

**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-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=None
checker=None
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)

- $CPI = \text{CPU Clock Cycles} / \text{instructions simulated}$
- Number of instructions committed
- Host time in seconds
- Number of instructions Fetch Unit has encountered (this should be gathered for the out-of-order processor only).

TABLE1: Hello program behavior on different CPU models

Parameters	AtomicSimpleCPU	TimingSimpleCPU	MinorCPU	DeriveO3CPU
Ticks	2652000	383148000	33436500	19267000
CPU clock domain	500	500	500	500
Clock Cycles	5304	766296	66873	38534
Instructions simulated	5275	5275	5287	5075
CPI	1	145	13	8
Committed instructions	5275	5275	5287	5274
Host seconds	0	0,02	0,02	0,03
Instructions encountered by Fetch Unit	/	/	/	11065

- 3) Download the test programs related to the **automotive** sector available in MiBench: `basicmath`, `bitcount`, `qsort`, and `susan`. These programs are freely available at <https://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 **large** 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.

TODO: To reduce the simulation time of `basicmath_large.c`, modify the number of iterations of the for loops as follows:

```
76  /* Now solve some random equations */
77  for(a1=1;a1<10;a1+=2) { // EDITED
78      for(b1=10;b1>0;b1-=1) { // EDITED
79          for(c1=5;c1<15;c1+=1) { // EDITED
80              for(d1=-1;d1>-.5;d1-=.5) { // EDITED
81                  SolveCubic(a1, b1, c1, d1, &solutions, x);
82                  printf("Solutions:");
83                  for(i=0;i<solutions;i++)
84                      printf(" %f",x[i]);
85                  printf("\n");
86              }
87          }
88      }
89  }
90
91  printf("***** INTEGER SQRT ROOTS *****\n");
92  /* perform some integer square roots */
93  for (i = 0; i < 1000; i+=2) // EDITED
94  {
95      usqrt(i, &q);
96      // remainder differs on some machines
97      // printf("sqrt(%3d) = %2d, remainder = %2d\n",
98      printf("sqrt(%3d) = %2d\n",
99          i, q.sqrt);
100  }
101  printf("\n");
102  for (l = 0x3fed0169L; l < 0x3fed4169L; l++)
103  {
104      usqrt(l, &q);
105      //printf("\nsqrt(%LX) = %X, remainder = %X\n", l, q.sqrt, q.frac);
106      printf("sqrt(%LX) = %X\n", l, q.sqrt);
107  }
108
109
110  printf("***** ANGLE CONVERSION *****\n");
111  /* convert some rads to degrees */
112  /* for (X = 0.0; X <= 360.0; X += 1.0) */
113  for (X = 0.0; X <= 360.0; X += .01) //EDITED
114      printf("%3.0f degrees = %12f radians\n", X, deg2rad(X));
115      puts("");
116  /* for (X = 0.0; X <= (2 * PI + 1e-6); X += (PI / 180)) */
117  for (X = 0.0; X <= (2 * PI + 1e-6); X += (PI / 5760))
118      printf("%12f radians = %3.0f degrees\n", X, rad2deg(X));
119
120
121  return 0;
122 }
123 }
```

- c) Simulate the resulting program using the gem5 different CPU models and collect the following information:

- Number of instructions simulated
- Number of CPU Clock Cycles
- Clock Cycles per Instruction (CPI)
- 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
 - h) Number of instructions Fetch Unit has encountered.
- Parameters f , g and h should be gathered exclusively for the out-of-order processor.

TABLE2: basicmath_large program behavior on different CPU models

Parameters	AtomicSimpleCPU	TimingSimpleCPU	MinorCPU	DerivO3CPU
Ticks	222416559500	31158520203000	364964286500	144932423500
CPU clock domain	500	500	500	500
Clock Cycles	444833119	62317040406	72992857	289864847
Instructions simulated	444833057	444833057	444833083	436251113
CPI	1	140	2	0,66
Committed instructions	444833057	444833057	444833083	436251113
Host seconds	130,66	1213,46	653,36	712,43
Prediction ratio	/	/	/	0,03
BTB hits	/	/	/	46229129
Instructions encountered by Fetch Unit	/	/	/	485507542