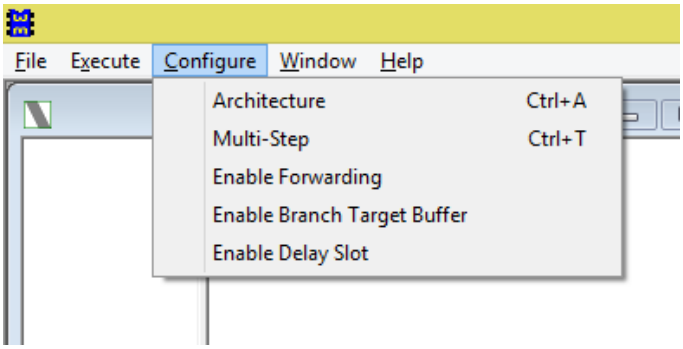
| **Architetture dei Sistemi di Elaborazione** | Delivery date:<br>Friday 15 October 2021 |
|---|---|
| **Laboratory 1** | Expected delivery of lab_01.zip including:<br>- Program_0.s<br>- Program_1.s<br>- lab_01.pdf (fill and export this file to pdf) |

Please, configure the winMIPS64 processor architecture with the *Base Configuration* provided in the following:

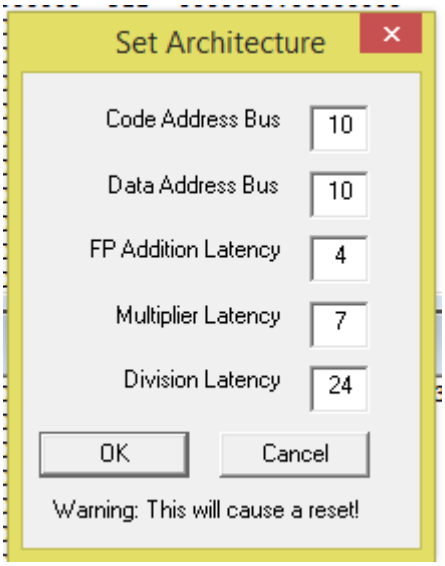
- *Integer ALU: 1 clock cycle*
- *Data memory: 1 clock cycle*
- *Branch delay slot: 1 clock cycle*
- Code address bus: 12
- Data address bus: 12
- Pipelined FP arithmetic unit (latency): 6 stages
- Pipelined FP multiplier unit (latency): 8 stages
- FP divider unit (latency): not pipelined unit, 28 clock cycles
- Forwarding optimization is disabled
- Branch prediction is disabled
- Branch delay slot optimization is disabled.

Use the Configure menu:

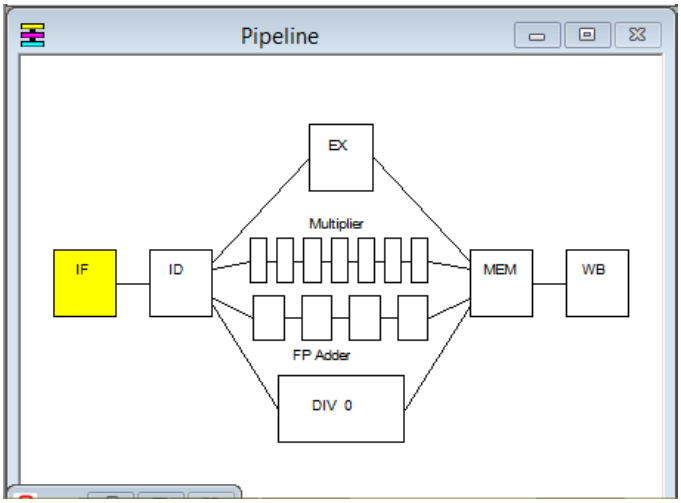
- remove the flags (where activating Enable options)
- Browse the Architecture menu →




Modify the defaults Architectural parameters (where needed)




← Verify in the Pipeline window that the configuration is effective




1) Exercise your assembly skills.
To write an assembly program called **program_0.s (to be delivered)** for the *MIPS64* architecture and to execute it.

The program must:

1. Given one array (`a`), find how many times the 8-bit unsigned value `val=0x2f` is included in it. The array contains 100 unsigned 16-bit integer numbers. Looks for the occurrence in both the most significant **byte** and the least significant **byte** of the 16-bit integer numbers. Store the result in a 8-bit variable (`res`).

   Example (with only 10 elements):
   ```
   a = 5, 0x01a1,0x2f, 17, 0x2fe0, 1, 0x96a4, 0x2f, 3, 0x2f
   res = 4
   ```

2) Exercise your assembly skills and use the main components of the simulator:
To write an assembly program called **program_1.s (to be delivered)** for the *MIPS64* architecture and to execute it.

The program must:

1. Given 2 arrays (`a` and `b`), compute their signed sum and store each result in a third array (i.e., `c[i] = a[i] + b[i]`). Each array contains 30 8-bit integer numbers.
2. Create two variables allocated in memory: `threshold_high` and `threshold_low`. For each element `c[i]`, check whether it is greater or lesser than a fixed threshold: if it is greater, increase `threshold_high`, else increase `threshold_low`. Assume the threshold is equal to 0x0. Note that 0x00 belongs to `threshold_high`.
3. Search for **both** the maximum and minimum in the array `c`. The program saves the obtained value in two variables allocated in memory, called `max` and `min` respectively.

Identify and use the main components of the simulator:

a. Running the *WinMIPS* simulator
   - Launch the graphic interface

...\winMIPS64\winmips64.exe

b. Assembly and check your program:
   - Load the program from the **`File→Open`** menu (*CTRL-O*). In the case the of errors, you may use the following command in the command line to compile the program and check the errors:

```
...\winMIPS64\asm program_1.s
```

c. Run your program step by step (*F7*), identifying the whole processor behavior in the six simulator windows:
**Pipeline**, **Code**, **Data**, **Register**, **Cycles** and **Statistics**

d. Repeat the process (a-b-c) for `program_0.S`

Table 1: **Programs performance for the processor's base configurations**

| | Number of clock cycles |
|---|---|
| program_0.S | 1610 |
| program_1.S | 616 |

3) Perform execution time measurements.
Search in the winMIPS64 folder the following benchmark programs:
   a. `isort.s`
   b. `mult.s`
   c. `program_0.s` (your program)
   d. `program_1.s` (your program)

Starting from the basic configuration with no optimizations, compute by simulation the number of cycles required to execute these programs (and then the weighted arithmetic mean). Assume a processor frequency of 5MHz. Then, vary the program weights as specified by the following Configurations. Compute the weighted arithmetic mean for every case and fill the table below **(fill all required data in the table before exporting this file to pdf format to be delivered)**:

1) Configuration 1
   Assume that the weight of all programs is the same (25%).
2) Configuration 2
   Assume that the weight of the program `program_0.s` is 55%.
3) Configuration 3
   Assume that the weight of the program `isort.s` is 40%.

Table 2: **Processor performance for different weighted programs**

| Program | Conf. 1 | Conf. 2 | Conf. 3 |
|---|---|---|---|
| `isort.s (46041)` | `2302us` | `1381.23us` | `3683.28us` |
| `mult.s (1880)` | `94us` | `56.4us` | `75.2us` |
| `program_0.s (1610)` | `81us` | `177.2us` | `64.4us` |
| `program_1.s (616)` | `30.8us` | `18.48us` | `24.64us` |
| TOTAL TIME | `2507.8us` | `1633.21us` | `3847.52u1s` |

For time computations, use a clock frequency of 5MHz(clock=2*10^-7s=0.2us).

## 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