# CSE 220: Systems Fundamentals I

**Stony Brook University**

**Programming Assignment #1**

**Fall 2020**

**Assignment Due: Sunday, September 20, 2020 by 11:59 pm EDT**

## Updates to this Document

- 9/14/2020: Clarified that your code should print a newline at the end of your output for Parts 3 and 4.
- 9/14/2020: Fixed a small typo in the bottom half of page 11.
- 9/8/2020: There was a mistake in the first example of Part 5 on page 13. It has now been corrected.
- 9/8/2020: A new example of High Card has been added to the examples in Part 5 on page 13.

## Learning Outcomes

After completion of this programming project you should be able to:

- Use system calls to print values to the screen in different formats.
- Design and implement algorithms in MIPS assembly that involve if-statements and counter-driven loops.
- Read and write values stored in a MIPS assembly .data section.
- Use bitwise operations to perform simple computations in MIPS assembly.

## Getting Started

Visit the course website and download the files hwk1.asm and MarsFall2020.jar. Fill in the following information at the top of hwk1.asm:

1. your first and last name as they appear in Blackboard
2. your Net ID (e.g., jsmith)
3. your Stony Brook ID # (e.g., 111999999)

Having this information at the top of the file helps us locate your work. If you forget to include this information but don't remember until after the deadline has passed, don't worry about it – we will track down your submission.

Inside hwk1.asm you will find some code to start with. Your job in this assignment is implement all the operations as specified below. If you are having difficulty implementing these operations, write out pseudocode or implement the algorithms in a higher-level language first. Once you understand the algorithm and what steps to perform, then translate the logic to MIPS assembly code.

**Important Information about CSE 220 Programming Projects**

- Read the entire project description document twice before starting. Questions posted on Piazza whose answers are clearly stated in the documents will be given lowest priority by the course staff.
- You must use the Stony Brook version of MARS posted on the course website. Do not use the version of MARS posted on the official MARS website. The Stony Brook version has a reduced instruction set, added tools, and additional system calls you might need to complete the homework assignments.
- When writing assembly code, try to stay consistent with your formatting and to comment as much as possible. It is much easier for your TAs and the professor to help you if we can quickly figure out what your code does.
- You personally must implement the programming assignments in MIPS Assembly language by yourself. You may not write or use a code generator or other tools that write any MIPS code for you. You must manually write all MIPS assembly code you submit as part of the assignments.
- Do not copy or share code. Your submissions will be checked against other submissions from this semester and from previous semesters.
- Submit your final .asm file to the course website by the due date and time. Late work will be penalized as described in the course syllabus. Code that crashes and cannot be graded will earn no credit. No changes to your submission will be permitted once the deadline has passed.

**How Your CSE 220 Assignments Will Be Graded**

With few exceptions, all aspects of your programming assignments will be graded entirely through automated means. Grading scripts will execute your code with input values (e.g., command-line arguments, function arguments) and will check for expected results (e.g., print-outs, return values, etc.) For homework assignment #1, your program will be generating output that will be checked for exact matches by the grading scripts. Therefore, it is imperative that you implement the "print statements" exactly as specified in the assignment.

Some other items you should be aware of:

- Each test case must execute in 20,000 instructions or fewer. Efficiency is an important aspect of programming. This maximum instruction count will be increased in cases where a complicated algorithm might be necessary, or a large data structure must be traversed. To find the instruction count of your code in MARS, go to the **Tools** menu and select **Instruction Statistics**. Press the button marked **Connect to MIPS**. Then assemble and run your code as normal.
- Any excess output from your program (debugging notes, etc.) will impact grading. Do not leave erroneous print-outs in your code.

- We will provide you with a small set of test cases for each assignment to give you a sense of how your work will be graded. It is your responsibility to test your code thoroughly by creating your own test cases.
- The testing framework we use for grading your work will not be released, but the test cases and expected results used for testing will be released.

**Configuring MARS for Command-line Arguments**

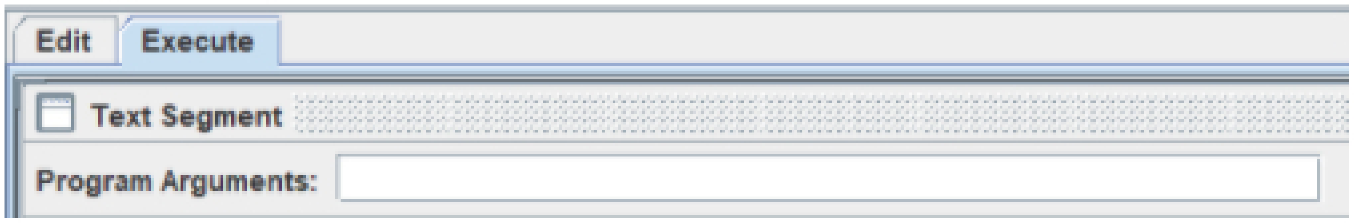
Your program is going to accept command-line arguments, which will be provided as input to the program. To tell MARS that we wish to accept command-line arguments, we must go to the Settings menu and check the box marked:

***Program arguments provided to the MIPS program***

While you're at it, also check the box marked:

***Initialize Program Counter to global 'main' if defined***

After assembling your program, in the **Execute** tab, you should see a text box where you can type in your command-line arguments before running the program:



The command-line arguments must be separated by spaces. Note that your program must always be run with at least one command-line argument. When your program is assembled and then run, the arguments to your program are placed in main memory before execution. Information about the arguments is then provided to your code using the argument registers, `$a0` and `$a1`. The `$a0` register contains the number of arguments passed to your program. The `$a1` register contains the starting address of an array of strings. Each element in the array is the starting address of the argument specified on the command-line.

All arguments are saved in memory as ASCII character strings, terminated by the null character (ASCII 0, which is denoted by the character `'\0'` in assembly code). So, for example, if we want to read an integer argument on the command-line, we actually must take it as a string of digit characters (e.g., `"2034"`) and then convert it to an integer ourselves in assembly code. We have provided code for you that stores the addresses of the command-line arguments at pre-defined, unique labels (e.g., `addr_arg0`, `addr_arg1`, etc.) Note that the strings themselves are not stored at these labels. Rather, the starting addresses of the strings are stored at those labels. You will need to use load instructions to obtain the contents of these strings stored at the addresses: `lw` to load the address of a string, then multiple `lbu` instructions to get the characters. For instance, `lw $s0, addr_arg2`, followed by `lbu`

`$t0, 4($s0)` would store the character located at index 4 in `$t0` (assuming 0-based indexes) of the third command line argument.

**Running the Program**

Running the provided hwk1.asm file is pretty simple. Hit F3 on the keyboard or press the button shown below to assemble your code:

If your code has any syntax errors, MARS will report them in the MARS **Messages** panel at the bottom of the window. Fix any syntax errors you may have. Then press F5 or hit the Run button shown below to run your program:

Any output generated by your program will appear in the **Run I/O** panel at the bottom of the window.

**Part 1: Validate the First Command-line Argument and the Number of Command-line Arguments**

For this assignment you will be implementing several operations that perform computations and do data manipulation.

In hwk1.asm, begin writing your program immediately after the label called `start_coding_here`. You may declare more items in the .data section after the provided code. Any code that has already been provided must appear exactly as defined in the given file. Do not delete or rename these labels, as doing so will negatively impact grading.

The number of arguments is stored in memory at the label `num_args` by code already provided for you. You will need to use various system calls to print values that your code generates. For example, to print a string in MIPS, you need to use system call 4. You can find a listing of all the official MARS system calls on the MARS website. You can also find the documentation for all instructions and supported system calls within MARS itself. Click the blue question mark in the right-hand end of the tool bar to open it.

Later in the document is a list of the operations that your program will execute. Each operation is identified by a single character. The character is given by the first command-line argument (whose address is `addr_arg0`). The parameter(s) to each argument are given as the remaining command-line arguments (located at addresses `addr_arg1`, `addr_arg2`, etc.). In this first part of the assignment your program must make sure that each operation is valid and has been given the correct number of parameters. Perform the validations in the following order:

1. The first command-line argument must be a string of length one that consists of one of the following characters: 1, 2, S, F, R or P. If the argument is a letter, it must be given in uppercase. If the argument is not one of these strings or if the argument contains more than one character, print the string found at label `invalid_operation_error` and exit the program (via system call 10). This string contains a newline character at the end, so you do not need to provide your own.

2. The 1, 2 and S operations expect two additional arguments. If the total number of command-line arguments for these commands is not three, print the string found at label `invalid_args_error` and exit the program (via system call 10). This string contains a newline character at the end, so you do not need to provide your own.

3. The F operation expects one additional argument. If the total number of command-line arguments for this command is not two, print the string found at label `invalid_args_error` and exit the program (via system call 10). This string contains a newline character at the end, so you do not need to provide your own.

4. The R operation expects six additional arguments. If the total number of command-line arguments for this command is not seven, print the string found at label `invalid_args_error` and exit the program (via system call 10). This string contains a newline character at the end, so you do not need to provide your own.

5. The P operation expects one additional argument. If the total number of command-line arguments for this command is not two, print the string found at label `invalid_args_error` and exit the program (via system call 10). This string contains a newline character at the end, so you do not need to provide your own.

Important: You must use the provided `invalid_operation_error` and `invalid_args_error` strings when printing error messages. Do not create your own labels for printing output to the screen. If your output is marked as incorrect by the grading scripts because of typos, then it is your fault for not using the provided strings, and you will lose all credit for those test cases.

Be sure to initialize all of your values (e.g., registers) within your functions. Never assume registers or memory will hold any particular values (e.g., zero). MARS initializes all of the registers and bytes of main memory to zeroes. The grading scripts for later assignments will fill the registers and/or main memory with random values before executing your code.

Later sections will explain how to validate the arguments for each operation.

**Examples of Invalid Input**

See the later sections of the documents for explanation of what arguments are valid for each operation.

| **Command-line Arguments** | **Label for String to Print** | **Expected Output** |
|---|---|---|
| `Signed 000E 32` | `invalid_operation_error` | `INVALID_OPERATION` |

| | | |
|---|---|---|
| `p HIJKL` | `invalid_operation_error` | `INVALID_OPERATION` |
| `F XYZ ABC` | `invalid_args` | `INVALID_ARGS` |

**Character Strings in MIPS Assembly**

In assembly, a string is a one-dimensional array of unsigned bytes. Therefore, to read each character of the string we typically need to use a loop. Suppose that `$s0` contains the base address of the string (that is, the address of the first character of the string). We could use the instruction `lbu $t0, 0($s0)` to copy the first character of the string into `$t0`. To get the next character of the string, we have two options: (i) add 1 to the contents of `$s0` and then execute lbu `$t0, 0($s0)` again, or (ii) leave the contents of `$s0` alone and execute `lbu $t0, 1($s0)`. Generally speaking, the first approach is easier and simpler to use, but the other approach works perfectly fine if the string is short in length and is always the same length. Note that syntax like `lbu $t0, $t1($s0)` is not valid; an immediate value (a constant) must be given outside the parentheses.

**Next: Process the Input**

If the program determines that the first command-line argument is a valid operation and that it has been given a correct number of additional arguments, the program continues by executing the appropriate operation as specified below. Note that you are permitted to add code to the .data section as necessary to implement these operations.

**Part 2: Process a String of Four Hexadecimal Digits that Represents a Signed Integer**

The 1, 2 and S operations treat the second command-line argument as a string of hexadecimal digit characters ('0' – '9', 'A' – 'F') that represent a signed one's complement number, two's complement number or sign/magnitude number, respectively. The leftmost character represents the most significant nibble (4 bits) of the integer. The operation converts the string into a 32-bit signed integer in two's complement, storing it in a single register. The code then prints the *N* rightmost bits of that register, where *N* is given by the third argument. In other words, the integer is printed as an *N*-bit, two's complement value. Finally, the code prints a newline character (`'\n'`). The number of bits to print given by the third argument should be at least 16. Helpful hint: you can give an ASCII character as a literal in MIPS (e.g., `li $a0, '\n'`).

There are different algorithms you can devise to implement this operation. To get started, think of how you would convert characters like `'7'` and `'D'` from the binary ASCII values `00110111` and `01000100`, respectively, to the binary values `0111` and `1101`, respectively. Also explore how you can extract individual bits from a register using bitwise operators.

- First command-line argument: the character 1, 2 or S

- Second command-line argument: exactly four characters that represent hexadecimal digits

- Third command-line argument: a number of bits ≥ 16 and ≤ 32

**Input Validation**

The second command-line argument must consist only of characters that represent hexadecimal digits. All letters must be provided in uppercase. An input containing any lowercase letters is considered invalid; in such cases, print the string `invalid_args_error` and terminate the program via system call 10. If the argument contains any other invalid characters, print the string found at label `invalid_args_error` and terminate the program. You may assume that the second command-line argument contains exactly four characters.

The third command-line argument must consist only of two characters that represent decimal digits.You may assume that the third command-line argument contains exactly two digit characters, but that those digits might represent a number in the range 0 through 99, inclusive. If the number is outside the range 16 through 32, print the string `invalid_args_error` and terminate the program. When the third argument is a valid number, you may assume that the input value may be expressed using that number of bits.

**Worked-out Example**

Suppose the command-line arguments are `"1" "FFF1" "25"`. These arguments indicate that the string `"FFF1"` represents a one's complement value and that we want to print out the two's complement representation of that value using 25 bits.

Note that $FFF1_{16}$ = $1111\ 1111\ 1111\ 0001_2$. The first argument of `"1"` indicates that we should treat this bitstring as the one's complement value of some integer. 1111 1111 1111 0001 represents the integer -14 in one's complement representation, which is represented in 25-bit two's complement as 1111111111111111111110010, which is the output of the code.

**Examples**

| **Command-line Arguments** | **Expected Output** |
|---|---|
| `2 FFFF 20` | `11111111111111111111` |
| `2 0011 25` | `0000000000000000000010001` |
| `2 7EA2 19` | `0000111111010100010` |
| `1 FFFE 20` | `11111111111111111111` |
| `1 FFF1 25` | `1111111111111111111110010` |
| `1 4190 32` | `00000000000000000100000110010000` |
| `S 000E 22` | `0000000000000000001110` |

| | |
|---|---|
| `S 800A 20` | `11111111111111110110` |
| `S 00FF 19` | `0000000000011111111` |
| `2 faCE 19` | `INVALID_ARGS` |
| `1 WOLF 28` | `INVALID_ARGS` |
| `S 01F1 05` | `INVALID_ARGS` |

**Part 3: Print a Decimal Fixed-point Number as a Binary Fixed-point Number**

The F operation takes a string of nine characters that represent a positive decimal real number and, using only integer arithmetic, converts the decimal value to binary and prints it to the screen. The whole number part of the output must not contain any leading zeros except in the case where the whole number part is zero. In this case, only a single zero may be printed. Finally, the code prints a newline character (`'\n'`).

The fractional part of the input number will always represent a value that can be computed by adding some combination of the values 0.5, 0.25, 0.125, 0.0625 and 0.03125 (that is, $2^{-1}$, $2^{-2}$, $2^{-3}$, $2^{-4}$ and $2^{-5}$). (This accommodation makes it possible to convert the fractional decimal value to binary using only integer arithmetic.) The output value must always contain exactly five bits to the right of the radix point.

- First command-line argument: the character F
- Second command-line argument: exactly three decimal digits characters, followed by a period, followed by exactly five decimal digit characters

**Input Validation**

You may assume that the input is always valid.

**Examples**

| **Command-line Arguments** | **Expected Output** |
|---|---|
| `F 612.68750` | `1001100100.10110` |
| `F 006.40625` | `110.01101` |
| `F 000.62500` | `0.10100` |
| `F 000.03125` | `0.00001` |
| `F 017.00000` | `10001.00000` |

|  |  |
|---|---|
| `F 195.18750` | `11000011.00110` |

**Part 4: Encode Six Numerical Fields as an R-Type MIPS Instruction**

The R operation takes six decimal values, treats them as the six fields of a MIPS R-type instruction, and, using shifting and masking operations, combines the four values into a single 32-bit integer that represents an R-type instruction. The program then prints this value in hexadecimal using syscall 34. Finally, the code prints a newline character (`'\n'`). An example will help to clarify this process.

- First command-line argument: the character R
- Second command-line argument: the string "00"
- Third command-line argument: a string that encodes a positive, two-digit decimal integer in the range [0, 31] (the rs field). A leading zero is provided if needed.
- Fourth command-line argument: a string that encodes a positive, two-digit decimal integer in the range [0, 31] (the rt field). A leading zero is provided if needed.
- Fifth command-line argument: a string that encodes a positive, two-digit decimal integer in the range [0, 31] (the rd field). A leading zero is provided if needed.
- Sixth command-line argument: a string that encodes a positive, two-digit decimal integer in the range [0, 31] (the shamt field). A leading zero is provided if needed.
- Seventh command-line argument: a string that encodes a positive, two-digit decimal integer in the range [0, 63] (the funct field). A leading zero is provided if needed.

A 32-bit R-type instruction consists of 6 fields, where the number below each field indicates its width in bits. Note that bit #0 is the rightmost bit:

| **Field** | opcode | rs | rt | rd | shamt | funct |
|---|---|---|---|---|---|---|
| **# of bits** | 6 | 5 | 5 | 5 | 5 | 6 |

Suppose the command-line arguments were the strings

```
R 00 15 17 03 14 29
```

The program must process each numerical argument in turn, converting each of the six strings into an integer. Remember that all data in a computer is stored in binary, so, after conversion, these values will be stored as the 32-bit values given below:

```
00000000000000000000000000000000
00000000000000000000000000001111
00000000000000000000000000010001
00000000000000000000000000000011
00000000000000000000000000001110
00000000000000000000000000011101
```

We treat these six values as the opcode, rs, rt, rd, shamt and funct fields, respectively. Next, using bitwise operations, we need to concatenate the six rightmost bits of the opcode, five rightmost bits of the rs, rt, rd and shamt fields, and 6 rightmost bits of the funct field:

```
000000 01111 10001 00011 01110 011101
```

When printed in hexadecimal, the output value (produced by syscall 34) will be `0x01f11b9d`.

**Input Validation**

You may assume that the second argument is always "00". You may assume that the third, fourth, fifth, six and seventh command-line arguments always consist of exactly (and only) two decimal digit characters that encode a positive integer. However, you may not assume that the values are in the legal ranges specified above. If any of the third, fourth, fifth, six and seventh command-line arguments is outside its legal range, print the string found at label `invalid_args_error` and exit the program (via system call 10).

Note that the shamt field is applicable only when performing a shift instruction. You do not need to check whether a non-zero shamt amount is given when a non-shifting instruction is provided. Simply have your code convert the shamt argument to a 5-bit binary value, regardless of what the funct field is, and incorporate that 5-bit value in the final 32-bit value computed by your code.

**Examples**

| Command-line Arguments | Expected Output |
|---|---|
| `R 00 15 17 03 14 29` | `0x01f11b9d` |
| `R 00 02 31 24 05 42` | `0x005fc16a` |
| `R 00 22 25 31 00 61` | `0x02d9f83d` |
| `R 00 17 41 22 30 08` | `INVALID_ARGS` |

**Part 5: Identify Non-standard, Five-card Poker Hands**

The P operation treats the second command-line argument as a string of exactly five characters that encode a non-standard five-card hand from draw poker.

The program must be able to identify some of the non-standard hands of five-card draw poker and print a message indicating which one it found. If the hand can be matched with two or more hands, the hand of highest rank is printed. If none of these five ranked hands is identified, the program prints HIGH_CARD. You may assume that when the P operation has been provided, the second argument always contains exactly 5 characters. For the purposes of this assignment, an Ace is always treated as a low card (i.e., less than 2), never as a high card (i.e., higher than King).

The hand ranks from highest-to-lowest, along with the relevant MIPS string to print, are:

| **Rank** | **Hand Name** | **Label for String to Print** | **Output on Screen** |
|---|---|---|---|
| 1 | Big bobtail | `big_bobtail_str` | `BIG_BOBTAIL` |
| 2 | Full house | `full_house_str` | `FULL_HOUSE` |
| 3 | Five and dime | `five_and_dime_str` | `FIVE_AND_DIME` |
| 4 | Skeet | `skeet_str` | `SKEET` |
| 5 | Blaze | `blaze_str` | `BLAZE` |
| 6 | Everything else (i.e., High card) | `high_card_str` | `HIGH_CARD` |

From Wikipedia:

1. Big bobtail: A four-card straight flush (four cards of the same suit in consecutive order).
2. Full house: three cards of one rank and two cards of another rank (example: 3-3-3-J-J).
3. Five and dime: 5-low, 10-high, with no pair (example: 5-6-7-8-10).
4. Skeet: A hand with a 2, a 5, and a 9, plus two other un-paired cards lower than 9 (example: 2-4-5-6-9).
5. Blaze: All cards are Jacks, Queens, and/or Kings.
6. High card: None of the above.

A single card is encoded as an ASCII character. Specifically, the ASCII code ranges employed are:

- 0x41 - 0x4D represent the A through K of Clubs
- 0x51 - 0x5D represent the A through K of Spades
- 0x61 - 0x6D represent the A through K of Diamonds
- 0x71 - 0x7D represent the A through K of Hearts

Note that the left hexadecimal digit encodes the suit, and the right digit encodes the rank. Valid ranks range 1 - 13 (0x1 - 0xD). Note that 11, 12 and 13 (0xB, 0xC, 0xD) correspond with Jack, Queen and King, respectively.

For example, 0x63 represents the 3 of Diamonds and corresponds with the ASCII character 'c'. Likewise, 0x4B represents the Jack of Clubs and corresponds with the ASCII character 'K'.

An example of a valid hand would be the string "vX[qd", which have ASCII codes:

- 0x76 = 6 of Hearts
- 0x58 = 8 of Spades
- 0x5B = Jack of Spades
- 0x71 = Ace of Hearts
- 0x64 = 4 of Diamonds

**Input Validation**

You may assume that the second command-line argument always consists of exactly five characters that encode valid cards. You may also assume that no card appears more than once in the input.

**Examples**

| Command-line Arguments | Meaning of Input | Expected Output |
|---|---|---|
| `P BVTUS` | 2♣6♠4♠5♠3♠ | `BIG_BOBTAIL` |
| `P BDCEG` | 2♣4♣3♣5♣7♣ | `BIG_BOBTAIL` |
| `P RTtbB` | 2♠4♠4♥2♦2♣ | `FULL_HOUSE` |
| `P WUxjI` | 7♠5♠8♥T♦9♣ | `FIVE_AND_DIME` |
| `P WRuiF` | 7♠2♠5♥9♦6♣ | `SKEET` |
| `P TRSYU` | 4♠2♠3♠9♠5♠ | `BIG_BOBTAIL` |
| `P [L}mK` | J♠Q♣K♥K♦J♣ | `BLAZE` |
| `P GIDuF` | 7♣9♣4♣5♥6♣ | `HIGH_CARD` |

**Academic Honesty Policy**

Academic honesty is taken very seriously in this course. By submitting your work for grading  you indicate your understanding of, and agreement with, the following Academic Honesty Statement:

1. I understand that representing another person's work as my own is academically dishonest.
2. I understand that copying, even with modifications, a solution from another source (such as the web or another person) as a part of my answer constitutes plagiarism.
3. I understand that sharing parts of my homework solutions (text write-up, schematics, code, electronic or hard-copy) is academic dishonesty and helps others plagiarize my work.
4. I understand that protecting my work from possible plagiarism is my responsibility. I understand the importance of saving my work such that it is visible only to me.
5. I understand that passing information that is relevant to a homework/exam to others in the course (either lecture or even in the future!) for their private use constitutes academic dishonesty. I will only discuss material that I am willing to openly post on the discussion board.

6. I understand that academic dishonesty is treated very seriously in this course. I understand that the instructor will report any incident of academic dishonesty to the University's Academic Judiciary.
7. I understand that the penalty for academic dishonesty might not be immediately administered. For instance, cheating on a homework assignment may be discovered and penalized after the grades for that homework have been recorded.
8. I understand that buying or paying another entity for any code, partial or in its entirety, and submitting it as my own work is considered academic dishonesty.
9. I understand that there are no extenuating circumstances for academic dishonesty.

**How to Submit Your Work for Grading**

To submit your hwk1.asm file for grading:

1. Go to the course website.
2. Click the Submit link for this assignment.
3. Type your SBU ID# on the line provided.
4. Press the button marked **Add file** and follow the directions to attach your file.
5. Hit Submit to submit your file grading.

**Oops, I messed up and I need to resubmit a file!**

No worries! Just follow the steps again. We will grade only your last submission.