CS2100 Computer Organisation
Lab #5: Making Function Calls
[This document is available on LumiNUS and module website http://www.comp.nus.edu.sg/~cs2100]

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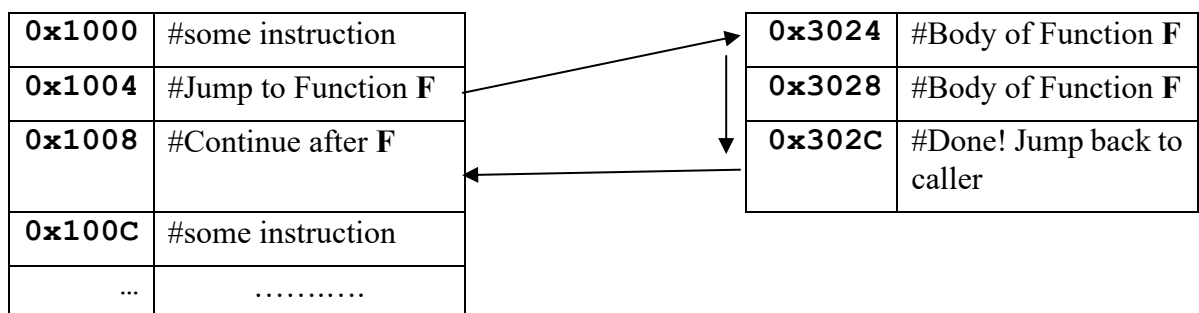
Lab Group: _B2b_

Note:
You should prepare your programs **before the lab**. Your lab TA will mark your work in your presence. You do not need to submit any program. Please do not send your programs to your lab TA after the lab; they will not be accepted.

Objective

In this lab, you will use **QtSpim** to explore the idea of function calls in MIPS Assembly Code. This document and its associated files (**sayHi.asm** and **arrayFunction.asm**) can be downloaded from the CS2100 module website or found in the ZIP file.

Task 1: Getting started (sayHi.asm) [5 marks]

Just like any high level programming language, modularization (separating code into well-defined procedures/functions) is an important idea for assembly programming. Conceptually, making function call is actually simple: we need to "*jump*" to another portion of code (the function body) then start executing the instructions in the function body. When we reach the end of that function, another "*jump*" is needed to go back to the caller.

`0x1000`	#some instruction		`0x3024`	#Body of Function **F**
`0x1004`	#Jump to Function **F**		`0x3028`	#Body of Function **F**
`0x1008`	#Continue after **F**		`0x302C`	#Done! Jump back to caller
`0x100C`	#some instruction			
...	………..			

So, the simplest kind of function call can be accomplished by just two "*jump*" instructions! To facilitate function calls, MIPS gives us two variants of the "**j**" instructions, the "**jal**" (jump-and-link) and the "**jr**" (jump by register). Don't worry, they are much easier than the name suggested.

First, download and load the assembly program "**sayHi.asm**" in QtSpim. The original content of the file is given on the next page.

```
# sayHi.asm
        .data
str1: .asciiz "Before function\n"
str2: .asciiz "After function\n"
str3: .asciiz "Inside function: Say Hi!\n"
        .text
main:
    li   $v0, 4     # system call code for print_string
    la   $a0, str1  # address of string to print
    syscall         # print the string

    jal sayHi       # Make a function call to sayHi()

    li   $v0, 4     # system call code for print_string
    la   $a0, str2  # address of string to print
    syscall         # print the string

    # End of main, make a syscall to "exit"
    li   $v0, 10    # system call code for exit
    syscall         # terminate program

# start of function sayHi()
sayHi:
    li   $v0, 4     # system call code for print_string
    la   $a0, str3  # address of string to print
    syscall         # print the string
                    # Use "jr" to go back to caller
```
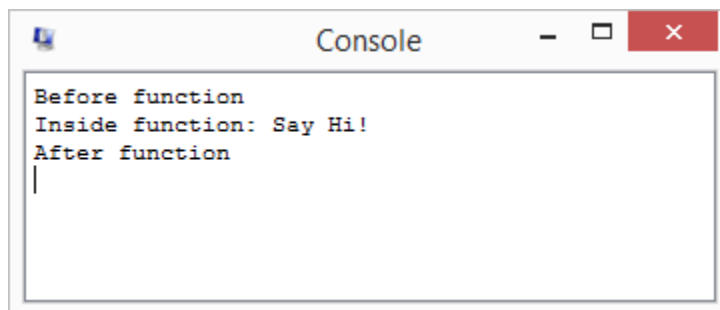
The intention of the program is to print 3 messages in the following order:

The first and third messages are printed in the "**main**" function while the second message is printed by the "**sayHi**" function. The given program is almost complete, with only one missing instruction. The purpose of this code is to demonstrate the necessary instructions needed for a making a function call.

Now, let us step through the program to make several observations. Use the "Single Step" button or press **F10** to go through the program line by line. Stop when you reach the instruction "**jal sayHi**".

Answer: The instruction address of "**jal sayHi**" is at 0x _0040000C_

Press **F10** one more time to execute the "**jal**" instruction. Answer the following:

Answer: The **PC** is now at **0x** 00400028

Answer: The register **$31** now contains **0x** 00400010

At this point, you should be able to see why the name of register **$31** is **$ra** (return address). Express the content of register **$31** with respect to the instruction address of the corresponding "**jal**" instruction. Use the notation **Addr(jal)** to indicate the instruction address of "**jal**" instruction.

Answer: **$31** = Addr(jal) + 4

If you continue stepping through, we will reach the end of the "**sayHi**" function and get 'stuck'. We need a way to go back to the main function **and continue from where we left off**. We can do this easily by the "**jr**" (jump by register) instruction which is missing in the program. This "**jr**" instruction takes a **register number** as operand. It will jump to the address stored in the specified register. For example,

        jr $15

The content of register **$15** will be used as the target address. This is known as **direct addressing** (the address is directly specified in full).

What is the correct register number to be used in the "**jr**" instruction so that we can jump back to main?

Answer: **jr** $31

Now, edit your code and insert the "**jr**" instruction accordingly. Run your program, you should see the 3 messages in the same order as shown in the earlier output screenshot.

Task 2: Let's share information (`arrayFunction.asm`) [15 marks]

We can now turn to other aspects of function call, namely function parameters (arguments) and function return value. Actually, we have encountered this idea in previous labs. Take a look at this very familiar sequence of using the system call **read_int**:

```
li $v0, 5          # System call code for read_int
syscall
sw $v0, 0($t1)     # "return result" is in $v0
```

You can see that there is an agreement to use the register **$v0** to store the system call code for the system call (a special kind of function call). Additionally, the return result (an integer read from user) is placed in register **$v0** when the system call is completed.

> **Key idea: we can pass information to the function by placing values in registers and retrieve the return result in the same way.**

Let us first attempt to pass information to a function. Download and load the **arrayFunction.asm** in QtSpim. The main function code is given below:

```
        .data
array:  .word 8, 2, 1, 6, 9, 7, 3, 5, 0, 4
newl:   .asciiz "\n"

        .text
main:
    # Print the original content of array
    # setup the parameter(s)
    # call the printArray function

    # Ask the user for two indices
    li   $v0, 5              # System call code for read_int
    syscall
    addi $t0, $v0, 0         # first user input in $t0

    li   $v0, 5              # System call code for read_int
    syscall
    addi $t1, $v0, 0         # second user input in $t1

    # Call the findMin function
    # setup the parameter(s)
    # call the function

    # Print the min item
    <code not shown>

    # Calculate and print the index of min item
    <code not shown>

    # End of main, make a syscall to "exit"
    li   $v0, 10            # system call code for exit
    syscall                # terminate program
```

The basic flow of the program is as follows:

1. Print the original content of array.
2. Ask the user for two indices **X** and **Y**, where X ≤ Y.
3. Find the minimum item between A[X] and A[Y] (inclusive).
4. Print the minimum item and the index of the minimum item.

[handwritten: $v0 → addr ; $v0 − $a0 over 4]

You'll need to code for parts 1, 3 and 4. Again, don't panic as most of the code are already written! For part 1, the following function is already given in the program:

```
###    Function printArray    ###
# Input: Array Address in $a0, Number of elements in $a1
# Output: None
# Purpose: Print array elements
# Registers used: $t0, $t1, $t2
# Assumption: Array element is word size (4-byte)
printArray:
        addi $t1, $a0, 0       # $t1 is the pointer to the item
        sll  $t2, $a1, 2       # $t2 is the offset beyond the last item
        add  $t2, $a0, $t2     # $t2 is pointing beyond the last item
loop:
        beq  $t1, $t2, end
        lw   $t3, 0($t1)       # $t3 is the current item
        li   $v0, 1            # system call code for print_int
        addi $a0, $t3, 0       # integer to print
        syscall               # print it
        addi $t1, $t1, 4
        j loop                 # Another iteration
end:
        li   $v0, 4            # system call code for print_string
        la   $a0, newl         #
        syscall               # print newline
        jr $ra                 # return from this function
```
[handwritten annotations: "×4" next to sll line; "→ reach last elem" next to beq line; "0 11 / 100 / 4"]

The comments at the beginning of the function give you a good idea of how to make use of this function. Pay special attention to the "input" information, which tells you where to place the expected parameters. **Without** changing this function, complete the first part of the main program. You only need to place the correct information in the registers **$a0** and **$a1** then make a function call. Test your program, and you should see the original content of array printed on screen. (Hint: Don't forget the use of "**li**" and "**la**" instructions).

Now, let's tackle something slightly more challenging. Let us now write a function to find the minimum element. The function header is given in the program as follows:

```
##################################################################
##
###    Function findMin
###
# Input: Lower Array Pointer in $a0, Higher Array Pointer in $a1
# Output: $v0 contains the address of minimum item
# Purpose: Find and return the minimum item
#              between $a0 and $a1 (inclusive)
# Registers used: <Fill in with your register usage>
# Assumption: Array element is word size (4-byte), $a0 <= $a1
findMin:
        # Your implementation here
        jr $ra                      # return from this function
```

Note that the function expects **two addresses,** i.e. the addresses of A[X] and A[Y] in registers `$a0` and `$a1` respectively. Once the minimum item is found, the address of the minimum item is returned to the caller. You are supposed to use the **array pointer** approach (Lecture #8, Slide 34 & Tutorial #3, Q1b) to implement the *findMin* function.

Once you have written the findMin function, you are left with the last piece of puzzle to solve. How do you find out the **index** of an item from the **address** of the item? (Hint: think about how we calculate the address of an item given the index of the item.)

Complete the main function by calling the *findMin* function. Then print both the minimum item and the index of the minimum item.

Below are two separate test runs (user input circled):

(handwritten) 3×4 + ($a0) = $address

Console — □ ✕

8216973504
0
4
1
2
|

Minimum item between A[0] to A[4], i.e. {8, 2, 1, 6, 9}
⇨ **Minimum item is "1"**
⇨ **Minimum item is at index 2**

Console — □ ✕

8216973504
7
9
0
8
|

Minimum item between A[7] to A[9], i.e. {5, 0, 4}
⇨ **Minimum item is "0"**
⇨ **Minimum item is at index 8**

Your lab TA will test your program with some test cases.

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Marking Scheme: Report (5 marks), Demonstration (15 marks); Total: 20 marks.