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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# of instructions = # of cycles_{ideal} = \frac{time}{cycle time} = \frac{10 \ s}{0.25 \times 10^{-9} \ s} = 40 \times 10^9 instructions
accesses_{L2} = (0.02 + 0.25 \times 0.1) \times 40 \times 10^9 = 1.8 \times 10^9
accesses_{memory} = 0.25 \times accesses_{L2} = 0.45 \times 10^9
stall \ cycles = (1.8 \times 20 + 0.45 \times 140) \times 10^9 = 99 \times 10^9
stall \ time = 99 \times 10^9 \times 0.25 \times 10^{-9} \ s = 24.7 \ s
actual \ time = ideal \ time + stall \ time = 10 + 24.7 = 34.7 \ s
```