Question 4 (20 points): For your Science Internship Program you have joined a startup that is developing a mobile hardware to be installed in the cashier of coffee shops and restaurants that participate in the PayItForward initiative. The idea of this initiative is that customers can anonymously pay a coffee or a meal to someone that cannot afford it.[1] The hardware is needed to allow independent scrutiny of the balances in each place. This startup has two versions of the hardware and two versions of the compiler to support this system. The main app run in this hardware is PIFStatus. The instructions executed by PIFStatus can be divided into four classes. The table below shows the average number of cycles per instruction for the two versions of hardware (with no L2 cache and with L2 cache). It also shows the total number of instructions executed when PIFStatus is compiled with optimization -O0 and -O3.

		Instruction Class			
		ALU	Mul	Branches	L/S
Cycles	No L2	35	54	40	138
	with L2	16	25	19	56
# instructions (in millions)	-O0	10	2	1	5
	-O3	8	1	1	

1. (**6 points**) What is the CPI when PIFStatus is compiled at the -O0 level and runs in the hardware with no L2?

$$\text{CPI}_{\text{no L2,O0}} = \frac{35 \times 10 + 54 \times 2 + 40 + 138 \times 5}{10 + 2 + 1 + 5} = \frac{1188}{18} = 66 \frac{\text{clocks}}{\text{instruction}}$$

2. (**7 points**) You have experimentally determined that PIFStatus compiled at the -O3 level and run with L2 is three times as fast as PIFStatus compiled at the -O0 level and run in the hardware with no L2. How many L/S instructions are executed when PIFStatus is compiled at the -O3 level?

$$\begin{aligned} \frac{\#\text{ clocks(no L2, O0)}}{\#\text{ clocks(L2, O3)}} &= \frac{1188}{16 \times 8 + 25 + 19 + 56 \times N} = \frac{1188}{172 + 56 \times N} = 3 \\ 516 + 168 \times N &= 1188 \\ N &= \frac{1188 - 516}{168} = \frac{672}{168} = 4.0 \end{aligned}$$

Thus when compiled at the -O3 level, PIFStatus executes 4 million instructions.

3. (**7 points**) If the execution time of PIFStatus compiled at the -O0 level and run on the hardware with no L2 is 594 miliseconds (1 milisecond $= 10^{-3}$ seconds), what is the frequency of clock, expressed in GHz (1 $GHz = 10^9$ Hz) in which the processor is executing?

[1] This question is inspired on The Nook Cafe in downtown Edmonton.

$$\begin{aligned}\text{Frequency}_{\text{(no L2,O0)}} &= \frac{\#\text{ clocks(no L2, O0)}}{\text{time(no L2, O0)}} \\ &= \frac{1188 \times 10^6}{594 \times 10^{-3}} = 2 \times 10^9 = 2\ GHz\end{aligned}$$