

**6.S077(6.1900)(6.0004): Introduction to Low-level Programming in C and
Assembly**

Fall 2022, Quarter 1

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#1 (16)	#2 (18)	#3 (13)	#4 (9)	#5 (16)	#6 (14)	#7 (14)	Total
16	18	13	9	16	14	14	100

Enter your answers in the spaces designated in each problem. Show your work for potential partial credit. You can use the extra white space and the backs of the pages for scratch work.

Problem 1. Binary Arithmetic (16 points)

A. (4 points): What is $0x68 \wedge (0x9C \mid 0x5A)$? Provide your result in both unsigned 8-bit binary and unsigned 8-bit hexadecimal.

Result in unsigned 8-bit binary (0b): <code>0x1011_0110</code>
Result in unsigned 8-bit hexadecimal (0x): <code>0xB6</code>

B. (2 points): What is the result of $((0b001 > 0b101) \&\& 0b100) == 0b001$? Assume all numbers are unsigned. Provide your result in decimal.

Result in Decimal: <code>0</code>
--

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 in 8-bit 2's complement notation (0b): <code>0b0000_1110</code>
31 in 8-bit 2's complement notation (0b): <code>0b0001_1111</code>
-31 in 8-bit 2's complement notation (0b): <code>0b1110_0001</code>
14-31 in 8-bit 2's complement notation (0b): <code>0b1110_1111</code>

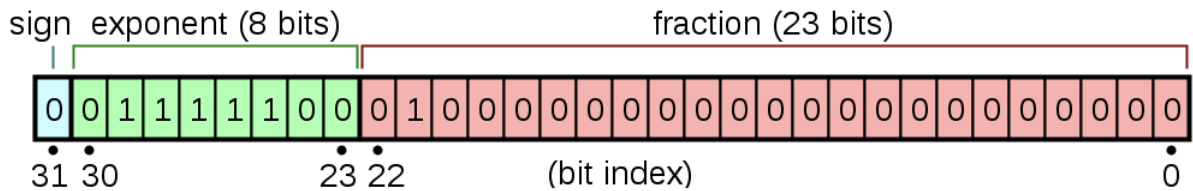
D. (2 points): How many bits are required to encode decimal values ranging from -128 to 127 in two's complement representation? How many bits are required to encode decimal values ranging from 0 to 127 in unsigned binary representation? Provide your answer in decimal.

Bits required for two's complement (in decimal):	8
Bits required for unsigned binary (in decimal):	7

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

Logical right shift (in binary):	0b0011_0110
Arithmetic right shift (in binary):	0b1111_0110

G. (2 Points) 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.



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

Decimal Equivalent:	8.5
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Problem 2. What If (18 points)

Suppose that we have a function `int is_uppercase(char c)` that returns 1 if `c` is an uppercase alphabetical character, and 0 otherwise. Similarly, suppose also that we have a function `int is_lowercase(char c)` that returns 1 if `c` is a lowercase alphabetical character, and 0 otherwise.

Find below another function `flip_case`, which flips the case of each character in the given string.

```
// 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. (6 points) Assume that this code is to be run on a 32-bit RISC-V processor. Determine if each of the following candidates are functionally equivalent to `x++`; in the above program.

Candidate	CIRCLE ONE:	
<code>&x = &x + 1;</code>	YES	NO
<code>*(&x) = x + 1;</code>	YES	NO
<code>x = (char *)((uint32_t)x + 4);</code>	YES	NO

B. (4 points) 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  ++;
}
```

Fill in the two blanks so that `flip_case` would retain its correctness. Pay attention to the existing code that precedes and/or follows the blanks; you are not allowed to modify or get rid of it. **Take note of the order of operations.**

Blank 1: <div style="text-align: center; color: red; font-weight: bold;">char**</div>	Blank 2: <div style="text-align: center; color: red; font-weight: bold;">(*x)</div>
---	---

C. (8 points) Consider the following code, which makes a call to `flip_case`. The implementation of `flip_case` is repeated below for your convenience.

```
#include <stdio.h>
int is_uppercase(char x); // implemented elsewhere
int is_lowercase(char x); // implemented elsewhere
// 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++;
    }
}
int main() {
    char str[] = "ababABAB";
    char *p = str;
    char **q = &p;
    flip_case(???) // <- REPLACE HERE
    printf("%s\n", str);
    return 0;
}
```

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

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){

    // 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){  
  
    // 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.

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', ...}
```

Note that `readChars` is passed a **pointer** to a `SerialBuffer`.

Be sure to leverage the **peekChars** function you just wrote.

Answer box provided on next page

```
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 (9 points)

Suppose we have a function `void find_mean(const float *arr, int n, float *mean)` that goes through the array `arr` of `n` real numbers, finds the arithmetic mean (i.e. average), and puts the result in the variable pointed to by `mean`.

Implement the function `mean_filter`, which takes an array `input` of `num_elems` real numbers, finds the arithmetic mean for each contiguous window of exactly `window_size` elements, and puts the results in the array `output`.

```
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 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]`

Problem 5. Assembly Language (16 points)

(A) (2 points) What is the **hexadecimal** encoding of the instruction **srai t3, a2, 6**? You can use the template below to help you with the encoding. Please show your work for partial credit.

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

srai t3, a2, 6 instruction encoding (0x): 0x40665E13

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.

(B) (4 points)

The first instruction executed is located at address 0x20.

<pre>. = 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</pre>	<p>Value left in x11: 0x <u>C0C0A0A0</u></p> <p>Value left in x12: 0x <u>3F3F5AF5</u></p>
--	---

(C) (10 points)

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>	<p>Value left in x1: 0x <u>10C</u></p> <p>Value left in x11: 0x <u>3000</u></p> <p>Value left in x12: 0x <u>22224444</u></p> <p>Value left in x13: 0x <u>22444400</u></p> <p>Value left in x14: 0x <u>00001CE</u></p>
--	---

Problem 6. Calling Convention (14 points)

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.

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
```

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) ___
```

```
_____
```

```
_____
```

```

# code copied here
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

```

```

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

```

```

# code copied here
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

```

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 (14 points)

Consider the following C function which takes an array of unsigned 32 bit integers **a** of length **b** and computes their product. We don't have a multiply instruction in our RV32I system, so we use the `mult` procedure (which you used in class, provided in appendix for reference) in order to actually do the multiplication:

```
int arrayProd(uint32_t* a, uint32_t b){
    // uint32_t *a: pointer to array
    // uint32_t b: length of array
    if (b == 1) {
        return a[0];
    }else {
        // multiply both numbers:
        return mult(arrayProd(a+1, b-1), a[0]);
    }
}
```

The equivalent assembly procedure for this function is below:

```
arrayProd:
    lw t0, 0(a0)
    li a3, 1
    beq a1, a3, end
    addi sp, sp, -8
    sw ra, 0(sp)
    sw t0, 4(sp)
    # SAMPLE POINT - prints ra, sp, a0, a1, a part of the stack
    addi a0, a0, 4
    addi a1, a1, -1
    jal arrayProd
    lw a1, 4(sp)
    jal mult # returns product of a0 and a1 (see appendix)

    _____
    lw ra, 0(sp)
    addi sp, sp, 8
end:
    mv a0, t0
    ret
```

Note the sample point line above. When this line is encountered, the four registers `ra`, `sp`, `a0`, and `a1` are printed as well as a region of the stack.

A. (2 points): What line of assembly should be substituted into the blank line in the `arrayProd` procedure above?

Line of assembly: `mv a0, t0`

B. (12 points): 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.

```
# SAMPLE POINT - prints ra, sp, a0, a1, a part of the stack
jal arrayProd
# SAMPLE POINT - prints ra, sp, a0, a1, a part of the stack
```

When the code is run, six sample snapshots are generated (including the one from before the initial call to `arrayProd`). They are shown **in chronological order** (#1 #2 #3 #4 #5 #6) below:

<pre>#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</pre>	<pre>#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</pre>
<pre>#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</pre>	<pre>#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</pre>
<pre>#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</pre>	<pre>#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</pre>

Answer the following questions:

(3 points) What is the hexadecimal address of the instruction that originally calls `arrayProd`?

Address: (0x). `0x00000200`

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

Address: (0x). `0x00000258`

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

Address: (0x). `0x00004000`

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

```
uint32_t a[ ] = {1, 3, 5, 8, 2};
```

Appendix 1: String functions

char *strcat(char *dest, const char *src) - appends the string pointed to by `src` to the end of the string pointed to by `dest`. This function returns a pointer to the resulting string `dest`.

char *strncat(char *dest, const char *src, size_t n) - appends the string pointed to by `src` to the end of the string pointed to by `dest` up to `n` characters long. This function returns a pointer to the resulting string `dest`.

char *strcpy(char *dest, const char *src) - copies the string pointed to, by `src` to `dest`. This returns a pointer to the destination string `dest`.

char *strncpy(char *dest, const char *src, size_t n) - copies up to `n` characters from the string pointed to, by `src` to `dest`. In a case where the length of `src` is less than that of `n`, the remainder of `dest` will be padded with null bytes. This function returns the pointer to the copied string.

int strcmp(const char *str1, const char *str2) - compares the string pointed to, by `str1` to the string pointed to by `str2`. This function return values that are as follows –

- if Return value < 0 then it indicates `str1` is less than `str2`.
- if Return value > 0 then it indicates `str2` is less than `str1`.
- if Return value = 0 then it indicates `str1` is equal to `str2`.

int strncmp(const char *str1, const char *str2, size_t n) - compares at most the first `n` bytes of `str1` and `str2`. This function return values that are as follows –

- if Return value < 0 then it indicates `str1` is less than `str2`.
- if Return value > 0 then it indicates `str2` is less than `str1`.
- if Return value = 0 then it indicates `str1` is equal to `str2`.

char *strchr(const char *str, int c) - searches for the first occurrence of the character `c` (an unsigned char) in the string pointed to by the argument `str`. This returns a pointer to the first occurrence of the character `c` in the string `str`, or NULL if the character is not found.

char *strrchr(const char *str, int c) - searches for the last occurrence of the character `c` (an unsigned char) in the string pointed to, by the argument `str`. This function returns a pointer to the last occurrence of character in `str`. If the value is not found, the function returns a null pointer.

char *strstr(const char *haystack, const char *needle) - function finds the first occurrence of the substring `needle` in the string `haystack`. The terminating `'\0'` characters are not compared. This function returns a pointer to the first occurrence in `haystack` of any of the entire sequence of characters specified in `needle`, or a null pointer if the sequence is not present in `haystack`.

char *strtok(char *str, const char *delim) - breaks string `str` into a series of tokens using the delimiter `delim`. This function returns a pointer to the first token found in the `string`. A null pointer is returned if there are no tokens left to retrieve.

Appendix 2: ASCII Table

ASCII Table

Dec	Hex	Oct	Char	Dec	Hex	Oct	Char	Dec	Hex	Oct	Char	Dec	Hex	Oct	Char
0	0	0		32	20	40	[space]	64	40	100	@	96	60	140	`
1	1	1		33	21	41	!	65	41	101	A	97	61	141	a
2	2	2		34	22	42	"	66	42	102	B	98	62	142	b
3	3	3		35	23	43	#	67	43	103	C	99	63	143	c
4	4	4		36	24	44	\$	68	44	104	D	100	64	144	d
5	5	5		37	25	45	%	69	45	105	E	101	65	145	e
6	6	6		38	26	46	&	70	46	106	F	102	66	146	f
7	7	7		39	27	47	'	71	47	107	G	103	67	147	g
8	8	10		40	28	50	(	72	48	110	H	104	68	150	h
9	9	11		41	29	51	)	73	49	111	I	105	69	151	i
10	A	12		42	2A	52	*	74	4A	112	J	106	6A	152	j
11	B	13		43	2B	53	+	75	4B	113	K	107	6B	153	k
12	C	14		44	2C	54	,	76	4C	114	L	108	6C	154	l
13	D	15		45	2D	55	-	77	4D	115	M	109	6D	155	m
14	E	16		46	2E	56	.	78	4E	116	N	110	6E	156	n
15	F	17		47	2F	57	/	79	4F	117	O	111	6F	157	o
16	10	20		48	30	60	0	80	50	120	P	112	70	160	p
17	11	21		49	31	61	1	81	51	121	Q	113	71	161	q
18	12	22		50	32	62	2	82	52	122	R	114	72	162	r
19	13	23		51	33	63	3	83	53	123	S	115	73	163	s
20	14	24		52	34	64	4	84	54	124	T	116	74	164	t
21	15	25		53	35	65	5	85	55	125	U	117	75	165	u
22	16	26		54	36	66	6	86	56	126	V	118	76	166	v
23	17	27		55	37	67	7	87	57	127	W	119	77	167	w
24	18	30		56	38	70	8	88	58	130	X	120	78	170	x
25	19	31		57	39	71	9	89	59	131	Y	121	79	171	y
26	1A	32		58	3A	72	:	90	5A	132	Z	122	7A	172	z
27	1B	33		59	3B	73	;	91	5B	133	[	123	7B	173	{
28	1C	34		60	3C	74	<	92	5C	134	\	124	7C	174	|
29	1D	35		61	3D	75	=	93	5D	135	]	125	7D	175	}
30	1E	36		62	3E	76	>	94	5E	136	^	126	7E	176	~
31	1F	37		63	3F	77	?	95	5F	137	_	127	7F	177	

Appendix 3: mult procedure

```
mult:
    bge a0, a1, init
    mv t0, a0
    mv a0, a1
    mv a1, t0
init:
    mv t0, zero
loop:
    beq a1, zero, done
    addi a1, a1, -1
    add t0, t0, a0
    j loop
done:
    mv a0, t0
    ret
```