Computer Architectures 02LSEOV	Delivery date: **October, 9th 2024**
Laboratory 1	Expected delivery of lab_01.zip including: • lab_01.pdf (fill and export this file to pdf)

This first lab is very introductory. Through it, you are expected to learn how to use WinMIPS and do the assigned task.

- The first thing to do is open the winmipstut.docx file and follow the WinMIPS documentation. Through it, you are expected to learn the basics of using WinMIPS so that you are ready to take on the next assignment.
- Consider a MIPS architecture with the following characteristics:
  - Integer ALU: 1 clock cycle
  - Data memory: 1 clock cycle
  - FP arithmetic unit: pipelined, 2 clock cycles
  - FP multiplier unit: pipelined, 8 clock cycles
  - FP divider unit: not pipelined, 10 clock cycles

  Given the following piece of code, run it on WinMIPS and see what it does. For each instruction, add a comment to describe what the instruction does using the same style of commenting as the example. Next, write down the number of clock cycles required to execute the first iteration of the following code. Since this is a pipelined processor, the number of clock cycles must be calculated as the number of clock cycles required in addition to the previous instruction.

```
; ********************** MIPS64 ************************
```

.data	comments	Clock cycles
v1: .byte 1, 2, 3, 4, 5		
v2: .byte 1, 2, 3, 4, 5		
v3: .space 5		
v4: .space 5		
.text		
daddui r5,r0,0	r5 ← pointer (i)	5
daddui r6,r0,5	r6 ← 5	1
cycle: lb r1,v1(r5)	r1 ← v1[i]	1
lb r2,v2(r5)	r2 ← v2[i]	1
daddu r3,r1,r2	r3 ← r1 + r2	2
dsub r4,r1,r2	r4 ← r1 - r2	1
sb r3,v3(r5)	v3[i] ← r3	1
sb r4,v4(r5)	v4[i] ← r4	1
daddui r5,r5,1	r5 ← r5 + 1	1
daddi r6,r6,-1	r6 ← r6 - 1	1
bnez r6,cycle	if (r6 != 0) jump to cycle	2

halt	exit	1
	Total:	66

Now, translate the above code in your preferred high-level language (i.e. C, Java, Python, C++, Javascript).

```
; ********************** C ***************************
#include <stdint.h>
int8_t *v1 = {1, 2, 3, 4, 5};
int8_t *v2 = {1, 2, 3, 4, 5};
int8_t v3[5], v4[5];

int r5 = 0;  // i = 0
int r6 = 5;

while (r2 != 0) {
   int8_t r1 = v1[r5];
   int8_t r2 = v2[r5];

   int8_t r3 = r1 + r2;
   int8_t r4 = r1 - r2;

   v3[r5] = r3;
   v4[r5] = r4;

   r5 += 1;
   r6 -= 1;
}
```

- Now, repeat the same operation done previously with this piece of code:

```
; ********************** MIPS64 ***********************
```

.data	comments	Clock cycles
v1: .double 1, 2, 3, 4, 5		
v2: .double 5, 4, 3, 2, 1		
v3: .double 6, 7, 8, 9, 10		
v4: .double 10, 9, 8, 7, 6		
v5: .space 40		
v6: .space 40		
.text		
daddui r1,r0,0	r1 ← pointer (i)	5
daddui r2,r0,5	r2 ← 5	1
cycle: l.d f1, v1(r1)	f1 ← v1[i]	1
l.d f2, v2(r1)	f2 ← v2[i]	1

	l.d f3, v3(r1)	f3 ← v3[i]	1
	l.d f4, v4(r1)	f4 ← v4[i]	1
	mul.d f5, f1, f2	f5 ← f1 + f2	8
	mul.d f6, f3, f4	f6 ← f3 + f4	1
	s.d f5, v5(r1)	v5[i] ← f5	1
	s.d f6, v6(r1)	v6[i] ← f6	1
	daddui r1,r1,8	r1 ← r1 + 8	1
	daddi r2,r2,-1	r2 ← r2 - 1	1
	bnez r2,cycle	if (r2 != 0) jump to cycle	2
halt		exit	1
	Total:		106

Now, translate the above code in your preferred high-level language (i.e. C, Java, Python, C++, Javascript).

```
; ********************** C **************************
double* v1 = {1.0, 2.0, 3.0, 4.0, 5.0};
double* v2 = {5.0, 4.0, 3.0, 2.0, 1.0};
double* v3 = {6.0, 7.0, 8.0, 9.0, 10.0};
double* v4 = {10.0, 9.0, 8.0, 7.0, 6.0};
double v5[5], v6[5];

int r1 = 0;  // i = 0
int r2 = 5;

while (r2 != 0) {
   double f1 = v1[r1];
   double f2 = v2[r1];
   double f3 = v3[r1];
   double f4 = v4[r1];

   double f5 = f1 * f2;
   double f6 = f3 * f4;

   // Store results
   v5[r1] = f5;
   v6[r1] = f6;

   // Increment the index and loop counter
   r1 += 8;
   r2 -= 1;
}
```

Relative to the above code, how much would the performance of the software increase if you could improve the functional unit related to the floating point multiplication of 4 clock cycles?

Decreasing by 4 the number of clock cycles for the floating point multiplication would mean reducing the additional clock cycles required for the instruction *mul.d f5, f1, f2* from 8 to 4.
As a consequence, since the total cycles executed by the program are 5 and we are reducing the clock cycles of each of them of 4, we get a total reduction of clock cycles of the program of 20, going from 106 to 86.
Since the total number of instructions is 58, the CPI goes from 1.828 to 1.483.
The fraction enhanced is p = (8+1)*5/106 = 0.425
The speedup enhanced is s = (8+1)*5 / ((4+1)*5) = 1.8
So the speedup overall is 1/((1-p) + p/s) = 1.233

Appendix: *winMIPS64 Instruction Set*

WinMIPS64
The following assembler directives are supported
.data - start of data segment
.text - start of code segment
.code - start of code segment (same as .text)
.org <n> - start address
.space <n> - leave n empty bytes
.asciiz <s> - enters zero terminated ascii string
.ascii <s> - enter ascii string
.align <n> - align to n-byte boundary
.word <n1>,<n2>.. - enters word(s) of data (64-bits)
.byte <n1>,<n2>.. - enter bytes
.word32 <n1>,<n2>.. - enters 32 bit number(s)
.word16 <n1>,<n2>.. - enters 16 bit number(s)
.double <n1>,<n2>.. - enters floating-point number(s)

where <n> denotes a number like 24, <s> denotes a string like "fred", and
<n1>,<n2>.. denotes numbers seperated by commas.

The following instructions are supported
lb - load byte
lbu - load byte unsigned
sb - store byte
lh - load 16-bit half-word
lhu - load 16-bit half word unsigned
sh - store 16-bit half-word
lw - load 32-bit word
lwu - load 32-bit word unsigned
sw - store 32-bit word
ld - load 64-bit double-word
sd - store 64-bit double-word
l.d - load 64-bit floating-point
s.d - store 64-bit floating-point
halt - stops the program

daddi - add immediate
daddui - add immediate unsigned
andi - logical and immediate
ori - logical or immediate
xori - exclusive or immediate
lui - load upper half of register immediate
slti - set if less than or equal immediate
sltiu - set if less than or equal immediate unsigned

beq - branch if pair of registers are equal
bne - branch if pair of registers are not equal
beqz - branch if register is equal to zero
bnez - branch if register is not equal to zero

j - jump to address
jr - jump to address in register
jal - jump and link to address (call subroutine)
jalr - jump and link to address in register (call subroutine)

dsll - shift left logical
dsrl - shift right logical
dsra - shift right arithmetic
dsllv - shift left logical by variable amount
dsrlv - shift right logical by variable amount
dsrav - shift right arithmetic by variable amount
movz - move if register equals zero
movn - move if register not equal to zero
nop - no operation
and - logical and
or - logical or
xor - logical xor
slt - set if less than
sltu - set if less than unsigned
dadd - add integers
daddu - add integers unsigned
dsub - subtract integers
dsubu - subtract integers unsigned

add.d - add floating-point
sub.d - subtract floating-point
mul.d - multiply floating-point
div.d - divide floating-point
mov.d - move floating-point
cvt.d.l - convert 64-bit integer to a double FP format
cvt.l.d - convert double FP to a 64-bit integer format
c.lt.d - set FP flag if less than
c.le.d - set FP flag if less than or equal to
c.eq.d - set FP flag if equal to
bc1f - branch to address if FP flag is FALSE
bc1t - branch to address if FP flag is TRUE
mtc1 - move data from integer register to FP register
mfc1 - move data from FP register to integer register