Problem 1: Rubric: Each section has 10 points:

a.

We define performance as execution time, so first find the execution time:

$$Exe.Time = \frac{Instruction\ Count \times CPI}{Clock\ rate}$$

P1

$$Exe.Time = \frac{5 \times 10^9 \times 0.9}{4 \times 10^9} = 1.125$$

P2

$$Exe.Time = \frac{1 \times 10^9 \times 0.75}{3 \times 10^9} = 0.25$$

P1 has higher clock rate but it is slower than P2. So, Clock rate is not a good measurement for the performance

b.

How long does it take P1 to execute 1.0E9 instructions:

$$Exe.Time = \frac{1 \times 10^9 \times 0.9}{4 \times 10^9} = 0.225$$

How many instructions P2 can run in the same time (0.225):

$$Instruction\ Count = \frac{Exe.Time\ \times Clock\ rate}{CPI}$$

$$Instruction\ Count = \frac{0.225\ \times 3 \times 10^9}{0.75} = 0.9 \times 10^9 = 0.9E9$$

In the same amount of time P2 execute fewer instructions than P1, So it is not correct that the larger number of instructions need a larger CPU time

c.

$$MIPS = \frac{Instruction\ Count}{Execution\ Time \times 10^6}$$

P1

$$MIPS = \frac{5 \times 10^9}{1.125 \times 10^6} = 4.4 \times 10^3 = 4.4E3$$

P2

$$MIPS = \frac{1 \times 10^9}{0.25 \times 10^6} = 4 \times 10^3 = 4E3$$

P1 has higher MIPS but P2 is faster so MIPS is not a good measurement for the performance

d.

$$No.FP\ operations = Percent\ of\ FP\ instructions \times Instruction\ Count$$

P1

$$No.FP\ operations = \frac{40}{100} \times 5 \times 10^9 = 2E9$$

$$MFLOPS = \frac{2 \times 10^9}{1.125 \times 10^6} = 1.8 \times 10^3 = 1.8E3$$

P2

$$No.FP\ operations = \frac{40}{100} \times 1 \times 10^9 = 0.4E9$$

$$MFLOPS = \frac{0.4 \times 10^9}{0.25 \times 10^6} = 1.6 \times 10^3 = 1.6E3$$

Although P1 has higher MFLOPS but P2 is faster. So MFLOPS is not a good measurement for the performance

Note:

As mentioned before MFLOPS shows how many (millions) instructions a processor can execute per second. So, it is dependent on the processor and on the program. If the program we are using for measurement has no floating-point instruction, then the MFLOPS will be zero no matter how fast the CPU is.

$$MFLOPS = No.FP\ operations/(execution\ time\ \times 1E6)$$

In this formula the execution time is the execution time of the program not only the execution time of the floating-point instructions in the program

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Problem 2: Rubric: Each part has 10 points:

(a) Calculate T_2, T_4, T_8, which are the times to execute program P on a two-, four-, eight-processor system, respectively.

Assume the time taken to execute on a single processor system is T.
$T_2 = 0.4T + (0.6/\mathbf{2})T = 0.7T$
$T_4 = 0.4T + (0.6/4)T = 0.55T$
$T_8 = 0.4T + (0.6/\mathbf{8})T = 0.475T$

(b) Calculate T_∞ on an system with an infinite number of processors. Calculate the speedup of the program on this system, where *speedup* is defined as $\frac{T}{T_\infty}$. What does this correspond to?

$T_\infty = 0.4T + (0.6/\infty)T = 0.4T$
$Speedup = (T/T_\infty) = T/0.4T = 2.5$
This corresponds to the speedup if "only" the serial portion had been executed.

Problem 3: Rubric: 15 points:

a) suppose the percentage of vectorization is x. Based on Amdahl's law, we have:

$$\text{Speedup}_{\text{overall}} = \frac{1}{\left(1 - \text{Fraction}_{\text{enhanced}}\right) + \frac{\text{Fraction}_{\text{enhanced}}}{\text{Speedup}_{\text{enhanced}}}}$$

$$2 = \frac{1}{\left(1 - X\right) + \frac{X}{20}}$$

$$X \approx 52.63\%$$

b) The maximum speed up can be achieved if the percentage of vectorization is 100%.

$$\begin{aligned}\text{MaxSpeedup}_{\text{overall}} &= \frac{1}{\left(1 - \text{Fraction}_{\text{enhanced}}\right) + \frac{\text{Fraction}_{\text{enhanced}}}{\text{Speedup}_{\text{enhanced}}}} \\ &= \frac{1}{\left(1 - 100\%\right) + \frac{100\%}{20}} \\ &= 20\end{aligned}$$

If only one-half of the maximum speedup is needed with the percentage of vectorization as *X*, using Amdahl's Law

$$\text{Speedup}_{\text{overall}} = \frac{1}{\left(1 - \text{Fraction}_{\text{enhanced}}\right) + \frac{\text{Fraction}_{\text{enhanced}}}{\text{Speedup}_{\text{enhanced}}}}$$

$$\frac{20}{2} = \frac{1}{\left(1 - X\right) + \frac{X}{20}}$$

$$X \approx 94.74\%$$

c) Based on Amdahl's Law, the speedup that the hardware group could achieve is

$$\begin{aligned}\text{Speedup}_{\text{overall}} &= \frac{1}{(1-\text{Fraction}_{\text{enhanced}})+\frac{\text{Fraction}_{\text{enhanced}}}{\text{Speedup}_{\text{enhanced}}}} \\ &= \frac{1}{(1-70\%)+\frac{70\%}{2\times 20}} \\ &\approx 3.1496\end{aligned}$$

For the compiler crew, they have to increase the original percentage of vecorization to X for achieving the same speedup as what the hardware group does. X can be found by using Amdahl's Law again as

$$\text{Speedup}_{\text{overall}} = \frac{1}{(1-\text{Fraction}_{\text{enhanced}})+\frac{\text{Fraction}_{\text{enhanced}}}{\text{Speedup}_{\text{enhanced}}}}$$

$$3.1496 = \frac{1}{(1-X)+\frac{X}{20}}$$

$$X \approx 71.84\%$$

So, the increase of the percentage of vectorization is 1.84%. Comparing to a significant additional engineering investment required by the hardware group, adding a small amount of the percentage of vectorization costs less. It is defiantly worth investing the compiler crew!

Problem 4: Rubric: each CPU time has 1.5 point

Q3.

	Instruction count	CPI
FP	50×10^6	1
INT	110×10^6	1
L/S	80×10^6	4
branch	16×10^6	2

$$\text{CPU time} = \frac{\text{Instruction count} \times \text{CPI}}{\text{Clock rate}}$$

$$\text{CPU time}_{(FP)} = \frac{50 \times 10^6 \times 1}{2 \times 10^9} = 25 \text{ ms}$$

$$\text{CPU time}_{(INT)} = \frac{110 \times 10^6 \times 1}{2 \times 10^9} = 55 \text{ ms}$$

$$\text{CPU time}_{(L/S)} = \frac{80 \times 10^6 \times 4}{2 \times 10^9} = 160 \text{ ms}$$

$$\text{CPU time}_{(branch)} = \frac{16 \times 10^6 \times 2}{2 \times 10^9} = 16 \text{ ms}$$

over all CPU time before improvement $= 25 + 55 + 160 + 16 = 256$ ms

a. (3 points):

I. two times faster →

over all CPU time after improvement = $\frac{256}{2} = 128$ ms

→ using Amdahl's law:

execution time after improvement =

$\frac{\text{execution time affected by improvement}}{\text{Amount of improvement}}$ + execution time unaffect

→ $128^{ms} = \frac{25}{\text{Amount of improvement}} + \underbrace{(55 + 160 + 16)}_{231\text{ ms}}$

→ not possible with any amount of improvement

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(Each part (b and c) has 3 points):

II. using Amdahl's law:

$$128 = \frac{160}{\text{Amount of improvement}} + \underbrace{(25+55+16)}_{96}$$

Amount of improvement = 5

→ we need to improve CPI of L/S instructions 5 times.

III.

execution time after improvement =

$$\left(25 \times \frac{60}{100}\right) + \left(55 \times \frac{60}{100}\right) + \left(160 \times \frac{70}{100}\right) + \left(16 \times \frac{70}{100}\right)$$

$= 171.2$ ms

$$\frac{\text{execution time after improvement}}{\text{execution time before improvement}} = \frac{171.2}{256} \simeq 67\%$$

→ the overall execution time is improved by

$100 - 67 = 33\%$

Problem 5: Rubric: calculating capacitive load for each processor has 5 points:

$$dynamic\ power = capacitive\ load\ \times voltage^2 \times Frequency \qquad \Rightarrow$$

$$capacitive\ load = \frac{dynamic\ power}{voltage^2 \times Frequency}$$

Processor A: $capacitive\ load = \frac{90}{1.25^2 \times 3.6 \times 10^9} = 16\ nF$

Processor B: $capacitive\ load = \frac{40}{0.9^2 \times 3.4 \times 10^9} = 14.52\ nF$