1. The performance drop versus an ideal pipeline with CPI of 1.0 for the two questions.
    a. For Q1, CPI(new) = 1.6642,
       %performance drop = (1.6642 – 1.0) / 1.0 = 66.42%
    b. For Q2, CPI(new) = 1.3903
       %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 // 2-cycle-stall
        slt     $2,$3,$2    // 2-cycle-stall
        beq     $2,$0,$L5   // 2-cycle-stall
 $L5:   addi    $1, $0, 1
        addi    $2, $0, 2
        addi    $3, $0, 3
        add     $3, $1, $2   // 1-cycle-stall
        lw      $4, 2($3)    // 2-cycle-stall
        add     $5, $4, $3   // 2-cycle-stall
        add     $2, $1, $3
        add     $2, $5, $4   // 1-cycle-stall
        add     $3, $1, $4
        lw       $3,16($fp)
        addu    $2,$3,1      // 2-cycle-stall
        move    $3,$2        // 2-cycle-stall
        sw      $3,16($fp)   // 2-cycle-stall
        j       $L2
```

   From the assembly code above, we can calculate **the expected CPI**:
   %#2-cycle-stall = **8/19**, %#1-cycle-stall=**2/19**
   CPI = 1 + (#2-cycle-stall * 2 / #insn + #1-cycle-stall / #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.