Question 5 (10 points): When executing in a simulator simulating perfect caches, a program executes in 10 seconds in a processor with a clock frequency of 4 GHz. Every instruction executes in one cycle. (Hint: you can use this information to compute the number of instructions executed in the ideal machine). 25% of the instructions access memory. In an actual machine the hit rate of the L1 instruction cache is 98%, the hit rate of the L1 data cache is 90%, the access time of the L2 cache is 20 cycles. The local miss rate of the L2 cache is 25%. The access time for main memory is 140 cycles. How long it will take to execute the same program in the actual machine?

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\begin{aligned}
\#\text{ of instructions} &= \#\text{ of cycles}_{\text{ideal}} = \frac{\text{time}}{\text{cycle time}} = \frac{10\ s}{0.25 \times 10^{-9}\ s} = 40 \times 10^9 \text{ instructions} \\
\text{accesses}_{\text{L2}} &= (0.02 + 0.25 \times 0.1) \times 40 \times 10^9 = 1.8 \times 10^9 \\
\text{accesses}_{\text{memory}} &= 0.25 \times \text{accesses}_{\text{L2}} = 0.45 \times 10^9 \\
\text{stall cycles} &= (1.8 \times 20 + 0.45 \times 140) \times 10^9 = 99 \times 10^9 \\
\text{stall time} &= 99 \times 10^9 \times 0.25 \times 10^{-9}\ s = 24.7\ s \\
\text{actual time} &= \text{ideal time} + \text{stall time} = 10 + 24.7 = 34.7\ s
\end{aligned}
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