#Exercise Week 1

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Question 1.

a. Which processor has the highest performance expressed in instruction per second?

$$InstructionPerSecond = \frac{Clock\ Rate}{CPI}$$

$$InstructionPerSecond_1 = \frac{3 \times 10^9}{1.5} = \mathbf{2 \times 10^9}\ \ (InstructionPerSecond)$$

$$InstructionPerSecond_2 = \frac{2.5 \times 10^9}{1} = \mathbf{2.5 \times 10^9}\ \ (InstructionPerSecond)$$

$$InstructionPerSecond_3 = \frac{4 \times 10^9}{2.2} = \mathbf{1.82 \times 10^9}\ \ (InstructionPerSecond)$$

⇨ From three results above, we can conclude that **P2 has the highest performance.**

b. If the processors each execute a program in 10 seconds, find the number of cycles and the number of instructions.

$$NumberOfCycles = Clock\ Rate \times Exe\ Time$$

$$NumberOfCycles_1 = 3 \times 10^9 \times 10 = \mathbf{30 \times 10^9}$$

$$NumberOfCycles_2 = 2.5 \times 10^9 \times 10 = \mathbf{25 \times 10^9}$$

$$NumberOfCycles_3 = 4 \times 10^9 \times 10 = \mathbf{40 \times 10^9}$$

$$NumberOfInstructions = IC = \frac{Clock\ Rate \times Exe\ Time}{CPI}$$

$$IC_1 = \frac{(3 \times 10^9 \times 10)}{1.5} = \mathbf{20 \times 10^9}$$

$$IC_2 = \frac{2.5 \times 10^9 \times 10}{1} = \mathbf{25 \times 10^9}$$

$$IC_3 = \frac{4 \times 10^9 \times 10}{2.2} = \mathbf{18.182 \times 10^9}$$

c. We are trying to reduce the time by 30% but this lead to an increase of 20% in the CPI. What clock rate should we have to get this time reduction?

$$Exe\ Time = \frac{IC \times CPI}{ClockRate}$$

$$New\ Exe\ Time = Exe\ Time \times 70\% = \frac{IC \times 120\% \times CPI}{NewClockRate}$$

$$\Rightarrow 0.7 = 1.2 \times \frac{ClockRate}{NewClockRate}$$

$$\Rightarrow NewClockRate = \frac{12}{7} \times ClockRate$$

$$\Rightarrow NewClockRate_1 = \frac{12}{7} \times 3 = \frac{36}{7} GHz$$

$$\Rightarrow NewClockRate_2 = \frac{12}{7} \times 2.5 = \frac{30}{7} GHz$$

$$\Rightarrow NewClockRate_3 = \frac{12}{7} \times 4 = \frac{48}{7} GHz$$

Question 2.

a. **Find the IPC (instructions per cycle) for each processor.**

$$IPC = \frac{1}{CPI} = \frac{IC}{Exe\ Time \times ClockRate}$$

$$IPC_1 = \frac{20 \times 10^9}{7 \times 3 \times 10^9} = \frac{20}{21} = \mathbf{0.952}$$

$$IPC_2 = \frac{30 \times 10^9}{10 \times 2.5 \times 10^9} = \mathbf{1.2}$$

$$IPC_3 = \frac{90 \times 10^9}{9 \times 4 \times 10^9} = \mathbf{2.5}$$

b. **Find the clock rate for P2 that reduces its execution time to that of P1.**

$$Exe\ Time_1 = \frac{IC_2 \times CPI_2}{NewClockRate_2}$$

$$\Rightarrow NewClockRate_2 = \frac{30 \times 10^9 \times 1.2^{-1}}{7} = 3.571 \times 10^9\ Hz = \mathbf{3.571\ GHz}$$

c. **Find the number of instructions for P2 that reduces its execution time to that of P3.**

$$New\ IC_2 = \frac{Exe\ Time_3 \times ClockRate_2}{CPI_2} = \frac{9 \times 2.5 \times 10^9}{(1.2)^{-1}} = \mathbf{27 \times 10^9}$$

Question 3.

a. **Given a program with 10^6 instructions divided into classes as follows: 10% class A, 20% class B, 50% class C, and 20% class D, which implementation is faster?**

$$Exe\ Time_1 = 10^6 \times \frac{0.1 \times 1 + 0.2 \times 2 + 0.5 \times 3 + 0.2 \times 3}{2.5 \times 10^9} = \mathbf{1.04 \times 10^{-3}}(s)$$

$$Exe\ Time_1 = 10^6 \times \frac{0.1 \times 2 + 0.2 \times 2 + 0.5 \times 2 + 0.2 \times 2}{3 \times 10^9} = \mathbf{0.667 \times 10^{-3}}(s)$$

b. **What is the global CPI for each implementation?**

$$CPI_{P1} = 0.1 \times 1 + 0.2 \times 2 + 0.5 \times 3 + 0.2 \times 3 = \mathbf{2.6}$$

$$CPI_{P2} = 0.1 \times 2 + 0.2 \times 2 + 0.5 \times 2 + 0.2 \times 2 = \mathbf{2}$$

c. **Find the clock cycles required in both cases.**

$$ClockRate_1 = IC_1 \times CPI_{P1} = \mathbf{2.6 \times 10^6}$$
$$ClockRate_2 = IC_2 \times CPI_{P2} = \mathbf{2 \times 10^6}$$

Question 4.

- What is the execution time of the above program?

$$Exe\ Time = 1000 \times \frac{0.2 \times 2.5 + 0.1 \times 1 + 0.2 \times 1.5 + 0.5 \times 2}{2 \times 10^9} = \mathbf{9.5 \times 10^{-7}}(s)$$

- What is the average CPI of the above the program?

$$Average\ CPI = 0.2 \times 2.5 + 0.1 \times 1 + 0.2 \times 1.5 + 0.5 \times 2 = \mathbf{1.9}$$

- Assume that we are trying to improve the loadstore instructions such that the execution time for this instructions type is reduced by a factor of 2. What is the speed-up of the program?

$$Speed-up=\frac{ExeTime}{NewExeTime}=\frac{0.2\times 2.5+0.1\times 1+0.2\times 1.5+0.5\times 2}{0.2\times \frac{2.5}{2}+0.1\times 1+0.2\times 1.5+0.5\times 2}=\frac{\mathbf{38}}{\mathbf{33}}=\mathbf{1,152}$$

Question 5.

Assume that the two design alternatives are to decrease the CPI of FPSQR to 2 or to decrease the average CPI of all FP operations to 2.5. Compare these two design alternatives using the processor performance equation.

Consider the initial measurement:

$$4\times 25\%=20\times 2\%+CPI_{FPnotSQR}\times 23\%\Longrightarrow CPI_{FPnotSQR}=\frac{60}{23}$$

Then, we compare two alternatives:

$$\frac{Exe\ Time_1}{Exe\ Time_2}=\frac{2\times 2\%+\frac{60}{23}\times 23\%+1.33\times 75\%}{2.5\times 25\%+1.33\times 75\%}=\mathbf{1.009}>1$$

⇨ The second alternatives has a higher performance, compared to the first one

Question 6.

a. **By how much must we improve the CPI of FP instructions if we want the program to run two times faster?**

$$\frac{New\ Exe\ Time}{Exe\ Time}=\frac{(50\times NewCPI_{FP}+110\times 1+80\times 4+16\times 2)\times \frac{10^6}{2\times 10^9}}{(50\times 1+110\times 1+80\times 4+16\times 2)\times \frac{10^6}{2\times 10^9}}$$

$$\Longrightarrow \frac{1}{2}=\frac{50\times NewCPI_{FP}+110\times 1+80\times 4+16\times 2}{50\times 1+110\times 1+80\times 4+16\times 2}$$

$$\Longrightarrow NewCPI_{FP}=-4.12$$

⟹ We can't just change the FPI of FP for the program to run 2 times faster

b. **By how much must we improve the CPI of L/S instructions if we want the program to run two times faster?**

$$\frac{New\ Exe\ Time}{Exe\ Time}=\frac{\left(50\times 1+110\times 1+80\times NewCPI_{L/S}+16\times 2\right)\times \frac{10^6}{2\times 10^9}}{(50\times 1+110\times 1+80\times 4+16\times 2)\times \frac{10^6}{2\times 10^9}}$$

$$\Longrightarrow \frac{1}{2} = \frac{50 \times 1 + 110 \times 1 + 80 \times NewCPI_{L/S} + 16 \times 2}{50 \times 1 + 110 \times 1 + 80 \times 4 + 16 \times 2}$$

$$\Longrightarrow NewCPI_{\frac{L}{S}} = 0.8 \Longrightarrow \frac{NewCPI_{\frac{L}{S}}}{CPI_{\frac{L}{S}}} = \frac{0.8}{4} = \mathbf{0.8}$$

c. By how much is the execution time of the program improved if the CPI of INT and FP instructions is reduced by 40% and the CPI of L/S and Branch is reduced by 30%?

$$\frac{New\ Exe\ Time}{Exe\ Time}$$
$$= \frac{(50 \times 1 \times 0.6 + 110 \times 1 \times 0.6 + 80 \times 4 \times 0.7 + 16 \times 2 \times 0.7) \times \frac{10^6}{2 \times 10^9}}{(50 \times 1 + 110 \times 1 + 80 \times 4 + 16 \times 2) \times \frac{10^6}{2 \times 10^9}}$$
$$= \mathbf{0.667}$$