Fall 2022 Homework Assignment #1

(50 points)

This is individual assignment. Every student must work on it alone. Group work is not permitted. All students who work in a group on this assignment will receive an automatic 0 for this assignment. In additional, such incidents will be reported as academic integrity violation. All solutions should be typed. No hand-written submissions will be accepted. Please submit your solution as:

• Email to the address in the header (MS Word or PDF)

Due date: September 21th, 11:59 PM.

Problem Set #1 (20 points)

Assume that program **A** has the following characteristics when executed on processors P1, P2, and P3

Processor	Clock Rate	Number of instructions	Execution time
P1	3.0 GHz	10×10^9	10 seconds
P2	2.0 GHz	5×10^9	5 seconds
P3	5.0 GHz	20×10^9	8 seconds

1.1. Find the IPC (number instructions per cycle) for each processor that executes program **A** described in the table above. (5 points)

1.2. Find the new clock rate of P2 that will yield the same CPI as processor P1. Assume that there are no other changes. (5 points)

1.3. Is it possible for both P1 and P2 to have the same ISA and same clock rate, and produce the number of instructions and execution time as in the table for the same (compiled by the same optimized compiler) program A? Explain. \ (5 points)

1.4. Find the number of instructions for P2 that will yield the same execution time for the above program as processor P3. Assume that there are no other changes. (5 points)

1.1. Number of cycles per second is $R_1 = 3\ 10^9$ c/s

Number of cycles $C_1 = R_1 \times T_1 = 3\ 10^9 \times 10 = 30\ 10^9\ c$

$IPC_1 = 10\ 10^9 / 30\ 10^9 = 0.33$

$R_2 = 2\ 10^9$ c/s

Number of cycles $C_2 = R_2 \times T_2 = 2\ 10^9 \times 5 = 10^{10}\ c$

$IPC_2 = 5\ 10^9 / 10\ 10^9 = 0.5$

$R_3 = 5\ 10^9$ c/s

Number of cycles $C_3 = R_3 \times T_3 = 5\ 10^9 \times 8 = 40\ 10^9\ c$

$IPC_3 = 20\ 10^9 / 40\ 10^9 = 0.5$

1.2. $R_2 = ?$ when $CPI_2 = CPI_1 = \frac{1}{IPC_1} = 3$ or equivalently $IPC_2 = 0.33$

Number of cycles $C_2 = R_2 \times T_2 = R_2 \times 5\ cycles$

$CPI_2 = \frac{C_2}{I_2} = (5R_2)/5\ 10^9 = 3$ =>

$R_2 = 5 \times 10^9 * 3/5$ cycles/s = 3GHz

1.3. No! If you run the same program on the same ISA with the same optimized compiler you should get the same IC (instruction count).

1.4. CPU time = Cycles/cycles_per_second = (I x CPI) / Clock rate
I = (CPU time x Clock rate) / CPI = CPU time x Clock rate x IPC
IP2 = 8s x 2x10^9 1/s x 0.5 = 8 x 10^9 *instructions*
➔ Or you could solve a simple proportion x/8 = (5 x 10^9)/5

Problem Set #2 (15 points)

Consider three different processors P1, P2, and P3 executing the same the same C program C_1. The clock rates and average CPI (number of clock cycles per instruction) for each processor is provided below.

Processor	Clock Rate	CPI
P1	3.0 GHz	1.5
P2	2.5 GHz	1.25
P3	3.5 GHz	5.0

2.1. Which processor has the best/highest performance, and the pairwise ratio of CPU times? (5 points)

2.2 What is the number of instructions/second per processor (5 points)

2.3 Assume that each CPU executes another C program C_2 in 20 seconds. The program was compiled with the same optimized compiler. Find the total number of cycles and the total number of instructions required to execute program C_2 on each processor. (5 points)

2.1.
Def 1: Time = Instruction count I x cycles per instruction x cycle duration
P1: T1 = I x 1/3.0 GHz x 1.5 cycles/instr. = Ix0.5x10-9 sec = 0.5I nsec
P2: T2 = I x 1/2.5 GHz x 1.25 cycles/instr. = Ix0.5x10-9 sec = 0.5I nsec
P3: T3 = I x 1/3.5 GHz x 5.0 cycles/instr. = 1.43I nsec
P1 and P2 have equally good performance
Perf1/Perf2 =1 Perf1/Perf3 =2.86 Perf2/Perf3 = 2.86

2.2.
Easy from the above Def 1: IPS = Instruction count/Time = $\boldsymbol{I/T1(2,3)}$
Or IPS = Clock rate / CPI
P1: 3.0 GHz / 1.5 cycles/instr. = 3.0x109 cycles/sec / 1.5 cycles/instr. = 2.0x10^9 instr./sec
P2: 2.5 GHz / 1.25 cycles/instr. = 2.5x109 cycles/sec / 1.25 cycles/instr. = 2.0x10^9 instr./sec
P3: 3.5 GHz / 5.0 cycles/instr. = 3.5x109 cycles/sec / 5.0 cycles/instr. = 0.7x10^9 instr./sec
P1 and P2 have the highest IPS (throughput), which is another performance metric.

2.3.
CPU Time = (Instruction count I)x (cycles per instruction) x cycle_duration

cycle_duration = 1/ Clock rate

IPS = Clock rate / CPI

- ⇨ **I = (CPU time x Clock rate) / CPI = CPU time x IPS**

Remember: Clock rate is in cycles per s (total number of cycles divided by time)

Total Cycles = I x CPI = (CPU time x Clock rate) / CPI) x CPI = CPU time x Clock rate

P1:

I = 20 sec x 2.0x10^9 instr./sec **= 40 G instr.**

Total Cycles = 20 sec x 3.0 GHz = 20 sec x 3.0x10^9 cycles/sec **= 60 x 10^9 cycles**

P2:

I = 20 sec x 2.0x10^9 instr./sec **= 40G instr.**

Total Cycles = 20 sec x 2.5 GHz = 20 sec x 2.5 x 10^9 cycles/sec **= 50 x 10^9 cycles**

P3:

I = 20 sec x 0.7x10^9 instr./sec **= 14G instr.**

Total Cycles = 20 sec x 3.5 GHz **= 70 x10^9 cycles**

Problem Set #3 **(15 points)**

Consider two different implementations of the same instruction set architecture. There are four classes of instructions: A, B, C, and D. The clock rates and instruction class CPIs for each implementation are provided in the table below:

ISA implementation	Clock Rate	CPI for class A	CPI for class B	CPI for class C	CPI for class D
P1	5.0 GHz	2.5	2	5	1.5
P2	3.5 GHz	3	1.5	4.5	1

3.1. Given a program with 10x10^9 instructions that has the following distribution of the instruction classes: 50% of class A, 10% of class B, 30% of class C, and 10% of class D. Determine which implementation will execute the above program faster? (5 points)

3.2 Assume that we are dealing with the program described in part 3.1 that got modified and all the class B and class D instructions have been replaced with class E instructions. Total number of instructions is now 11.5x10^9 instructions and the split is 50% of class A, 25% of class C, and 25% of class E. P1 has CPI of 1.2 for class E and P2 has the CPI of 1 for the same class. What is the total number of clock cycles required for each implementation? What is the time now? (5 points)

Has the replacement of classes B and D with a faster instruction class improved the performance and has it changed the ranking of implementations? Why? (2 pts bonus)

3.3. Assume the following distribution of instructions for a given program:

	Arithmetic operations	Store operations	Load operations	Branch operations
Number of instructions	500	120	160	120
CPI	2	5	4	1

What are the execution time and the average CPI of the above program on a 2.36 GHz processor? (5 points)

3.1:

P1: 10x109x (0.5 x 2.5 + 0.1 x 2 + 0.3 x 5 + 0,1x1.5) *1/(5x109) = ($10x10^9/5x10^{9)}$ x (1.25 + 0.2 + 1.5 + 0.15) = 6.2s

P2: 10x109 x (0.5 x 3 + 0.1 x 1.5 + 0.3 x 4.5 + 0.1x1) *1/(3.5x109) = 2.86 x (1.5 + 0.15 + 1.35 + 0.1) = 8.86s

3.2:

P1: 11.5x109 x (0.5 x 2.5 + 0.25 x 5 + 0.25 x 1.2) *1/(5x109) = 2.3 x (1.25 + 1.25 + 0.5) = 6.44s

P2: 11.5x109 x (0.5 x 3 + 0.25 x 4.5 + 0.25x1) *1/(3.5x109) = 3.29 x (1.5 + 1.125 + 0.25) = 9.36s

For clocks, just multiple with clock rate.

3.3.

C = 500×2 + 120×5 + 160×4+120×1 = 2360 clocks

CPI = 2360/900 =2.6

Time = C/R = 2360/2.36 = 1000 ns = 1us