

Problem 1 (17 points).

Operation	CPI	Frequency
Call/Return	2	5%
Branches	2	20%
ALU	1	45%
Load/Store	2	25%
FP Operation	5	5%

1a. (2 points).

$$CPI_e = 5\% \times 2 + 20\% \times 2 + 45\% \times 1 + 25\% \times 2 + 5\% \times 5 = 1.7 \text{ cycles.}$$

1b. (3 points).

$$CPI_e = 5\% \times (1 \times 100\% + 2 \times 0\%) + 20\% \times (1 \times 70\% + 2 \times 30\%) + 45\% \times 1 + 25\% \times (1 \times 40\% + 2 \times 60\%) + 5\% \times 5 = 1.41 \text{ cycles.}$$

1c. (4 points).

$$\text{Fraction of execution doing FP} = 5\% \times 5 / 1.7 = 14.7\%$$

$$\text{Speedup} = 1 / [(1 - 14.7\%) + 14.7\% / 1.2] = 1.025 \Rightarrow 2.5\% \text{ faster.}$$

1d. (3 points). Replace 20% of 25 lw/sw instructions \Rightarrow 20 lw/sw plus 5/2 = 2.5 new ld/sd instructions.

New instruction distribution:

LW/SW	20.0%	2 cycles
LD/SD	2.5%	3
B/Call	25.0%	2
ALU	45.0%	1
FP	5.0%	5
total	97.5%	

$$CPI_e = 2 \times 20/97.5 + 3 \times 2.5/97.5 + 2 \times 25/97.5 + 1 \times 45/97.5 + 5 \times 5/97.5 = 1.72 \text{ cycles}$$

$$\text{perf} = IC \times CPI \times CT \Rightarrow CT_{old} = CT_{new}$$

$$\text{ratio of perf} = (IC_{old} \times CPI_{old}) / (IC_{new} \times CPI_{new})$$

$$= (1 \times 1.7) / (.975 \times 1.72) = 1.0137 \Rightarrow 1.37\% \text{ faster.}$$

1e. (5 points).

$$CPI_c = 1 \times 0.02 \times 10 + 0.25 \times 0.04 \times (10 + 0.4 \times 10) = 0.34 \text{ cycles.}$$

Problem 2 (13 points).

2a. (8 points).

dm: index all blocks $\Rightarrow 2^{14} = 16\text{KB page}$
 tag = 18 index = 10 offset = 4

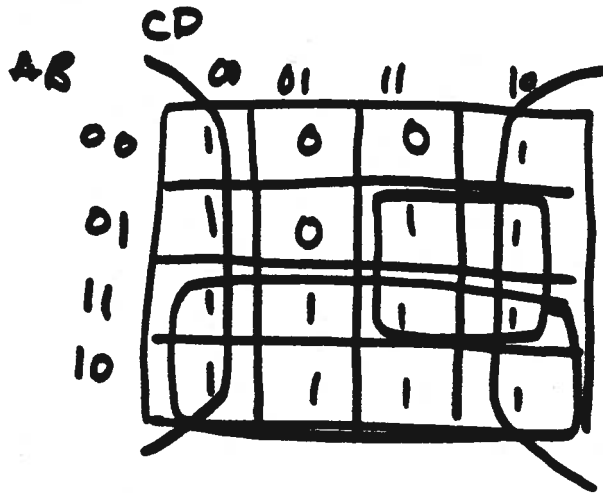
4-way: $2^{14}/4 \Rightarrow 2^{12} = 4\text{KB page}$
 tag = 20 index = 8 offset = 4

2b. (5 points).

dm: 16KB page \rightarrow 2K pages in mm \rightarrow 204800 refs/pf
 $204800 \text{ r/pf} \times 1.6 \text{ c/i} / 1.3 \text{ r/i} = 252\text{K c/pf} \Rightarrow 3.97\text{u pf/c}$
 $3.97\text{u pf/c} \times 16 \text{ KB/pf} / 4 \text{ B/c} = 0.016 \text{ B/c} \Rightarrow 1.6\%$

4-way: 4KB page \rightarrow 8K pages in mm \rightarrow 809600 refs/pf
 $809600 \text{ r/pf} \times 1.6 \text{ c/i} / 1.3 \text{ r/i} = 1.01\text{M c/pf} \Rightarrow 0.99\text{u pf/c}$
 $0.99\text{u pf/c} \times 4 \text{ KB/pf} / 4 \text{ B/c} = 0.0010 \text{ B/c} \Rightarrow 0.10\%$

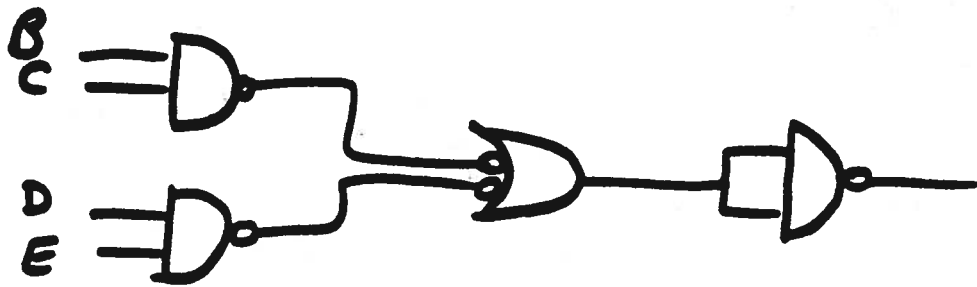
Problem 3 (4 points).



$A + \bar{D} + BC$

Problem 4 (4 points).

$\overline{(B \cdot C) + (D \cdot E)}$

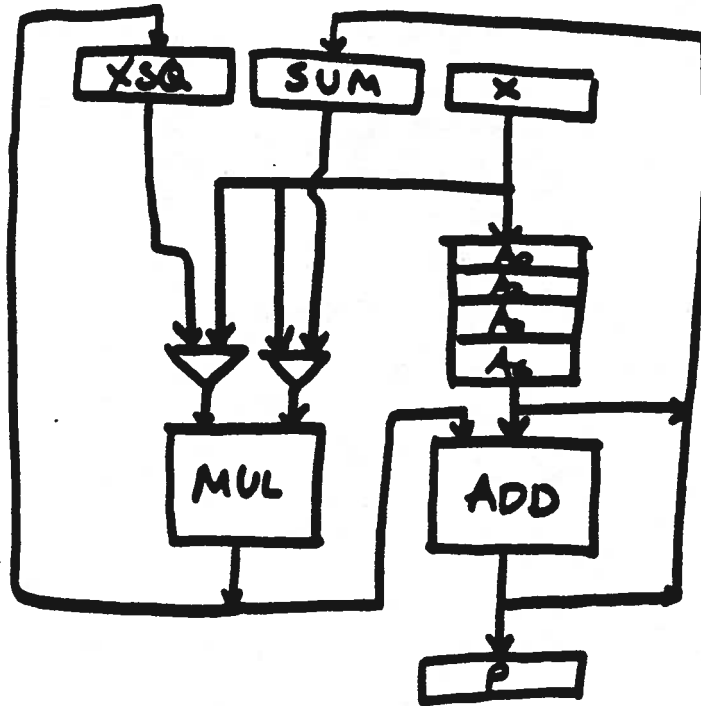


Problem 5 (22 points).

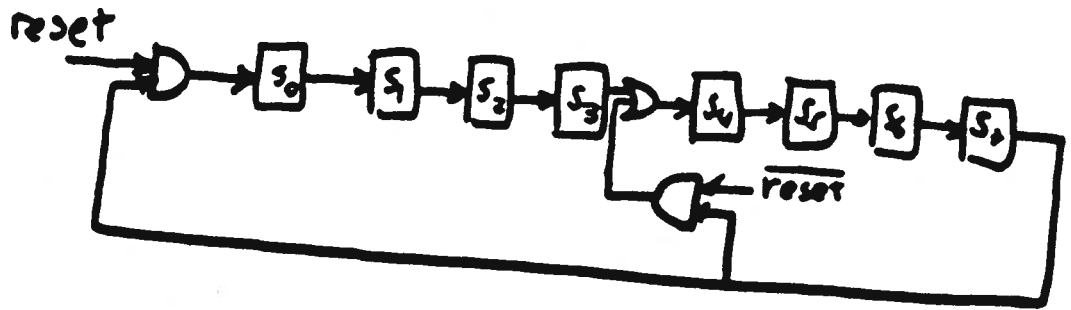
5a. (4 points).

5 buses, to carry values: SUM
 XSQ
 A_i
 $SUM + XSQ$
 $SUM + XSQ + A_i$

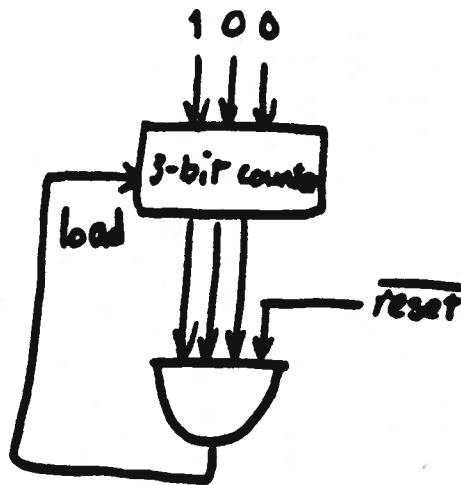
5b. (7 points).



5c. (7 points). Simplest solution:



OR



5d. (4 points).

Data processing unit:

More registers to hold A_i , otherwise unchanged.

Control unit:

Use the counter approach.

Need to modify the LOAD condition

Add a reset signal for the counter.