffer{
  char termChar;          // char to stop reading at
  char charBuffer[64];    // 64 element wide buffer to store characters in
  uint8_t size;           // number of chars stored in buffer
};
```

A. (3 points) First let's model how the buffer receives data. An example of an empty `SerialBuffer`, with the newline as the terminating character, is shown below:

```
struct SerialBuffer buf;
buf.termChar = '\n';
buf.size = 0;
```

When the buffer receives a character, the buffer adds the char to the `charBuffer` array at the smallest available index. It then also increments the active buffer size count by one.

Write a function **`receiveChar`** that takes in a `SerialBuffer` struct (by value) and a character to add to the buffer and returns an updated `SerialBuffer` instance.
Assume the buffer has enough space for an incoming character, `c`.

```
struct SerialBuffer receiveChar(struct SerialBuffer buf, char c){

}
```

```
struct SerialBuffer receiveChar(struct SerialBuffer buf, char c){
```

```
struct SerialBuffer receiveChar(struct SerialBuffer buf, char c){




  // one possible answer
  buf.charBuffer[buf.size++] = c;
  return buf;
```

B. (4 points): Sometimes we want to peek into our serial buffer without removing any characters from the buffer. Write a function called **`peekChars`** that receives **a pointer to a buffer instance** and returns how many characters are in the buffer **up to and including** the first termination character (reflected in `termChar`). Assume the buffer contains at least one terminating character.

```
int peekChars(struct SerialBuffer *buf){

}
```

B. (4 points): Sometimes we want to peek into our serial buffer without removing any characters from the buffer. Write a function called **`peekChars`** that receives **a pointer to a buffer instance** and returns how many characters are in the buffer **up to and including** the first termination character (reflected in `termChar`). Assume the buffer contains at least one terminating character.

```
int peekChars(struct SerialBuffer *buf){


    // one possible answer
    int count = 0;
    while (buf->charBuffer[count] != buf->termChar){
      count++;
    }
    count++;
    return count;


}
```

C. (6 points): Consider the case where we want to read from an active `SerialBuffer` instance.

```
struct SerialBuffer buf;
```

This buffer has already been populated with multiple characters and at least one terminating character.

Create a function, **`readChars`**, that reads characters from the buffer **up to and including the buffer's termination character**. Store this string of characters as a properly terminated C-string in `char *message`, which you can assume will be large enough to store the resulting message.

Note that `readChars` is passed a **pointer** to a `SerialBuffer`.
Be sure to leverage the **`peekChars`** function you just wrote.

```
void readChars(struct SerialBuffer *buf, char *message){
```

Be sure to update the buffer by both updating the `charBuffer` array and the buffer size.
As an example:

```
// up to this point buf has been populated and contains:
// buf.charBuffer = {'h','e','l','l','o','\n','b','y','e','\n', ...}
```

```
printf("%c", buf.termChar); // prints: "\n"
printf("%d", buf.size);     // prints: "10"

char msg[65];             // large enough to store message from buffer
readChars(&buf, msg);     // move chars up to termChar from buffer to msg

printf("%s", msg);        // prints: "hello\n"
printf("%d", buf.size); // prints: "4"

// now at this point buf.charBuffer = {'b','y','e','\n', ...}
```

```
void readChars(struct SerialBuffer *buf, char *message){

}
```

```c
void readChars(struct SerialBuffer *buf, char *message){




 // a possible answer

  int count = peekChars(buf);

  //load bytes onto message
  for (int i = 0; i < count; i++){
    *(message + i) = buf->charBuffer[i];
  }

  //terminate message
  *(message + count) = 0;

  //update buffer
  for (int i = count; i < buf->size; i++){
     buf->charBuffer[i-count] = buf->charBuffer[i];
  }
  buf->size -= count;




}
```

Problem 4

An Average Filter

Fill in the blanks.

```
void find_mean(const float *arr, int n, float *mean); // Defined elsewhere.

void mean_filter(const float *input, int num_elems, int window_size, float *output) {
   for (int i = 0; i+window_size-1 < num_elems; i++) {
      float buffer;
      float *ptr = &buffer;
      find_mean(___(A)___, ___(B)___, ___(C)___);
      *(output+i) = ___(D)___;
   }
}

// For example, if num_elems=4, input={3, 2, 7, 6}, window_size=3, then
// there are two contiguous windows, each with the following arithmetic means:
// output[0] = (3+2+7)/3.0 = 4.0
// output[1] = (2+7+6)/3.0 = 5.0
```

Fill in the blanks.

```
void find_mean(const float *arr, int n, float *mean); // Defined elsewhere.

void mean_filter(const float *input, int num_elems, int window_size, float *output) {
   for (int i = 0; i+window_size-1 < num_elems; i++) {
      float buffer;
      float *ptr = &buffer;
      find_mean(___(A)___, ___(B)___, ___(C)___);
      *(output+i) = ___(D)___;
   }
}

// For example, if num_elems=4, input={3, 2, 7, 6}, window_size=3, then
// there are two contiguous windows, each with the following arithmetic means:
// output[0] = (3+2+7)/3.0 = 4.0
// output[1] = (2+7+6)/3.0 = 5.0
```

find_mean() averages `n` elements in an float array `arr` and returns the mean in float pointer `mean`.

Fill in the blanks.

Fill in the blank (A):
Fill in the blank (B):
Fill in the blank (C):
Circle ALL correct answers (D):

Fill in the blanks.

Fill in the blank (A): `input+i` or `&input[i]`
Fill in the blank (B):
Fill in the blank (C):
Circle ALL correct answers (D):

As we iterate over the elements in the float array `input`, we need to offset the array being passed into `find_mean()`.

Fill in the blanks.

Fill in the blank (A): `input+i` or `&input[i]`
Fill in the blank (B): `window_size`
Fill in the blank (C):
Circle ALL correct answers (D):

We only want to calculate the mean over `window_size` arguments!

Fill in the blanks.

Fill in the blank (A): `input+i` or `&input[i]`
Fill in the blank (B): `window_size`
Fill in the blank (C): `ptr` or `&buffer`
Circle ALL correct answers (D):

There are multiple ways of passing along a reference to the float `buffer` that will contain the result of our averaging.

Fill in the blanks.

Fill in the blank (A): `input+i` or `&input[i]`		
Fill in the blank (B): `window_size`		
Fill in the blank (C): `ptr` or `&buffer`		
Circle ALL correct answers (D):		
`buffer`	`*buffer`	`&buffer`
`ptr`	`*ptr`	`&ptr`
`ptr[0]`	`*ptr[0]`	`&ptr[0]`

Multiple ways of updating the array! We just want to store the value of `buffer` in the `output` array. Directly storing `buffer` or dereferencing `ptr` work.

Problem 5

Assembly Language

A. What is hexadecimal encoding of the instruction `srai t3, a2, 6`? You can use the template below to help you with the encoding.

[31:25]	[24:20]	[19:15]	[14:12]	[11:7]	[6:0]
0100000	shamt	rs1	funct3	rd	opcode

SRAI	`srai rd, rs1, shamt`

0100000	shamt	rs1	101	rd	0010011	SRAI

Registers	Symbolic names
x0	zero
x1	ra
x2	sp
x3	gp
x4	tp
x5-x7	t0-t2
x8-x9	s0-s1
x10-x11	a0-a1
x12-x17	a2-a7
x18-x27	s2-s11
x28-x31	t3-t6

A. What is hexadecimal encoding of the instruction `srai t3, a2, 6`? You can use the template below to help you with the encoding.

[31:25]	[24:20]	[19:15]	[14:12]	[11:7]	[6:0]
0100000	shamt	rs1	funct3	rd	opcode

SRAI	`srai rd, rs1, shamt`

0100000	shamt	rs1	101	rd	0010011	SRAI

- shamt = 6 = 0b00110
- rs1 = a2 = x12 = 12 = 0b01100
- rd = t3 = x28 = 28 = 0b11100
- funct3 = 0b101
- Opcode = 0b0010011
- 0100000_00110_01100_101_11100_0010011
- 0x40665E13

Registers	Symbolic names
x0	zero
x1	ra
x2	sp
x3	gp
x4	tp
x5-x7	t0-t2
x8-x9	s0-s1
x10-x11	a0-a1
x12-x17	a2-a7
x18-x27	s2-s11
x28-x31	t3-t6

B. provide the hexadecimal values of the specified registers after each sequence has been executed. Assume that each sequence execution ends when it reaches the `end` label

```
. = 0x20
        li x11, 0x600
        lw x11, 0x0(x11)
        bge x11, x0, L1
        xori x12, x11, 0xA55
        j end

L1:  srli x12, x11, 8
end:

. = 0x600
X:   .word 0xC0C0A0A0
```

B. provide the hexadecimal values of the specified registers after each sequence has been executed. Assume that each sequence execution ends when it reaches the `end` label

- x11 = 0x600
- x11 = 0xC0C0A0A0
- x11 MSB is 1, so negative
  - We don't branch
- x12 = 0xC0C0A0A0 ^ 0xA55
- Don't forget to sign extend
- `0xC0C0A0A0`
- `0xFFFFFA55`
- `0x3F3f5af5`

XOR Truth Table

Input 1	Input 2	Output
0	1	1
0	0	0
1	1	0
1	0	1

```
. = 0x20
        li x11, 0x600
        lw x11, 0x0(x11)
        bge x11, x0, L1
        xori x12, x11, 0xA55
        j end

L1:  srli x12, x11, 8
end:

. = 0x600
X:   .word 0xC0C0A0A0
```

For the RISC-V instruction sequences below, provide the hexadecimal values of the specified registers after each sequence has been executed. Assume that each sequence execution ends when it reaches the `end` label. Also assume that all registers are initialized to 0 before execution of each sequence begins.

The first instruction executed is located at address 0x100

<pre>. = 0x20
f:
        slli x13, x12, 8
        ret
 	
. = 0x100
        lui x11, 0x3
        lw x12, 0x4(x11)
        jal x1, f
        ori x14, x1, 0xC2
end:
 	
. = 0x3000
.word 0x11112222
.word 0x22224444
.word 0x33336666</pre>
	Value left in x1: 0x______________________
	
	Value left in x11: 0x_____________________
	
	Value left in x12: 0x_____________________
	
	Value left in x13: 0x_____________________
	
	Value left in x14: 0x_____________________

For the RISC-V instruction sequences below, provide the hexadecimal values of the specified registers after each sequence has been executed. Assume that each sequence execution ends when it reaches the `end` label. Also assume that all registers are initialized to 0 before execution of each sequence begins.

- Starting at 0x100, `x11` becomes 0x3000 since `lui` shifts the immediate by 12 and then sets the register to that result
- `x12` = 0x22224444 since `lw x12, 0x4(x11)` loads the value at address 0x3004
- `jal x1, f` unconditionally jumps to the `f` label and executes the code there
  - `x1` gets set to the address of the `jal` instruction + 4 = 0x10C
    - Every instruction is 4 bytes
  - `x1` is the `ra` register
- `x13` = 0x22444400
- `ret` makes the program jump back to the address stored in `ra` which is also `x1`
- `x14` = 0xC2 | 0x10C = 0x1CE

The first instruction executed is located at address `0x100`.

```
. = 0x20
f:
      slli x13, x12, 8
      ret

. = 0x100
      lui x11, 0x3
      lw x12, 0x4(x11)
      jal x1, f
      ori x14, x1, 0xC2
end:

. = 0x3000
.word 0x11112222
.word 0x22224444
.word 0x33336666
```

Value left in x1: 0x______10C_________

Value left in x11: 0x_____3000_________

Value left in x12: 0x____22224444______

Value left in x13: 0x____22444400______

Value left in x14: 0x____000001CE_____

Problem 6

Calling Convention

```
# drawBoard Arguments:
# (1) screen_buffer
# (2) locations: array holding locations of snake segments on board
# (3) num_locations: length of locations array.
# (4) food: location of food
```

```
drawBoard:
      slli a2, a2, 2
      add a2, a2, a1
      mv s0, a0
loop:
      bge a1, a2, end
      mv a0, s0
      lw a1, 0(a1)
      li a2, 1
      call setPixel
      addi a1, a1, 4
      j loop
end:
      mv a0, s0
      mv a1, a3
      li a2, 1
      call setPixel
      ret
```

You decided to write Snake in RISC-V assembly. You implement a `drawBoard` function to render the game board. `drawBoard` uses one helper function, `setPixel`. to set a given pixel to be 0 (off) or 1 (on). It's C function signature is shown below:

```
void setPixel(uint32_t *screen_buffer, uint8_t location, uint8_t val);
```

You can assume that setPixel works as expected and follows calling convention. You do not have access to the assembly implementation of `setPixel,` so you cannot make any further assumptions about its implementation.

Unfortunately, your program does not work, and you suspect that it is due to calling convention. Please add appropriate instructions (**either increment/decrement stack pointer, load word from stack, or save word to stack only**) into the blank spaces on the right to make `drawBoard` follow calling convention. You can assume that `drawBoard` will work as expected once it follows the calling convention.

If the procedure already follows calling convention, write NO INSTRUCTIONS NEEDED. For full credit, you should only save registers that must be saved onto the stack, restore registers that must be restored, and minimize the number of instructions used. You may not need to use all the blank lines.

Calling convention refresher

```
drawBoard:
      slli a2, a2, 2
      add a2, a2, a1
      mv s0, a0
loop:
      bge a1, a2, end
      mv a0, s0
      lw a1, 0(a1)
      li a2, 1
      call setPixel
      addi a1, a1, 4
      j loop
end:
      mv a0, s0
      mv a1, a3
      li a2, 1
      call setPixel
      ret
```

- Since we are calling another procedure, we must store `ra` before the **first** `call` instruction and load it back before we `ret`
  - Only need to store `ra` **once**, no matter how many procedures are called
  - The caller needs the original `ra` value so `ret` can return to the correct address
- `s` registers are **callee** saved. We must store their values **before** we, as the callee, use them. We then load their original values right before we `ret`.
  - This is why `s` register values persist between procedure calls
- `a` registers are **caller** saved. If we call other procedures and these registers have values we want to use after, we must store them to then load back after.
  - `a` and `t` registers are not guaranteed to stay the same between calls
  - We load them back every time we need that stored value

```
# drawBoard Arguments:
# (1) screen_buffer
# (2) locations: array holding locations of snake segments on board
# (3) num_locations: length of locations array.
# (4) food: location of food
```

```
drawBoard:
      slli a2, a2, 2
      add a2, a2, a1
      mv s0, a0
loop:
      bge a1, a2, end
      mv a0, s0
      lw a1, 0(a1)
      li a2, 1
      call setPixel
      addi a1, a1, 4
      j loop
end:
      mv a0, s0
      mv a1, a3
      li a2, 1
      call setPixel
      ret
```

- Allocate enough space on the stack
- Store `ra` because we call other procedures
- Store `a3` because we use its value here also after a `call setPixel`
- Store `s0` because we will be using it (overwriting it with our own value)
- Store `a2` since we care about its value **after** we set it with `slli` and `add`
    - And we need it for our branch condition after a potential `call setPixel` from looping

```
drawBoard:

    ___addi sp, sp, -20________
    ____sw ra, 0(sp)___________
    _____sw a3, 8(sp)__________
    ______sw s0, 12(sp)________
    ___________________________
    ___________________________

    slli a2, a2, 2
    add a2, a2, a1
    mv s0, a0

    ______sw a2, 4(sp)_________
    ___________________________
    ___________________________
```

```
# drawBoard Arguments:
# (1) screen_buffer
# (2) locations: array holding locations of snake segments on board
# (3) num_locations: length of locations array.
# (4) food: location of food
```

```
drawBoard:
      slli a2, a2, 2
      add a2, a2, a1
      mv s0, a0
loop:
      bge a1, a2, end
      mv a0, s0
      lw a1, 0(a1)
      li a2, 1
      call setPixel
      addi a1, a1, 4
      j loop
end:
      mv a0, s0
      mv a1, a3
      li a2, 1
      call setPixel
      ret
```

- We store `a1` because we will be using this same value to branch
- Load `a1` and `a2` since their values could have changed with `call setPixel`
    - And we use them for our branch instruction

```
loop:
      bge a1, a2, end

      ____________________________

      _______sw a1, 16(sp)_______

      ____________________________

      ____________________________

      ____________________________

      ____________________________

      mv a0, s0
      lw a1, 0(a1)
      li a2, 1
      call setPixel

      _______lw a1, 16(sp)_______

      _______lw a2, 4(sp)________

      addi a1, a1, 4
      j loop
```

```
# drawBoard Arguments:
# (1) screen_buffer
# (2) locations: array holding locations of snake segments on board
# (3) num_locations: length of locations array.
# (4) food: location of food
```

```
drawBoard:
	slli a2, a2, 2
	add a2, a2, a1
	mv s0, a0
loop:
	bge a1, a2, end
	mv a0, s0
	lw a1, 0(a1)
	li a2, 1
	call setPixel
	addi a1, a1, 4
	j loop
end:
	mv a0, s0
	mv a1, a3
	li a2, 1
	call setPixel
	ret
```

- We load `a3` since we want to use its original value
- At the end, we load back `s0` and `ra` to get their original values
  - `ra` is used to return to the proper address after the procedure is done
  - `s0` needs to keep its original value after we use it
- Don't forget to increment `sp` since we are no longer use that stack space
- `a1`, `a2`, and `a3` are never guaranteed to be the values they started as, so we don't need to load them

```
end:
	_____lw a3, 8(sp)__________
	mv a0, s0
	mv a1, a3
	li a2, 1
	call setPixel
	___________________________
	___________________________
	___________________________
	______lw s0, 12(sp)________
	_____lw ra, 0(sp)__________
	______addi sp, sp, 20______
	ret
```

Problem 7

Stack Detective

A. What line of assembly should be substituted into the blank line in the `arrayProd` procedure above?

- **mv t0, a0**
- Our answer from the `mult` procedure call is in a0.
- t0 is not guaranteed to be known after the call
- Before we `ret,` we move t0 into a0
    - So we must ensure t0 is also the value we are returning

B. A user creates an array and passes it and its length into `arrayProd`. Immediately prior to and immediately after the procedure call, a sample of the ra, sp, a0, and a1 is collected as well as a region of the stack.

```
#1  sp  =0x00080280 ra  =0x00000000
    a0  =0x00004000 a1  =0x00000005
Address: Data:
0x80258: 0x000ff3af
0x8025c: 0x00000018
0x80260: 0x0000035c
0x80264: 0x00000011
0x80268: 0x00000008
0x8026c: 0x00000001
0x80270: 0x0000035c
0x80274: 0x00000011
0x80278: 0x00000808
0x8027c: 0x0000a321
0x80280: 0x00000781
```

```
#2  sp  =0x00080278 ra  =0x00000204
    a0  =0x00004000 a1  =0x00000005
Address: Data:
0x80258: 0x000ff3af
0x8025c: 0x00000018
0x80260: 0x0000035c
0x80264: 0x00000011
0x80268: 0x00000008
0x8026c: 0x00000001
0x80270: 0x0000035c
0x80274: 0x00000011
0x80278: 0x00000204
0x8027c: 0x00000001
0x80280: 0x00000781
```

```
#3  sp  =0x00080270 ra  =0x0000025C
    a0  =0x00004004 a1  =0x00000004
Address: Data:
0x80258: 0x000ff3af
0x8025c: 0x00000018
0x80260: 0x0000035c
0x80264: 0x00000011
0x80268: 0x00000008
0x8026c: 0x00000001
0x80270: 0x0000025c
0x80274: 0x00000003
0x80278: 0x00000204
0x8027c: 0x00000001
0x80280: 0x00000781
```

```
#4  sp  =0x00080268 ra  =0x0000025C
    a0  =0x00004008 a1  =0x00000003
Address: Data:
0x80258: 0x000ff3af
0x8025c: 0x00000018
0x80260: 0x0000035c
0x80264: 0x00000011
0x80268: 0x0000025c
0x8026c: 0x00000005
0x80270: 0x0000025c
0x80274: 0x00000003
0x80278: 0x00000204
0x8027c: 0x00000001
0x80280: 0x00000781
```

```
#5  sp  =0x00080260 ra  =0x0000025C
    a0  =0x0000400C a1  =0x00000002
Address: Data:
0x80258: 0x000ff3af
0x8025c: 0x00000018
0x80260: 0x0000025c
0x80264: 0x00000008
0x80268: 0x0000025c
0x8026c: 0x00000005
0x80270: 0x0000025c
0x80274: 0x00000003
0x80278: 0x00000204
0x8027c: 0x00000001
0x80280: 0x00000781
```

```
#6  sp  =0x00080280 ra  =0x00000204
    a0  =0x000000F0 a1  =0x00000000
Address: Data:
0x80258: 0x000ff3af
0x8025c: 0x00000018
0x80260: 0x0000025c
0x80264: 0x00000008
0x80268: 0x0000025c
0x8026c: 0x00000005
0x80270: 0x0000025c
0x80274: 0x00000003
0x80278: 0x00000204
0x8027c: 0x00000001
0x80280: 0x00000781
```

B1) What is the hexadecimal address of the instruction that originally calls `arrayProd`?

- Look at first snapshot after initial call
- ra is 0x00000204
- ra stores the address of the instruction after the procedure call
  - Which is 4 bytes after
- Therefore, the address of the original call is ra - 4
  - **0x00000200**

```
#2  sp  =0x00080278 ra  =0x00000204
    a0  =0x00004000 a1  =0x00000005
Address: Data:
0x80258: 0x000ff3af
0x8025c: 0x00000018
0x80260: 0x0000035c
0x80264: 0x00000011
0x80268: 0x00000008
0x8026c: 0x00000001
0x80270: 0x0000035c
0x80274: 0x00000011
0x80278: 0x00000204
0x8027c: 0x00000001
0x80280: 0x00000781
```

B2) What is the hexadecimal address of the instruction that is responsible for the recursive calls to `arrayProd`?

- Look at ra in the following snapshots
- It is repeatedly 0x0000025C
- The recursive call will be ra - 4
  - **0x00000258**

```
#3  sp  =0x00080270 ra  =0x0000025C
    a0  =0x00004004 a1  =0x00000004
Address: Data:
0x80258: 0x000ff3af
0x8025c: 0x00000018
0x80260: 0x0000035c
0x80264: 0x00000011
0x80268: 0x00000008
0x8026c: 0x00000001
0x80270: 0x0000025c
0x80274: 0x00000003
0x80278: 0x00000204
0x8027c: 0x00000001
0x80280: 0x00000781
```

B3) What is the hexadecimal address of the array `a` provided to the initial call of `arrayProd`?

- Look at arguments that `arrayProd` takes in
  - `uint32_t* a` in a0
  - `uint32_t b` in a1
- `a` is the pointer of the array provided to `arrayProd`
  - A pointer is a variable that stores the address of something in memory
- Snapshot 1 shows us the value of a0 right before we first call `arrayProd`

```
#1  sp  =0x00080280 ra  =0x00000000
    a0  =0x00004000 a1  =0x00000005
Address: Data:
0x80258: 0x000ff3af
0x8025c: 0x00000018
0x80260: 0x0000035c
0x80264: 0x00000011
0x80268: 0x00000008
0x8026c: 0x00000001
0x80270: 0x0000035c
0x80274: 0x00000011
0x80278: 0x00000808
0x8027c: 0x0000a321
0x80280: 0x00000781
```

B4) Specify a C array below that is identical to the one the user must have handed into `arrayProd`.

- Let's look at the last snapshot for values added in the stack
  - `{ 1, 3, 5, 8 }` coupled with `ra`'s
- Notice that the value in `a0` is the result of multiplying each element in the array
- From the first snapshot, `a1` was 5
  - `a1` corresponds to the length of the array
- 0x0F0 = 240 = 1*3*5*8*???
  - ??? = 2
- The array is `{ 1, 3, 5, 8, 2 }`

```
#6  sp  =0x00080280 ra  =0x00000204
    a0  =0x000000F0 a1  =0x00000000
Address: Data:
0x80258: 0x000ff3af
0x8025c: 0x00000018
0x80260: 0x0000025c
0x80264: 0x00000008
0x80268: 0x0000025c
0x8026c: 0x00000005
0x80270: 0x0000025c
0x80274: 0x00000003
0x80278: 0x00000204
0x8027c: 0x00000001
0x80280: 0x00000781
```