Comp Sci 310, Fall 2014 Summers Assignment 1
100 points

DUE: Before class on **Friday, 9/19**
Absolutely no late assignments accepted

You must work in pairs on this and the following assignments and submit only one hard copy of your answers with both names on it. **For full credit**, you must **type** your answers.

Since team work will become increasingly important throughout the semester, you are expected to spend time reflecting on your team's strategies to deal with problems and work effectively. Eventually, you will have to assess in writing your own and your partner's performance. It is thus to your advantage, for this and every subsequent assignment, to take a deliberate approach to all aspects of your team's work and the skills that each one of you is bringing to the table, including responsibility and commitment, quality of work, timeliness of work, communication skills, helpfulness, and overall attitude.

Answer the following questions. Each answer will be graded mostly based on the level of detail and clarity in the justification of the answer. The final answer will often account for a smaller part of the grade. **Do not forget the units**, when applicable.

1. (15 points) Consider the following measurements for three different processors P1, P2, P3 and a given program P:

Processor	Clock rate	Number of instructions	CPU execution time
P1	2 Ghz	$6 * 10^9$	3 s
P2	1.5 Ghz	$2 * 10^9$	9 s
P3	3 Ghz	$9 * 10^9$	12 s

   a. (5 points) What is the CPI of each processor?
   b. (5 points) What is the clock rate in GHz for P2 that would reduce its execution time to that of P1?
   c. (5 points) What is the number of instructions that would reduce P3's execution time to that of P2?

2. (15 points) Consider three different processors P1, P2 and P3 executing the same instruction set with clock rates and CPIs given in the following table:

Processor	Clock rate	CPI
P1	1 Ghz	0.6
P2	2 Ghz	1.5
P3	2.5 Ghz	2.0

   a. (5 points) Which processor has the highest performance?
   b. (5 points) What should the clock rate of each processor be if we want to reduce the execution time by 30%, given that this enhancement increases the CPI by 20%?
   c. (5 points) If each processor executes a program in 10 seconds, find the number of cycles taken and the number of instructions executed by each processor.

3. The table below shows the instruction count and execution time for a given high-level language program after it is translated by two different compilers into machine code for a processor with a 2 ns clock cycle time:

Compiler A		Compiler B	
IC	Execution time	IC	Execution time
$1.5 * 10^9$	2.0 s	$2.6 * 10^9$	1.5 s

   a. (5 points) What is the average CPI for each program?
   b. (5 points) A new compiler is developed that generates a 600-million-instruction-long executable that has an average CPI of 0.8. What is the relative speedup of the new executable over the executable produced by compiler A? Repeat this question with compiler B.

4. (10 points) Consider two different implementations of the same instruction set containing five classes of instructions with the following CPIs:

Processor	Clock rate	CPI Class A	CPI Class B	CPI Class C	CPI Class D	CPI Class E
P1	2.3 Ghz	4	2	3	1	3
P2	3.5 Ghz	3	2	4	3	4

   a. (5 points) Define the *peak performance* as the fastest rate that a processor can execute an instruction sequence. What are the peak performances of these two processors expressed in instructions per second?
   b. (5 points) If the number of instructions executed in a certain program is divided equally among the classes of instructions except for class A, which occurs six times as often as each of the others, which processor is faster?

5. (15 points) Assume that computer C implements the Larc architecture, which is a load-store architecture (or register-register architecture) in which both stores for all ALU operations come from registers. Therefore, to add two data elements in memory, a typical program P, running on C, would look like this:

```
lw R1 <address1>
lw R2 <address2>
add R3 R1 R2
sw R3 <address3>
```

   We measure the instruction mix on an average workload for C and obtain the percentages shown in the middle column of the following table:

Instruction type	Frequency	CPI
ALU ops	40%	1
Loads	23%	3
Stores	12%	3
Branches	25%	3

   The last column of this table includes the clock cycle count per instruction for each type. During our measurements, we also notice that 25% of all ALU operations directly use a value loaded from memory that is not used again.

Therefore, we are considering building C2, a computer that implements a modified Larc architecture, called Larc2, that keeps all previous instructions but adds a new type of ALU operations for which one of the operands is in memory (both the other source operand and the result of the ALU operation are still stored in registers). These new register-memory ALU instructions have a CPI of 2. Furthermore, the new implementation decrease the clock cycle time by 20% and increases the CPI of branch instructions by 1 (the CPI of other instructions is not affected).

a. (10 points) Build a new table for Larc, similar to the table given above for Larc. To do so, you will have to compute the new frequencies in the average workload for all instruction types, given that some of the code fragments like the one above will be replaced by code fragments like this one:

```
lw R1 <address1>
newadd R3 R1 <address2>
sw R3 <address>
```

b. (5 points) Should we build C2, i.e., is it faster than C on an average workload?

6. (20 points) A classic way to assess the speed of a processor is to use its MIPS rating, where "MIPS" stands for "Millions of Instructions that the processor can execute Per Second". So the MIPS rating is computed using the following formula:

MIPS rating = instruction count / (CPU execution time * 10^6)

For example, if a processor can execute 12 billion instructions in 400 seconds, it can then execute an average of $12 * 10^9 / 400 = 3 * 10^7$ instructions per second, that is, 30 MIPS. Clearly, the MIPS rating varies inversely to execution time. In other words, for a given number of instructions, the smaller the execution time, the faster the processor and thus the higher the MIPS rating. MIPS is an intuitive and easy-to-understand performance metric. Or is it? Answer the following questions. As always, make sure to justify each answer precisely.

a. (8 points) Plug the CPU performance equation into the formula given above for the MIPS rating and simplify the resulting formula F as much as possible. Then, for each component in the CPU performance equation, discuss whether the way it appears in F is in agreement with your intuition about how it should affect the MIPS rating. Your final answer must contain one formula (F) and three bullet points, one for each component in the CPU performance equation.

Finally, use F to help you answer the following three questions. Each answer must start with one of the words "True" or "False" followed by a precise justification.

b. (4 points) Is it true that a given processor always has the same MIPS rating regardless of the software it runs?
c. (4 points) Is the MIPS rating a good metric to compare the performance of two processors A and B, given that A executes the x86 (that is, IA-32) ISA, while processor B executes the ARM ISA?
d. (4 points) Is the MIPS rating a good predictor of which one of two processors will run a given program faster? Hint: It may be helpful to make up easy numbers and compare predictions with actual execution times.

7. (15 points) Suppose that computer C does not have a hardware implementation of its integer multiplication instruction but uses instead a software implementation (that is, a library function written in machine language) that multiplies two integers by executing a sequence of shift and add instructions. Assume that the execution time of program P on C takes T=500 seconds, 350 of which are devoted to

multiplications.

As a lead designer for the next generation C' of computer C, you are considering adding a hardware unit for multiplication that would greatly speed up this operation.

a. (5 points) What would the relative speedup in the execution of P be if the hardware unit in C' sped up each multiplication by a factor of 4? The relative speedup is defined as the ratio of T over the execution time T' of P on C'.
b. (2 points) What would the value of T' be in part (a)?
c. (4 points) What should the relative speedup per multiplication of the new multiplication hardware over the software implementation be if your goal is to speed up the execution of P by 60%?
d. (4 points) What should the relative speedup per multiplication of the new multiplication hardware over the software implementation be if your goal is to speed up the execution of P by 80%?