Course Name: Computer Architecture Lab

Course Number and Section: **14:332:333:02**

Experiment: Lab 1 – Machine Language, SPIM, High-to-Low Level Conversion

Lab Instructor: Bangtian Liu

Date Performed: 1/23/18

Date Submitted: 2/4/18

Submitted by: Yuqing Feng (yf184)

Purpose

This laboratory exercise taught me how to perform basic operations in MIPS assembly code and to run programs on QTSpim. Assembly language is important for understanding what is happening in the memory when higher level languages run. I learned basic arithmetic operations and system calls that display text to the user as well as get user input. Finally, I figured out how to use QTSpim and run it step by step for debugging.

Approach

Before beginning assignments, I needed to learn MIPS. Instructions are divided into sections from 32 bits depending on the type of format. For I-type instruction, it is split up as op, rs, rt and then a constant or address. For example, the add command adds together rs and rt and puts the result into that address. For R-type, op is also 0's while there is still rs and rt. Instead of a constant or address, the remaining 16 bits are divided as rd, shamt, and funct. These determine which type of operation is being performed.

Next, RAM memory transfer is an important part of loading and saving data, especially for assigning array elements values. "lw $destination, offset($base)" loads the destination with the value at the offset($base) address. "sw $source, offset($base)" saves the value in source into offset($base).

I also learned the importance of understanding the bytes of elements in arrays. If the array elements are 1 byte each, incrementing by one for the address will get to the next element, but if they are 4 bytes each, I need to increment by four to get to the next element. While C automatically does this, it is manual in assembly.

Important operations were "add", "addi" (for adding an immediate number, not a register), "sub", "div", and "mult" (and retrieval of the value with "mflo $dest").

For reading and printing, "syscall" is used. For syscall to know what to do, $v0 must be loaded with a code. When reading values, the value the user inputs is put into $v0 and to put it

into a register, one must use “move $t0, $v0” so the value is stored in $t0. The codes below specify what syscall will do:

$v0 code	What it does	Arguments needed
1	Print int	Value in $a0
2	Print float	Value in $f12
3	Print double	Value in $f12
4	Print string	Value in $a0
5	Read int	-
6	Read float	-
7	Read double	-
8	Read string	Addr. to store $a0 No. of char $a1
9	Memory allocation	Bytes storage $a0
10	Exit program	
11	Print character	Integer in $a0
12	Read character	

For Assignment 5, I had to translate for loops from C to MIPS. The syntax for “for loops” in MIPS is:

```
loopA:
beq $t0, $s0, end       # if i == a, end
…
addi $t0, $t0, 1        # add 1 to i
j loopA                 # jump back to the top
end:
```

The incrementing variable and the limit of i can be set through this. The loop is named in case of nested loops, so that they can be distinguished when jumping up to the top.

Using everything I learned above during the lab, I completed the below assignments and checked the coded ones (pasted below and attached as .asm files) in QTSpim.

Results

Assignment 1 – Machine Language Instructions in Binary

	op	rs	rt	constant
addi $3, $0, 15	001000	00011	00000	0000000000001111

	op	rs	rt	rd	shamt	funct
mult $8, $12	000000	01000	01100	00000	00000	011000

Assignment 2 – C to MIPS

C code:

A[8*i] =A[2*i] – B[2*i]

Variables f, g, h, i, j are $s0, $s1, $s2, $s3, $s4

Arrays A and B are $s6 and $s7

*temporary variables assumed: $a0, $a1, $a2 and $s5

a. 1 byte

```
sll $s0, $s3, 3        # f = 8*i – shift 3 for 1 byte is 2^3 = 8 times
sll $s1, $s3, 1        # g = 2*i – shift 1 for 1 byte is 2^1 = 2 times
add $a0, $s6, $s1      # stores address of the element at 2*i in A
add $a1, $s7, $s1      # stores address of the element at 2*i in B
lb $s2, 0($a0)         #h = content in the address (h = A[2*i])
```

```
lb $s4, 0($a1)        #j = content in the address (j = B[2*i])
sub $s5, $s2, $s4     #stores $s2 - $s4 (A[2*i] – B[2*i])
add $a2, $s6, $s0     #gets address of A[8*i]
sw $s5, 0($a2)        #saves contents of $s5 into A[8*i] address
```

b. 4 bytes

```
sll $s0, $s3, 5       # f = 8*i – shift 5 for 4 bytes, need to shift (2^2)*(2^3), so 2^5
sll $s1, $s3, 3       # g = 2*i – shift 3 for 4 bytes, shift (2^2)(2^1) = 2^3
add $a0, $s6, $s1     # stores address of the element at 2*i in A
add $a1, $s7, $s1     # stores address of the element at 2*i in B
lw $s2, 0($a0)        #h = content in the address (h = A[2*i])
lw $s4, 0($a1)        #j = content in the address (j = B[2*i])
sub $s5, $s2, $s4     #stores $s2 - $s4 (A[2*i] – B[2*i])
add $a2, $s6, $s0     #gets address of A[8*i]
sw $s5, 0($a2)        #saves contents of $s5 into A[8*i] address
```

Assignment 3 – MIPS to C

Variables f, g, h, i, j are $s0, $s1, $s2, $s3, $s4

Arrays A and B are $s6 and $s7

MIPS code	→	C code
addi $t0, $s6, 8	→	t0 = A + 2;
add $t1, $s3, $0	→	t1 = i;
sw $t1, 12($s7)	→	B[3] = t1;
lw $t0, 12($s6)	→	t0 = A[3];
add $s0, $t1, $t0	→	s0 = t1 + A[3];

Assignment 4 – Syscall and MIPS Program

1. $v0 in syscall

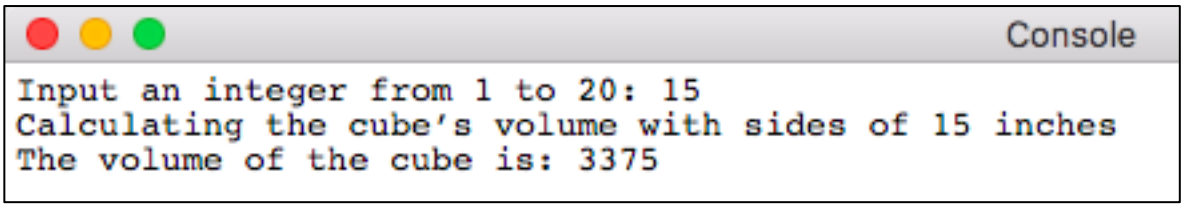
   $v0 tells the syscall what to do. The codes assigned to $v0 have different meanings.

$v0 code	What it does	Arguments needed
1	Print int	Value in $a0
2	Print float	Value in $f12
3	Print double	Value in $f12
4	Print string	Value in $a0
5	Read int	-
6	Read float	-
7	Read double	-
8	Read string	Addr. to store $a0 No. of char $a1
9	Memory allocation	Bytes storage $a0
10	Exit program	
11	Print character	Integer in $a0
12	Read character	

2. MIPS Program

   Objective: ask user to input integer between 1 and 20, report that it is calculating volume of cube, calculate, and report the volume of the cube with a message

   Running result:



   MIPS Program (assignment4.asm file):

```
.data
  inputStr: .asciiz "Input an integer from 1 to 20: "
  calcStr: .asciiz "Calculating the cube's volume with sides of "
  inchStr: .asciiz " inches"
  outputStr: .asciiz "\nThe volume of the cube is: "

.text
.globl main
main:
  li $v0, 4             # print input string - prompt
  la $a0, inputStr
  syscall

  li $v0, 5             #command to read integer
  syscall
  move $t0, $v0         #store user input in $t0 register

  li $v0, 4             #print calculating string
  la $a0, calcStr
  syscall

  li $v0, 1             #print user input
  move $a0, $t0
  syscall

  li $v0, 4             #finish printing calculating string
  la $a0, inchStr
  syscall

  mult $t0, $t0         #multiply by itself and store in $t1
  mflo $t1
```

```
mult $t1, $t0          #multiply the square $t1 by $t0 and store in $t2
mflo $t2

li $v0, 4              #print output string
la $a0, outputStr
syscall

li $v0, 1              #print result to user
move $a0, $t2
syscall

li $v0, 10             #exit program
syscall
```

Assignment 5 – C to MIPS

a -> $s0, b -> $s1, i -> $t0, j -> $t1

```
for (i=0; i<a; i++){
    for (j=0; j<b; j++){
        D[j] = i**2 + j**2;
    }
}
```

MIPS Code (assignment5.asm attached):

```
    loopA:
    beq $t0, $s0, end      # if i == a, end

     loopB:
```

```
beq $t1, $s1, end      # if j == b, end

mult $t0, $t0          #$t2 = i^2
mflo $t2

mult $t1, $t1          #$t3 = j^2
mflo $t3

add $t2, $t2, $t3      #$t2 = i^2 + j^2

li $t3, 4              #can't use mult with just immediate, load 4 in
mult $t1, $t3
mflo $t3               #$t3 = j*4 (4 bytes assumed)

add $a0, $s2, $t3      #get the address of the jth element in array D

sw $t2, 0($a0)         #save i^2+j^2 into $a0, which is the jth element of D

addi $t1, $t1, 1       # add 1 to j
j loopB                # jump back to the top
end:

addi $t0, $t0, 1       # add 1 to i
j loopA                # jump back to the top
end:
```

Assignment 6 – Arithmetic Progression

Arithmetic progression: a1 + (n-1)*d

Running code:

```
Input integer a1: 3
Input nth term integer n: 6
Input common difference integer d: 2
The answer is: 13
```

3, 5, 7, 9, 11, **13** <- 6th in the progression

MIPS Code (assignment6.asm attached):

```
.data
  a1Str: .asciiz "Input integer a1: "
  nStr: .asciiz "\nInput nth term integer n: "
  dStr: .asciiz "\nInput common difference integer d: "
  outStr: .asciiz "\nThe answer is: "
.text
.globl main
main:
li $v0, 4                #command to print a1Str
la $a0, a1Str
syscall
li $v0, 5                #command to read a1
syscall
move $t0, $v0            #store input in $t0 (a1) register
```

```
li $v0, 4           #command to print nStr
la $a0, nStr
syscall
li $v0, 5           #command to read n
syscall
move $t1, $v0       #store input in $t1 (n) register
li $v0, 4           #command to print dStr
la $a0, dStr
syscall
li $v0, 5           #command to read n
syscall
move $t2, $v0       #store input in $t2 (d) register

#solving
sub $t1, $t1, 1     #n = n-1
mult $t1, $t2
mflo $t3            #$t3 = (n-1)*d
add $t4, $t0, $t3   #$t4 = a1 + (n-1)*d

li $v0, 4           #command to print outStr
la $a0, outStr
```

```
syscall
li $v0, 1                #print the answer (stored in $t4)
move $a0, $t4
syscall
li $v0, 10               #exit program
syscall
```

Conclusion

Assignment 1 was important in showing the difference between I type and R type format. It also shows me the connection between assembly and binary, as assembly language is much closer to binary than higher level languages. Assignment 2 taught me how to locate array elements when there are different element byte sizes. Using sll to shift the i, variable I learned that the shift left value is different if it is 1 byte or 4 bytes. Load byte "lb" is used when it is just one byte, but load word "lw" must be used when there are 4 bytes. To get the addresses of the elements, I had to add the shifted values to the starting address of the array. Assignment taught me to translate MIPS into C code. Assignment 4 let me explore the uses of syscall and $v0 values as well as write a program using these concepts. The program printed and read strings and integers, which allowed me to use the concepts to create a working program. Assignment 5 taught me how to use for loops and nested for loops. I further solidified my understanding of getting an array element and assigning it a value. Finally, Assignment 6 allowed me to test everything I learned with an arithmetic challenge. I used printing and integer requesting as well as arithmetic operations to get the answer.

For the runnable assignments, I ran them on QTSpim and confirmed the correct outputs of my programs. I also used the running step by step feature for debugging purposes. Overall, I learned so much about programming in MIPS and how the computer actually makes the higher level code run. This was a great lesson in memory access, basic operations, and system calls in MIPS.