1. A MIPS-like processor working at 2GHZ is available. This processor runs a program P with the following distribution of instructions.

Tipo	%	CPI
load	25	1.2
store	15	1
add	40	1.4
mult	10	1.4
branch	10	1.2

An improvement in the manufacturing process leads to an increase in the integration scales, which enables the addition of a second execution stage just after the memory access stage. This modification enriches the instruction set with arithmetic instructions having one operand in memory (`load-add`) and with combined arithmetic instructions (`add-mult`) executing two operation within a single instruction. However, adding such instructions requires a new instruction format making more complex the decoding process. Since the decoding stage is already the slowest one, this modification slows down in 5% the clock period.

Once analyzing the code generated by the compiler, it is determined that new arithmetic instructions `load-add` affect to 25% of `load` instructions. These percentage of `load` instructions and the `add` instructions following them are replaced by the new `load-add` instructions. On the other hand, `add-mult` affect to 12.5 % of `add` instructions, which are followed by a `mult` instructions. In this case the sequence of two instructions (`add` and `mult`) is replaced by the new `add-mult` instructions. Furthermore, both new arithmetic instructions, `load-add` and `add-mult`, have a CPI of 2.

(a) Compute the execution time of program P in the original processor. Express that time attending to the number n of executed instructions.

(b) Assuming the compiler uses the new instructions whenever possible, How many instructions would contain program P if executed in the new processor?

(c) Compute the new distribution of instructions including instructions `load-add` and `add-mult`.

(d) Calculate the average CPI with the modified datapath when new instructions are used.

(e) Justify whether the modification of the datapath and the use of the new instructions is worthy from the perspective of the execution time of program P.

Solución:

(a) Compute the execution time of program P in the original processor.

$$T_{ex} = I \times CPI \times T$$

We have that $I = n$, $T = 1/2 \cdot 10^6$. The only term missing is CPI

$$\begin{aligned} CPI &= 0.25 \times 1.2 + 0.15 \times 1 + 0.5 \times 1.4 + 0.1 \times 1.2 \\ &= 0.3 + 0.15 + 0.7 + 0.12 = 1.27 \\ T_{ex} &= n \times 1.27 \times 0.5 \text{ ns} = 0.635 \cdot n \text{ ns} \end{aligned}$$

(b) How many instructions would contain program P if executed in the new processor?
Number of cases where a `load` instruction is followed by a `add` instruction, so they can be replaced by the new `load-add` instruction:

$$I_{load-add} = n \times 0.25 \times 0.25 = n \times 0.0625$$

Number of cases where an `add` instructions is followed by `mul` instruction, so they can be replaced by the new `mult-add`:

$$I_{add-mul} = n \times 0.4 \times 0.125 = n \times 0.05$$

In each of the aforementioned cases the number of instructions in the program is reduced in one instruction, as a result:

$$I' = n - n \times 0.0625 - n \times 0.05 = 0.8875 \cdot n$$

(c) New distribution of instructions in the new processor

$$f_{\text{load}} = \frac{0.25 - 0.25 \times 0.25}{0.8875} = \frac{0.1875}{0.8875} = 21.13\%$$

$$f_{\text{store}} = \frac{0.15}{0.8875} = 16.90\%$$

$$f_{\text{add}} = \frac{0.4 - 0.4 \times 0.125 - 0.25 \times 0.25}{0.8875} = \frac{0.2875}{0.8875} = 32.39\%$$

$$f_{\text{mult}} = \frac{0.1 - 0.4 \times 0.125}{0.8875} = \frac{0.05}{0.8875} = 5.63\%$$

$$f_{\text{branch}} = \frac{0.1}{0.8875} = 11.27\%$$

$$f_{\text{load-add}} = \frac{0.25 \times 0.25}{0.8875} = \frac{0.0625}{0.8875} = 7.04\%$$

$$f_{\text{add-mult}} = \frac{0.4 \times 0.125}{0.8875} = \frac{0.05}{0.8875} = 5.63\%$$

(d) New CPI

$$CPI' = \frac{0.1875 \times 1.2 + 0.15 \times 1 + 0.2875 \times 1.4 + 0.05 \times 1.4 + 0.1 \times 1.2 + 0.0625 \times 2 + 0.05 \times 2}{0.8875}$$

$$CPI' = \frac{0.225 + 0.15 + 0.4025 + 0.07 + 0.12 + 0.125 + 0.1}{0.8875} = \frac{1.1925}{0.8875} = 1.34$$

(e) New execution time

$$T'_{ej} = I' \times CPI' \times T'$$

$$T' = 1.05 \times 0.5 \text{ ns} = 0.525 \text{ ns}$$

$$T'_{ej} = 0.8875 \times n \times \frac{1.1925}{0.8875} \times 0.525 \text{ ns} = 1.1925 \times 0.525 \times n \text{ ns} = 0,6261 \cdot n \text{ ns}$$

$$S = \frac{T_{ej}}{T'_{ej}} = \frac{0.635 \cdot n}{0.6261 \cdot n} = 1,0142 \rightarrow 1,42\%$$

□

Rúbricas:

	A	B	C	D
1a	Selects the formula $t = I \times CPI \times T$ (20%).	Computes the CPI from a distribution of instructions, the CPI of each instruction, and the clock period considering the clock frequency (40%).	Applies the formula with the corresponding units (40%).	
1b	Combines percentages of affected instructions (33%).	Computes the variations in the number of instructions of each type (33%).	Compute the total number of instructions in the new program (33%)	
1c	Combines percentages of affected instructions (33%).	Computes the variations in the number of instructions of each type (33%).	Provides the new distribution of instructions in the program (33%).	
1d	Computes the CPI from a distribution of instructions and the CPI of each instructions (100%).			
1e	Selects the formula $t = I \times CPI \times T$ (20%).	Computes the new clock period (20%).	Applies the formula with the corresponding units (30%).	Justifies correctly whether the modification is worthy and supports the decision by computing the speed up and interpreting it, or by comparing the resulting execution times (30%).