Week 1: Computer performance and MIPS Instruction Set Architecture

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2. Quiz

2.1.

a. What is CPU execution time? Distinguish system performance and CPU performance.

b. What is CPU time equation? (Write the equation in all forms from general to detailed)

c. What hardware/software components affect a program's performance (affect the factors in the CPU performance equation)?

Answer:

a. Is the total time a CPU spends computing on a given task and does not include time spent waiting for I/O or running other programs.

b. CPU execution time for a program = CPU clock cycles x Clock cycle time

$$= \frac{CPU\ clock\ cycles}{Clock\ rate}$$

= Instruction count x CPI x Clock cycle time

$$= \frac{\text{Instruction count x CPI}}{Clock\ rate}$$

c. There are many things that affect a program's performance.
Ex: **compiler**, **programming language**, and **algorithm** affect instruction count, **CPI**, **Instruction set architecture**, **clock rate**…

2.2. Consider three different processors P1, P2 and P3 executing the same instruction net.

Processor	Clock rate	CPI
P1	3 GHz	1.5
P2	2.5 GHz	1
P3	4 GHz	2.2

a. Which processor has the highest performance expressed in instructions per second?

b. If the processors each execute a program in 10 seconds, find the number of cycles and the number of instructions.

c. We are trying to reduce the execution time by 30%, but this leads to an increase of 20% in the CPI. What clock rate should we have to get this time reduction?

Answer:

a. CPU time = $\frac{\text{Instruction count x CPI}}{Clock\ rate}$

Because P1, P2, P3 execute the same instruction net, so we compare their performance by CPI/Clock rate. So the P2 processor has the highest performance.

b. CPU time = 10s

Processor	Number of cycles	Number of instructions
P1	$3 * 10^{10}$	$2 * 10^{10}$
P2	$2.5 * 10^{10}$	$2.5 * 10^{10}$
P3	$4 * 10^{10}$	$1.81 * 10^{10}$

c. CPU time = $\frac{\text{Instruction count x CPI}}{Clock\ rate}$

$$\frac{70\%}{100\%} = \frac{\frac{120\%CPI}{x(CR)}}{\frac{CPI}{CR}} \Rightarrow x(CR) = \frac{120\ x\ 100}{70}\ CR$$

⇒ x = 171.42%

So we should increase of 71,42% of clock rate to get that time reduction.

2.3. Consider two different implementations of the same instruction set architecture. The instructions can be divided into four classes according to their CPI (classes A, B, C, and D).

Processor	Clock rate	CPI class A	CPI class B	CPI class C	CPI class D
P1	2.5 GHz	1	2	3	3
P2	3 GHz	2	2	2	2

a. Given a program with a dynamic instruction count of 10^6 instructions divided into classes as follows: 10% class A, 20% class B, 50% class C, and 20% class D, which processor is faster?
b. Find the average CPI for each implementation.
c. Find the total clock cycles required in both cases.

Answer:

a. CPI of P1 = 0.1 * 1 + 0.2 * 2 + 0.5 * 3 + 0.2 * 3 = 2.6
CPI of P2 = 0.1 * 2 + 0.2 * 2 + 0.5 * 2 + 0.2 * 2 = 2
The processor P2 is the faster.
b. CPU time of P1 = $(10^6 * 2.6) / (2.5 * 10^9) = 1.04 * 10^{-3}$ (s)
CPU time of P2 = $(10^6 * 2) / (3 * 10^9) = 0.66 * 10^{-3}$ (s)
c. CPU clock cycles for a program = Instruction count * CPI

Processor	Instruction count	Clock cycles
P1	$1 * 10^6$	$2.6 * 10^6$
P2	$1 * 10^6$	$2 * 10^6$

2.4. A given application written in Java runs 15 seconds on a desktop processor. A new Java compiler is released that requires only 0.6 as many instructions as the old compiler. Unfortunately, it increases the CPI by 1.1. How fast can we expect the application to run using this new compiler?
Answer: CPU time (new) = CPU time (given) * 1.1 * 0.6 = 15 * 1.1 * 0.6 = 9.9 (seconds)

2.5 Question 5

Two compiler complied a program into 2 different code sequences that require the instruction counts as shown in below table. Know that the CPI of instructions class A is 1, class B is 2, class C is 3.

Class	Instruction counts	
	Sequence 1	Sequence 2
A	2	4
B	1	1
C	2	1

a. Which code sequence executes the most instructions?

b. Which will be faster?

c. What is the CPI for each sequence?

Answer:

a. Sequence 2 executes 4 + 1 + 1 = 6 instruction

Sequence 1 executes:2 + 1 + 2 = 5 instruction

=> Sequence 2 executes the most instructions.

b. Sequence 1 will be faster.

c. + Sequence 1: CPI = 2

+ Sequence 2: CPI = 1.5

2.6 Question 6

a. What are 32-bit MIPS instruction formats? Explain fields of these formats.

b. Encode this MIPS instruction to machine binary, then rewrite it in hex representation:

sw $t1, 32($t2)

c. Which MIPS code represents the following machine binary code?
00000010001100100100000000100000

Answer:

a. Three instruction categories: I-format, J-format, and R-format.

Name	Layout					
Size	6 bits	5 bits	5 bits	5 bits	5 bits	6 bits

R-format	op	rs	rt	rd	shamt	funct
I-format	op	rs	rt	address/ immediate		
J-format	op	target address				

-op (opcode): basic operation of the instruction.
-rs: the first register source operand.
-rt: the second register source operand.
-rd: the register destination operand, which gets the result of the operation.
-shamt: shift amount to be used in shift instructions, zero otherwise.
-funct: called the function code.

b. Encode : **sw $t1, 32($t2)**
Binary: **101011 01010 01001 0000000000100000**
Hex: **0xAD49 0020**

c. MIPS code represents the following machine binary code:
add $t0, $s1, $s2

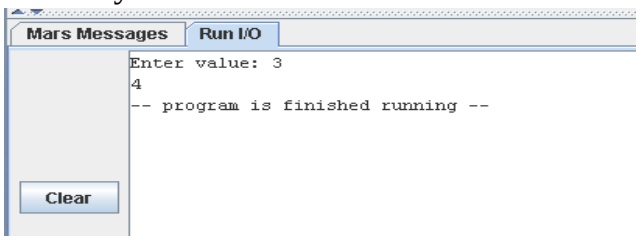
3. Exercise

3.1. Write a simple MIPS program that can execute these steps:

1. Print a sentence to terminal to request an integer number from user;
2. Collect the number and increase it by 1;
3. Print the result to terminal.

```
.data
mess : .asciiz "Enter value: "

.text
main:
   li $v0, 4
   la $a0, mess
   syscall

   li $v0, 5
   syscall

   move $t0, $v0
   add $t0, $t0, 1

   li $v0, 1
   move $a0, $t0
   syscall

   li $v0, 10
```

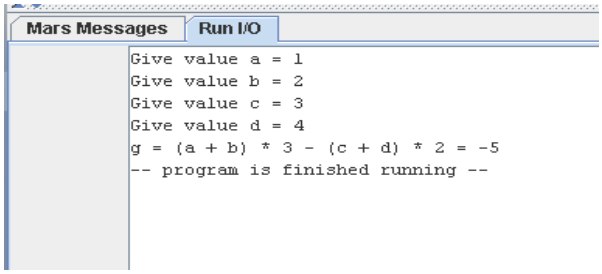
```
        syscall
```



3.2.

Write a small program that allows users to input values for variables a, b, c, and d. The program then calculates the following expressions and prints the results to terminal. $g = (a + b) \times 3 - (c + d) \times 2$

```
.data
        messa: .asciiz "Give value a = "
        messb: .asciiz "Give value b = "
        messc: .asciiz "Give value c = "
        messd: .asciiz "Give value d = "
        result:  .asciiz "g = (a + b) * 3 -
(c + d) * 2 = "
.text
main:
        #a
        li $v0, 4
        la $a0, messa
        syscall
        li $v0, 5
        syscall
        move $t0, $v0
        #b
        li $v0, 4
        la $a0, messb
        syscall
        li $v0, 5
        syscall
        move $t1, $v0
        #c
        li $v0, 4
        la $a0, messc
        syscall
        li $v0, 5
        syscall
        move $t2, $v0
        #d
        li $v0, 4
        la $a0, messd
        syscall
        li $v0, 5
        syscall
        move $t3, $v0
        #res = $t4
        add $t4, $t0, $t1 # (a+b) = $t4
        mul $t4, $t4, 3 # (a+b)*3

        add $t5, $t2, $t3 # (c+d) = $t5
        mul $t5, $t5, 2

        sub $t4, $t4, $t5 #res

        #print
        li $v0, 4
        la $a0, result
        syscall
        li $v0, 1
        move $a0, $t4
        syscall

        li $v0, 10
        syscall
```

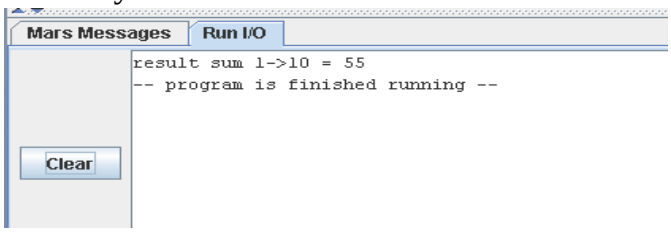


3.3 Write a MIPS program with the following requirements:

1. Declare an integer array with 10 synthetic data elements.
2. Calculate the sum of all array elements.
3. Print the result to the terminal.

```
.data
    mess: .asciiz  "result sum 1->10 = "
    array: .word 1,2,3,4,5,6,7,8,9,10
.text
main:
    li $v0, 0 #i = 0
    li $t4, 10
    la $s1, array
    li $t0, 0
FOR_LOOP:
    bge $s0, $t4, END_FOR
    lw $t1, ($s1)
    add $t0, $t0, $t1
    addi $s1, $s1, 4
    addi $s0, $s0, 1
    j FOR_LOOP
END_FOR:
        addi $s0, $s0, -1
        addi $s1, $s1, -4
PRINT:
        li $v0, 4
        la $a0, mess
        syscall
        li $v0, 1
        move $a0, $t0
        syscall
```

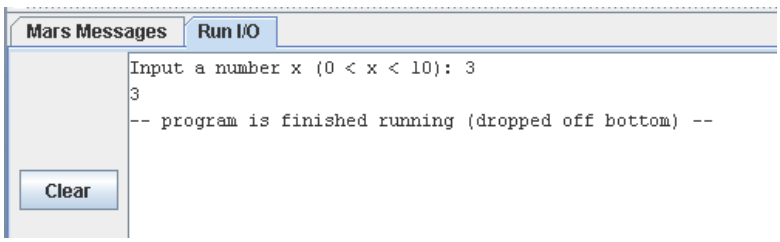
```
END: li $v0, 10
        syscall
```



3.4. Write a MIPS program with the following requirements:

1. Declare an integer array with 10 synthetic data elements.
2. Print a sentence to terminal to request an integer number that is greater than 0 and less than 10 (assume that user strictly follow this rule).
3. Print value of the element at index collected from the previous step.

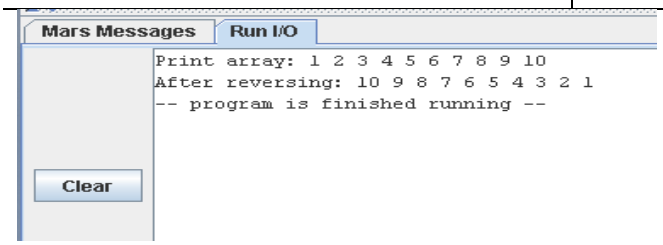
```
.data
        array: .word 0,1,2,3,4,5,6,7,8,9
        mess: .asciiz "Input a number x (0 < x < 10): "
.text
        li $v0,4
        la $a0,mess
        syscall

        li $v0,5
        syscall

        move $t0,$v0
        mul $t0,$t0, 4

        la $s0,array
        add $s0,$s0,$t0
        lw $a0,0($s0)
        li $v0,1
        syscall
```



3.5. Write a MIPS program that reverses an 10 elements integer array. For example, the array initially stores 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, the program will change the array to be 10, 9, 8, 7, 6, 5, 4, 3, 2, 1.

```
.data
        array: .word 1, 2, 3, 4, 5, 6, 7, 8,
9, 10
        print: .asciiz "Print array: "
        r_print: .asciiz "\nAfter
reversing: "
        space: .asciiz " "
.text
        la $a0, print
        li $v0, 4
        syscall

        la $a1, array
        jal printarr

        la $a0, r_print
        li $v0, 4
        syscall

        jal r_loop
        jal printarr

        li $v0, 10
        syscall

printarr:
        addi $t0, $0, 0
   ploop:
        beq $t0, 10, end
        sll $t1, $t0, 2
        add $t2, $t1, $a1
la $a0, space
        li $v0, 4
        syscall

        addi $t0, $t0, 1
        j ploop

end:    jr $ra

r_loop:
        addi $t0, $0, 0
   rloop:
        beq $t0, 5, r_end
        sll $t1, $t0, 2
        add $t2, $t1, $a1
        lw $t8, ($t2)

        addi $t3, $0, 36
        sub $t3, $t3, $t1
        add $t4, $t3, $a1
        lw $t9, ($t4)

        sw $t8, ($t4)
        sw $t9, ($t2)

        addi $t0, $t0, 1
        j rloop

r_end:  jr $ra
```

```
lw $t3, ($t2)
move $a0, $t3
li $v0, 1
syscall
```

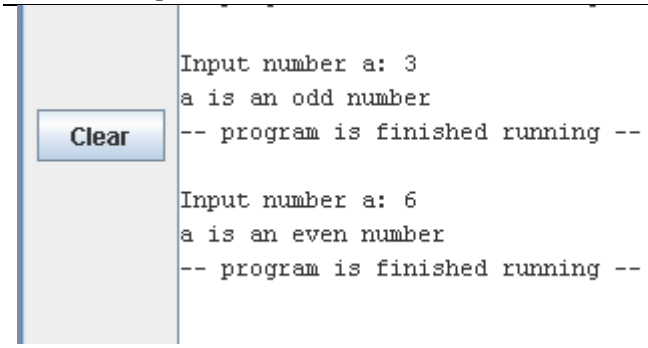


3.6.

Write a MIPS program that determine an input number is odd or even as the psedocode below.

```
if(a % 2 == 1) { Print string: "a is an odd number"}
else           { Print string: "a is an even number"}
```

```
.data
        mess: .asciiz "Input number a: "
        odd_mess: .asciiz "a is an odd number"
        even_mess: .asciiz "a is an even number"
.text
        li $v0, 4
        la $a0, mess
        syscall

        li $v0, 5
        syscall
        move $t0, $v0

        li $t1, 2
        div $t0, $t1
        mfhi $t1
        beq $t1, 0,even
odd:    li $v0,4
        la $a0, odd_mess
        syscall

        li $v0, 10
        syscall

even:   li $v0,4
        la $a0, even_mess
        syscall

        li $v0, 10
        syscall
```

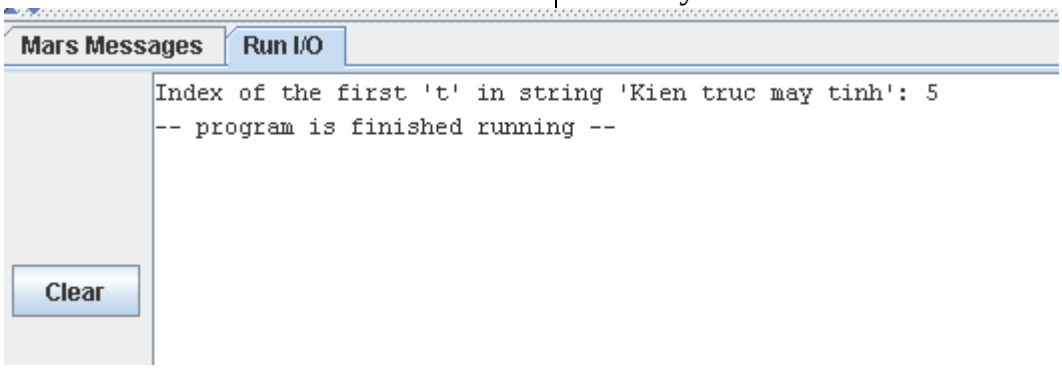


3.7.

Write a MIPS program that reflects the pseudocode below to determine the index of the first 't' in string "Kien truc may tinh".

```
i = 0;
while(charArray[i] != 't' && charArray[i] != '\0'){
  i++;
}
```

```
.data
char:   .byte   't'
str_s:  .asciiz "Kien truc may tinh"
int_t:  .word  0

res_mess: .asciiz  "Index of the first 't' in string 'Kien truc may tinh': "

.text
.globl  main
main:
        lb      $t1,char
        la      $t2,str_s
        lb      $t3,0($t2)
        addi    $t0,$zero,0 #index = 0
while:
        beq     $t3,$t1, end_while
        addi    $t0,$t0,1
        la      $t2,1($t2)
        lb      $t3,0($t2)
        j       while
end_while:
        sw      $t0,int_t

print:  la      $a0,res_mess
        addi    $v0,$zero,4
        syscall
        lw      $a0,int_t
        addi    $v0,$zero,1
        syscall

end:
        addiu   $v0,$zero,10
        syscall
```



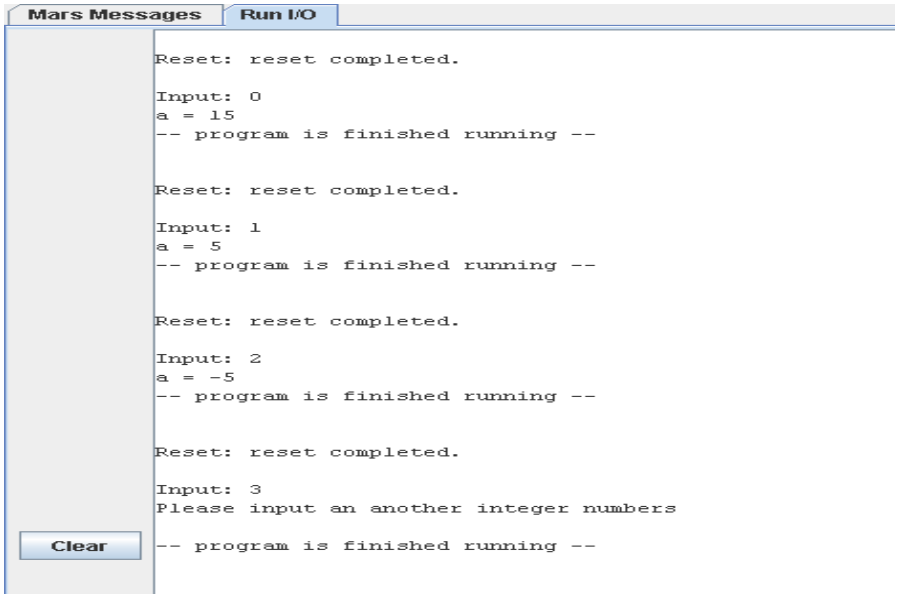
3.8.

Implement the following C code by using MIPS code. Assume that b and c are 10 and 5, respectively while input variable is read from keyboard. Print value of a to the terminal.

```
switch (input) {
  case 0: a = b + c; break;
  case 1: a = b - c; break;
  case 2: a = c - b; break;
  default: printf{"Please input an another integer numbers\n"};
  break;
}
```

```
.data
int_a:  .word  0
input:  .word  13

mess1:          .asciiz "Input: "
mess2:          .asciiz "Please input an
another integer numbers \n"
res_mess: .asciiz "a = "

.text
.globl  main

main:
        la      $a0,mess1
        addi    $v0,$zero,4
        syscall

        addi    $v0,$zero,5
        syscall
        sw      $v0,input

        lw      $t0,int_a
        lw      $t1,input
        addi    $t2,$zero,0
        addi    $t3,$zero,0
        add     $t2,$t2,10
        add     $t3,$t3, 5
```

```
#xet case
case:
        beq $t1, 0, case1
        beq $t1, 1, case2
        beq $t1, 2, case3
        j default
case1: add      $t0,$t2,$t3
        j       endswitch
case2: sub      $t0,$t2,$t3
        j       endswitch
case3: sub      $t0,$t3,$t2
        j       endswitch
default:
        la $a0, mess2
        addi    $v0,$zero,4
        syscall
        j end
endswitch:      sw      $t0,int_a

print:  la      $a0,res_mess
        addi    $v0,$zero,4
        syscall
        lw      $a0,int_a
        addi    $v0,$zero,1
        syscall
end:
        addiu   $v0,$zero,10
        syscall
```


Mars Messages
Run I/O
Reset: reset completed.
Input: 0
a = 15
-- program is finished running --
Reset: reset completed.
Input: 1
a = 5
-- program is finished running --
Reset: reset completed.
Input: 2
a = -5
-- program is finished running --
Reset: reset completed.
Input: 3
Please input an another integer numbers
Clear
-- program is finished running --