

## CS2100 Computer Organization

### Tutorial 2

#### Discussion Questions

Discuss these on the Forum. Answers will not be given.

#### D1. Exploration: C to MIPS

Go to this website <https://godbolt.org/> and copy the C code below into the left box, and ensure that you choose “C” in the dropdown list in green in the screenshot after the C code, and choose MIPS gcc 5.4 (el) or MIPS gcc 5.4 in the dropdown list circled red. (do not choose MIPS64 gcc 5.4 or MIPS64 gcc 5.4 (el):

```
int main(void) {  
    int a, b, c;  
  
    a = 3;  
    b = 5;  
    c = a + b;  
    return 0;  
}
```

The screenshot shows the Godbolt Compiler Explorer interface. On the left, the C source code is entered in a text area. The code is: 

```
int main(void) {  
    int a, b, c;  
  
    a = 3;  
    b = 5;  
    c = a + b;  
    return 0;  
}
```

 The language dropdown menu is set to 'C', which is highlighted with a green circle. The compiler dropdown menu is set to 'MIPS gcc 5.4 (el)', which is highlighted with a red circle. The right pane displays the generated MIPS assembly code, which includes instructions like `addiu $sp,$sp,-32`, `sw $fp,28($sp)`, `move $fp,$sp`, `li $2,3`, `sw $2,8($fp)`, `li $2,5`, `sw $2,12($fp)`, `lw $3,8($fp)`, `lw $2,12($fp)`, `nop`, `addu $2,$3,$2`, `sw $2,16($fp)`, `move $2,$0`, `move $sp,$fp`, `lw $fp,28($sp)`, `addiu $sp,$sp,32`, `j $31`, and `nop`. The bottom status bar indicates 'Output (0/0) MIPS gcc 5.4 (el) - cached (33368)'.

The following is extracted from the Assembly output.

```
addiu    $sp,$sp,-32
sw        $fp,28($sp)
move     $fp,$sp
li        $2,3                # 0x3
sw        $2,8($fp)
movz     $31,$31,$0
li        $2,5                # 0x5
sw        $2,12($fp)
lw        $3,8($fp)
lw        $2,12($fp)
nop
addu     $2,$3,$2
sw        $2,16($fp)
move     $2,$0
move     $sp,$fp
lw        $fp,28($sp)
addiu    $sp,$sp,32
j        $31
nop
```

We covered **sw**, **lw** and **j** in lecture, but not the rest. Find out what they are. (Note: **li** will be used in the labs later and **nop** will be mentioned in the topic on Pipelining. **move**, like **li**, is a pseudo-instruction. **\$sp**, **\$fp**, **movz**, **addiu**, and **addu** are not in the syllabus.)

D2. For each of the following instructions, indicate if it is valid or not. If not, explain why and suggest a correction. Note that the **|** in (d) is the bitwise OR operation.

- a. **add** \$t1, \$t2, \$t3                      # \$t3 = \$t1 + \$t2
  - b. **addi** \$t1, \$0, 0x25                    # \$t1 = 0x25
  - c. **subi** \$t2, \$t1, 3                      # \$t2 = \$t1 - 3
  - d. **ori** \$t3, \$t4, 0xAC120000            # \$t3 = \$t4 | 0xAC120000
  - e. **sll** \$t5, \$t2, 0x21                    # shift left \$t2 33 bits and store in \$t5
-

## 1. Bitwise operations

Find out about the following bitwise operations in C and explain and illustrate each of them with an example.

- `|` (bitwise OR)
  - `&` (bitwise AND)
  - `^` (bitwise XOR)
  - `~` (one's complement)
  - `<<` (left shift)
  - `>>` (right shift)
- `unsigned int a = 60; /* 60 = 0011 1100 */`  
`unsigned int b = 13; /* 13 = 0000 1101 */`  
  
`a=5 == 00000101`  
`b=22 == 00010110`

You may use the following code template for your illustration. Variables of the data type `char` take up 8 bits of memory.

```
#include <stdio.h>

typedef unsigned char byte_t;

void printByte(byte_t);

int main(void) {
    byte_t a, b;

    a = 5;
    b = 22;
    printf("a      = "); printByte(a);      printf("\n");
    printf("b      = "); printByte(b);      printf("\n");
    printf("a|b    = "); printByte(a|b);    printf("\n");
    return 0;
}

void printByte(byte_t x) {
    printf("%c%c%c%c%c%c%c%c",
        (x & 0x80 ? '1' : '0'),
        (x & 0x40 ? '1' : '0'),
        (x & 0x20 ? '1' : '0'),
        (x & 0x10 ? '1' : '0'),
        (x & 0x08 ? '1' : '0'),
        (x & 0x04 ? '1' : '0'),
        (x & 0x02 ? '1' : '0'),
        (x & 0x01 ? '1' : '0'));
}
```

## 2. Swapping

We have discussed in lecture how to swap two variables in a function:

```
void swap(int *a, int *b) {  
    int t = *a;  
    *a = *b;  
    *b = t;  
}
```

In the above code, a temporary variable `t` is used.

A possible alternative is to use some bitwise operator to perform the swap, without using any temporary variable. Write a function to do this.

## 3. MIPS Bitwise Operations

Implement the following in MIPS assembly. Assume that variables `a`, `b` and `c` are mapped to registers `$s0`, `$s1` and `$s2` respectively. Each part is independent of all the other parts. **For bitwise instructions (e.g. `and`, `or`, `andi`, etc), any immediate values you use can only be shown in binary.** This is optional for non-bitwise instructions (e.g. `addi`, etc).

Note that bit 31 is the most significant bit (MSB) on the left, and bit 0 is the least significant bit (LSB) on the right, i.e.:

MSB					LSB
Bit 31	Bit 30	Bit 29	...	Bit 1	Bit 0

- Set bits 2, 8, 9, 14 and 16 of `b` to 1. Leave all other bits unchanged.
- Copy over bits 1, 3 and 7 of `b` into `a`, without changing any other bits of `a`.
- Make bits 2, 4 and 8 of `c` the inverse of bits 1, 3 and 7 of `b` (i.e. if bit 1 of `b` is 0, then bit 2 of `c` should be 1; if bit 1 of `b` is 1, then bit 2 of `c` should be 0), without changing any other bits of `c`.

#### 4. MIPS Arithmetic

Write the following in MIPS Assembly, using as few instructions as possible. You may rewrite expressions to minimize the number of instructions used. In all parts you can assume that variables **a**, **b**, **c** and **d** are mapped to registers \$s0, \$s1, \$s2 and \$s3 respectively. Each part is independent of the others.

a.  $c = a + b$

b.  $d = a + b - c$

c.  $c = 2b + (a - 2)$

d.  $d = 6a + 3(b - 2c)$

#### 5. [AY2013/14 Semester 2 Exam]

The mysterious MIPS code below assumes that **\$s0 is a 31-bit binary sequence**, i.e. the MSB (most significant bit) of **\$s0** is assumed to be zero at the start of the code.

```
add $t0, $s0, $zero # make a copy of $s0 in $t0
lui $t1, 0x8000
lp: beq $t0, $zero, e
    andi $t2, $t0, 1
    beq $t2, $zero, s
    xor $s0, $s0, $t1
s:  srl $t0, $t0, 1
    j lp
e:
```

a) For each of the following initial values in register **\$s0** at the beginning of the code, give the hexadecimal value of the content in register **\$s0** at the end of the code.

- Decimal value **31**.
- Hexadecimal value **0x0AAAAAAA**.

b) Explain the purpose of the code in one sentence.