

1. The performance drop versus an ideal pipeline with CPI of 1.0 for the two questions.
  - a. For Q1,  $CPI_{\text{new}} = 1.6642$ ,  
 $\% \text{performance drop} = (1.6642 - 1.0) / 1.0 = 66.42\%$
  - b. For Q2,  $CPI_{\text{new}} = 1.3903$   
 $\% \text{performance drop} = (1.3903 - 1.0) / 1.0 = 39.03\%$
2. Explain how your microbenchmark collected statistics validate the correctness of your code for the first problem statement.

The microbenchmark is run 1000000 times in a loop and the content in a loop is translated to the following assembly:

```

$L2    lw     $2,16($fp)
        lui    $3,15
        ori    $3,$3,16959
        slt    $2,$3,$2
        beq    $2,$0,$L5
$L5:   addi   $1,$0,1
        addi   $2,$0,2
        addi   $3,$0,3
        add    $3,$1,$2
        lw     $4,2($3)
        add    $5,$4,$3
        add    $2,$1,$3
        add    $2,$5,$4
        add    $3,$1,$4
        lw     $3,16($fp)
        addu   $2,$3,1
        move   $3,$2
        sw     $3,16($fp)
        j      $L2

```

From the assembly code above, we can calculate **the expected CPI**:

$\% \#2\text{-cycle-stall} = 8/19$ ,  $\% \#1\text{-cycle-stall} = 2/19$

$CPI = 1 + (\#2\text{-cycle-stall} * 2 / \# \text{insn} + \#1\text{-cycle-stall} / \# \text{insn}) = 1 + (2 * 8/19 + 2/19) = 1.9474$

We compiled the program using O0 optimization and we ran “sim-safe mbq1” to get the following statistics:

```

sim_num_insn      19006312 # total number of instructions executed
sim_num_refs      4003722 # total number of loads and stores executed
sim_elapsed_time   3 # total simulation time in seconds
sim_inst_rate     6335437.3333 # simulation speed (in insts/sec)
sim_num_RAW_hazard_q1 10000933 # total number of RAW hazards (q1)
sim_num_RAW_hazard_s1_q1 2000079 # total number of 1-cycle-stall RAW hazards (q1)
sim_num_RAW_hazard_s2_q1 8000854 # total number of 2-cycle-stall RAW hazards (q2)
CPI_from_RAW_hazard_q1 1.9471 # CPI from RAW hazard (q1)

```

The percentage of 1-cycle stall instruction =  $2000079/19006312 = 2/19$

The percentage of 2-cycle stall instruction =  $8000854/19006312 = 8/19$

The CPI reported by sim-safe for part1 is **1.9471**

All the statistics match with what we expect.