Computer Architectures **02LSEOV 02LSEOQ [AA-LZ]**	Delivery date: Thursday 15/11
Laboratory **4**	Expected delivery of lab_04.zip must include: - this document compiled possibly in pdf format.

1) Introducing gem5
gem5 is freely available at: `http://gem5.org/`
the laboratory version uses the ALPHA CPU model previously compiled and placed at:

```
/opt/gem5/
```

the ALPHA compilation chain is available at:

```
/opt/alphaev67-unknown-linux-gnu/bin/
```

   a. Write a hello world C program (`hello.c`). Then compile the program, using the ALPHA compiler, by running this command:

```
~/my_gem5Dir$  /opt/alphaev67-unknown-linux-gnu/bin/alphaev67-unknown-linux-gnu-gcc -static -o hello hello.c
```

   b. Simulate the program

```
~/my_gem5Dir$ /opt/gem5/build/ALPHA/gem5.opt /opt/gem5/configs/example/se.py -c hello
```

In this simulation, gem5 uses *AtomicSimpleCPU* by default.

   c. Check the results
   your simulation output should be similar than the one provided in the following:

```
~/my_gem5Dir$ /opt/gem5/build/ALPHA/gem5.opt /opt/gem5/configs/example/se.py -c hello
gem5 Simulator System.  http://gem5.org
gem5 is copyrighted software; use the --copyright option for details.

gem5 compiled Sep 20 2017 12:34:54
gem5 started Jan 19 2018 10:57:58
gem5 executing on this_pc, pid 5477
command line: /opt/gem5/build/ALPHA/gem5.opt /opt/gem5/configs/example/se.py -c hello

Global frequency set at 1000000000000 ticks per second
warn: DRAM device capacity (8192 Mbytes) does not match the address range assigned
(512 Mbytes)
0: system.remote_gdb.listener: listening for remote gdb #0 on port 7000
warn: ClockedObject: More than one power state change request encountered within the
same simulation tick
**** REAL SIMULATION ****
info: Entering event queue @ 0.  Starting simulation...
info: Increasing stack size by one page.
hola mundo!
Exiting @ tick 2623000 because target called exit()
```

- Check the output folder
  in your working directory, gem5 creates an output folder (`m5out`), and saves there 3 files: `config.ini`, `config.json`, and `stats.txt`. In the following, some extracts of the produced files are reported.

- Statistics (`stats.txt`)

```
---------- Begin Simulation Statistics ----------
sim_seconds                  0.000003      # Number of seconds simulated
sim_ticks                     2623000      # Number of ticks simulated
final_tick                    2623000      # Number of ticks from beginning of simulation
```

```
sim_freq                 1000000000000     # Frequency of simulated ticks
host_inst_rate                 1128003     # Simulator instruction rate (inst/s)
host_op_rate                   1124782     # Simulator op (including micro ops) rate(op/s)
host_tick_rate               564081291     # Simulator tick rate (ticks/s)
host_mem_usage                  640392     # Number of bytes of host memory used
host_seconds                      0.00     # Real time elapsed on the host
sim_insts                         5217     # Number of instructions simulated
sim_ops                           5217     # Number of ops (including micro ops) simulated
... ... ...
system.cpu_clk_domain.clock 500     # Clock period in ticks
... ... ...
```

- Configuration file (`config.ini`)

```
... ... ...
[system.cpu]
type=AtomicSimpleCPU
children=dtb interrupts isa itb tracer workload
branchPred=Null
checker=Null
clk_domain=system.cpu_clk_domain
cpu_id=0
default_p_state=UNDEFINED
do_checkpoint_insts=true
do_quiesce=true
do_statistics_insts=true
dtb=system.cpu.dtb
eventq_index=0
fastmem=false
function_trace=false
```

2) Simulate the same program using different CPU models

Help command:

```
~/my_gem5Dir$ /opt/gem5/build/ALPHA/gem5.opt /opt/gem5/configs/example/se.py -h
```

List the CPU available models:

```
~/my_gem5Dir$ /opt/gem5/build/ALPHA/gem5.opt /opt/gem5/configs/example/se.py --list-cpu-types
```

a. *TimingSimpleCPU* simple CPU that includes an initial memory model interaction

```
~/my_gem5Dir$ /opt/gem5/build/ALPHA/gem5.opt /opt/gem5/configs/example/se.py --cpu-type=TimingSimpleCPU -c hello
```

b. *MinorCPU* the CPU is based on an in order pipeline including caches

```
~/my_gem5Dir$ /opt/gem5/build/ALPHA/gem5.opt /opt/gem5/configs/example/se.py --cpu-type=MinorCPU --caches -c hello
```

c. *DerivO3CPU* is a superscalar processor

```
~/my_gem5Dir$ /opt/gem5/build/ALPHA/gem5.opt /opt/gem5/configs/example/se.py --cpu-type=DerivO3CPU --caches -c hello
```

Create a table gathering for every simulated CPU the following information:

- Ticks
- Number of instructions simulated
- Number of CPU Clock Cycles
  - Number of CPU clock cycles = Number of ticks / CPU Clock period in ticks (usually 500)
- Clock Cycles per Instruction (CPI)

- CPI = CPU Clock Cycles / instructions simulated
- Number of instructions committed
- Host time in seconds.

Table 1: Hello program behavior on different CPU models

CPU Parameters	AtomicSimpleCPU	TimingSimpleCPU	MinorCPU	DeriveO3CPU
Ticks	2653000	32546000	30448500	17629500
CPU clock domain	500	500	500	500
Clock Cycles	5307	65092	60897	35260
Simulated instructions	5277	5277	5289	5077
CPI	1.006	12.335	11.514	6.945
Committed instructions	5277	5277	5289	5077
Host seconds	0.01	0.01	0.05	0.06

3) Download the test programs related to the automotive sector available in MiBench: `basicmath`, `bitcount`, `qsort`, and `susan`. These programs are freely available at http://vhosts.eecs.umich.edu/mibench/

   a) compile the program `basicmath` using the provided *Makefile* using the ALPHA compiler *hint:*

   add a variable to the Makefile in order to use the ALPHA compiler:

   ```
   CROSS_COMPILE = /opt/alphaev67-unknown-linux-gnu/bin/alphaev67-unknown-linux-gnu
   CC=$(CROSS_COMPILE)-gcc
   ```

   and substitute all the `gcc` occurrences with the new variable as follows:

   gcc → $(CC)

   b) Simulate the program `basicmath` using the *small* set of inputs and the default processor (*AtomicSimpleCPU)*, saving the output results. In the case the simulation time is higher than a couple of minutes, modify the program in order to reduce the simulation time; for example, in the case of `basicmath`, it is necessary to reduce the number of iterations the program executes in order to reduce the computational time.

   c) Simulate the resulting program using the gem5 different CPU models and collect the following information:
      a) Number of instructions simulated
      b) Number of CPU Clock Cycles
      c) Clock Cycles per Instruction (CPI)
      d) Number of instructions committed
      e) Host time in seconds
      f) Prediction ratio for Conditional Branches (Number of Incorrect Predicted Conditional Branches / Number of Predicted Conditional Branches)
      g) BTB hits.

      Parameters *f* and *g* should be gathered only for the out-of-order processor.

Table 2: `basicmath_small` program behavior on different CPU models

CPU Parameters	AtomicSimpleCPU	TimingSimpleCPU	MinorCPU	DeriveO3CPU
Ticks	17097772000	52592929000	39328906500	17790548000

CPU clock domain	500	500	500	500
Clock Cycles	34195545	105185858	78657813	35581097
Simulated instructions	34195483	34195483	34195509	33426416
CPI	1.000001	3.076016	2.300238	1.064460
Committed instructions	34195483	34195483	34195509	33426416
Host seconds	35.49	61.98	150.28	163.77
Prediction ratio			3804956	3904708
BTB hits			165851	133656

A simpler basicmath was used to perform the computations, obtained by reducing the number of iterations for every loop by half.