1. Consider the system shown in Figure 4.60 of the textbook.

> *lw $2, 100($1)*
> *add $3, $1, $2*
> *lw $4, 100($2)*
> *and $1, $4, $2*
> *slt $2, $1, $5*

How many clock cycles are required to execute the instructions on the given datapath? Justify your answer. (30 points)

lw $2, 100($1)	IF	ID	EX	M	WB						
add $3, $1, $2		IF	ID	ID	EX	M	WB				
lw $4, 100($2)			IF	IF	ID	EX	M	WB			
and $1, $4, $2				IF	ID	ID	EX	M	WB		
slt $2, $1, $5					IF	IF	ID	EX	M	WB	
CYCLE	1	2	3	4	5	6	7	8	9	10	11	12

There is going to be a total of 11 clock cycles. There is a Load Hazard (in red) that forwarding cannot fix, so a delay must be used (in green).
S + N – 1 + Delay = 5 + 5 – 1 + 2 = 11

2. Consider the system given in Figure 4.60 of the textbook. Find the number of clock cycles required to execute the instruction with register forwarding? Justify your answer. (30 points)

> *add $3, $1, $2*
> *or $4, $2, $3*
> *and $1, $4, $2*
> *slt $2, $1, $5*

add $3, $1, $2	IF	ID	EX	M	WB				
or $4, $2, $3		IF	ID	EX	M	WB			
and $1, $4, $2			IF	ID	EX	M	WB		
slt $2, $1, $5				IF	ID	EX	M	WB	
CYCLE	1	2	3	4	5	6	7	8	9

There is going to be a total of 8 clock cycles. Where (S + N – 1 => 5 + 4 – 1 = 8)

3. Find the number of clock cycles required to execute the instruction sequence given below if the system given in Figure 4.62 of the textbook is used.
a) Branch taken (20 points)
b) branch not taken (20 points)

        add $3, $1, $2
        or $4, $2, $3
        beq $1, $2, L1
        and $1, $4, $2
        slt $2, $1, $5
L1:   lw $12, 0($18)
        sw $12, 4($18)

(a) When branch is taken, there will be a total of 11 clock cycles. The instruction number 4 is flushed (in red) and has L1 start right after the IF.
S + N − 1 + Branch Flush + Delay = 5 + 5 − 1 + 1 + 1 = 11

add $3, $1, $2	IF	ID	EX	M	WB							
or $4, $2, $3		IF	ID	EX	M	WB						
beq $1, $2, L1			IF	ID	EX	M	WB					
and $1, $4, $2				IF	ID	EX	M	WB				
slt $2, $1, $5					IF	ID	EX	M	WB			
					←	←	*FL*	*US*	*HED*			
L1: lw $12, 0($18)						IF	ID	EX	M	WB		
sw $12, 4($18)							IF	ID	ID	EX	M	WB
CYCLE	1	2	3	4	5	6	7	8	9	10	11	12

(b) When branch is not taken, number of clock cycles will be 12. There is a write/read hazard in the store word instruction that will need a delay.
S + N − 1 + Delay = 5 + 7 − 1 + 1 = 12

add $3, $1, $2	IF	ID	EX	M	WB							
or $4, $2, $3		IF	ID	EX	M	WB						
beq $1, $2, L1			IF	ID	EX	M	WB					
and $1, $4, $2				IF	ID	EX	M	WB				
slt $2, $1, $5					IF	ID	EX	M	WB			
L1: lw $12, 0($18)						IF	ID	EX	M	WB		
sw $12, 4($18)							IF	ID	ID	EX	M	WB
CYCLE	1	2	3	4	5	6	7	8	9	10	11	12