4)

R-type	lw	sw	beq
11	13	10	9
40%	30%	10%	20%

$CPI = (0.4 \times 11) + (0.3 \times 13) + (0.1 \times 10) + (0.2 \times 9)$

CPI = 11.1 cycles

5) a) Iterations: 32

7ns/iteration

$32 \times 7 =$ **224ns**

b) Iterations: 16

7ns/iteration

$16 \times 7 = 112$ ns

+Adder delay

$112ns + 7ns =$ **119ns**

6) Delay = $(k+7)T$

$G_{i0} = a_0 b_0$

↳ a_0/b_0 avail. @ $T=0$

$G_0 = (2+7)T =$ **9T**

$P_0 = a_0 \oplus b_0$

↳ a_0, b_0 avail. @ $T=0$

$P_0 = (2+7)T =$ **9T**

$G_{25} = a_{25} b_{25}$

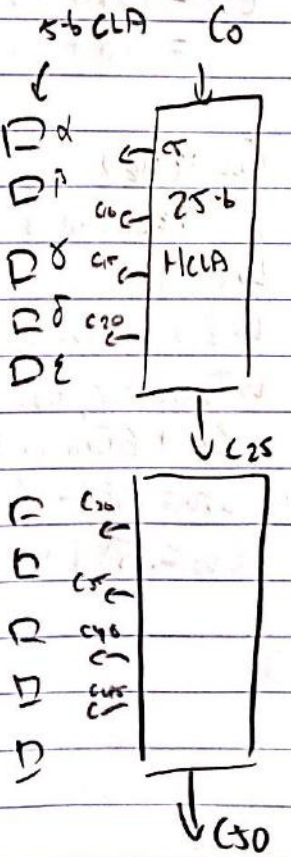
↳ a_{25}/b_{25} avail @ $T=0$

$G_{25} = (2+7)T =$ **9T**

$P_{25} = a_{25} \oplus b_{25}$

↳ a_{25}/b_{25} avail. @ $T=0$

$P_{25} = (2+7)T =$ **9T**



6) $C_4 = (G_4) + (G_3 P_4) + (G_2 P_3 P_4) + (G_1 P_2 P_3 P_4) + (G_0 P_1 P_2 P_3 P_4)$

↳ All G_i / P_i avail. @ 9T

↳ Therefore, $G_0 P_1 P_2 P_3 P_4$ is critical path

↳ G_i + 5 Fan-In AND + 5 Fan-in OR = 9T + (5+7)T + (5+7)T = **33T**

$P_\alpha = (P_4 P_3 P_2 P_1 P_0)$

↳ All G_i / P_i avail. @ 9T

$P_\alpha = (5+7)T + 9T =$ **21T**

$C_{25} = (G_\varepsilon) + (G_\delta P_\varepsilon) + (G_\gamma P_\delta P_\varepsilon) + (G_\beta P_\gamma P_\delta P_\varepsilon) + (G_\alpha P_\beta P_\gamma P_\delta P_\varepsilon) +$
$(C_0 P_\alpha P_\beta P_\gamma P_\delta P_\varepsilon)$

↳ G_α is avail. at 33T

↳ C_0 is avail. @ 0T

↳ Therefore, $G_\alpha P_\beta P_\gamma P_\delta P_\varepsilon$ is the critical path

G_α + 5 Fan-in AND + 6 Fan-in OR

$C_{25} = 33T + (5+7)T + (6+7)T$

$= 33T + 12T + 13T =$ **58T**

$C_{50} = (G_\varepsilon) + (G_\delta P_\varepsilon) + (G_\gamma P_\delta P_\varepsilon) + (G_\beta P_\gamma P_\delta P_\varepsilon) + (G_\alpha P_\beta P_\gamma P_\delta P_\varepsilon) +$
$(C_{25} P_\alpha P_\beta P_\gamma P_\delta P_\varepsilon)$

↳ G_α is avail. @ 33T

↳ C_{25} is avail. @ 58T

↳ Therefore, $C_{25} P_\alpha P_\beta P_\gamma P_\delta P_\varepsilon$ is the critical path

C_{25} + 6 Fan-in AND + 6-Fan-in OR

$C_{50} = 58T + (6+7)T + (6+7)T$

$C_{50} = 58T + 13T + 13T =$ **84T**

6) $C_{45} = (G_8) + (G_8 P_8) + (G_{12} P_8 P_9) + (G_{16} P_{12} P_8 P_9) + (G_{25} P_{16} P_{12} P_8 P_9)$

↳ G_{16} is avail @ 33T

↳ G_{25} is avail. @ 58T

↳ Therefore $G_{25} P_{16} P_{12} P_8 P_9$ is the critical path

C_{25} + 5 Fan-in AND + 5 Fan-in OR

$C_{45} = 58T + (5+7)T + (5+7)T$

$C_{45} = 58T + 12T + 12T = \boxed{82T}$

$C_{49} = (G_3) + (G_2 P_3) + (G_1 P_2 P_3) + (G_{10} P_1 P_2 P_3) + (G_{45} P_0 P_1 P_2 P_3) +$

↳ $G_{45} P_0 P_1 P_2 P_3$ is critical path

C_{45} + 5 Fan-in AND + 5 Fan-in OR

$82T + (5+7)T + (5+7)T$

$C_{49} = 82T + 12T + 12T = \boxed{106T}$

$S_{49} = (a_{49} \oplus b_{49}) \oplus C_{49}$

↳ C_{49} is the critical path

C_{49} + 2 Fan-in XOR

$106T + (2+7)T =$

$S_{49} = 106T + 9T = \boxed{115T}$

8) Single-cycle => $\boxed{CPI = 1}$

$CT = \frac{1}{f} = \frac{1}{3.5 \times 10^9 Hz} = \boxed{0.27 \times 10^{-9} s}$

$IC = \boxed{300 \text{ bil.}}$

$ET = IC \times CPI \times CT$

$ET = 3 \times 10^{11} \times 1 \times 0.29 \times 10^{-9} s$

$ET = 0.87 \times 10^2 = \boxed{87 s}$

8) CPI = 1 => single-cycle

$CT = 0.29 \times 10^{-9}s + 300 \times 10^{-12}s$

$CT = 0.29 \times 10^{-9}s + 0.3 \times 10^{-9}s$

$CT = 0.59_{ns}$

$0.4 \times 300,000,000,000$

$120,000,000,000$ LWs $\times 25\%$

$130,000,000,000$ LWs $\rightarrow$ $30,000,000,000$ LWAs

$30,000,000,000$ Adds

$IC = 300 \times 10^9 - 30 \times 10^9 = 270 \times 10^9$

$ET = 270 \times 10^9 \times 0.59 \times 10^{-9} = 159.3s$

Main Controller

Input or Output	Signal Name	R-format	lw	sw	Beq
Inputs	Op5	0	1	1	0
	Op4	0	0	0	0
	Op3	0	0	1	0
	Op2	0	0	0	1
	Op1	0	1	1	0
	Op0	0	1	1	0
Outputs	RegDst	1	0	X	X
	ALUSrc	0	1	1	0
	MemtoReg	0	1	X	X
	RegWrite	1	1	0	0
	MemRead	0	1	0	0
	MemWrite	0	0	1	0
	Branch	0	0	0	1
	ALUOp1	1	0	0	0
	ALUOp0	0	0	0	1

ALU Controller

opcode	ALUOp	Operation	funct	ALU function	ALU control	WTFC
lw	00	load word	XXXXXX	add	0010	0
sw	00	store word	XXXXXX	add	0010	0
beq	01	branch equal	XXXXXX	subtract	0110	0
R-type	10	add	100000	add	0010	0
		subtract	100010	subtract	0110	0
		AND	100100	AND	0000	0
		OR	100101	OR	0001	0
		set-on-less-than	101010	set-on-less-than	0111	0
R-type	10	WTF	111111	subtract	0110	1