

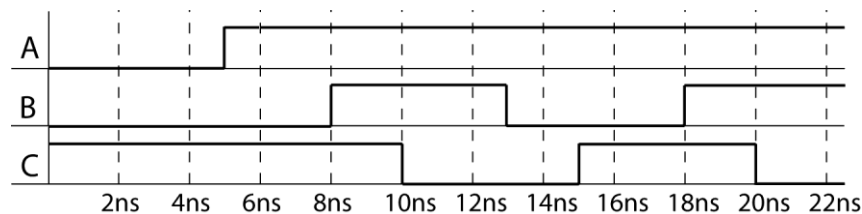
Chapter 2: Introduction to Verilog®

- 2.1 (a) HDL – Hardware Description Language
FPGA – Field Programmable Logic Array
- (b) Verilog has statements that execute concurrently since it must model real hardware in which the components are all in operation at the same time.
- (c) A hardware description language allows a digital system to be designed and debugged at a higher level of abstraction than schematic capture with gates, flip-flops, and standard MSI building blocks. The details of the gates and flip-flops do not need to be handled during early phases of design. Designs are more portable when low-level library-specific details are not included in the model. HDLs allow the creation of such portable high-level behavioral models.
- 2.2 (a) Legal: A_123, _A123, c1__c2, and1; Illegal: 123A (starts with number), \$A123_ (starts with \$), and (reserved word).
- (b) None of the Verilog identifiers are equivalent since Verilog is case sensitive.

2.3 (a)



(b)



```

2.4 module Gate(A, B, C, D, Z);
    input A, B, C, D;
    output Z;

    wire E, F, G, H, I;

    assign #5 H = A & B & C;
    assign #5 E = H | D;
    assign #5 G = ~(B | C);
    assign #5 F = ~(G & A);
    assign #2 I = ~F;
    assign #5 Z = E ^ I;
endmodule

```

- 2.5 (a)

```

module one_bit_sub(x, y, bin, diff, bout);
    input x, y, bin;
    output diff, bout;

    assign diff = x ^ y ^ bin;
    assign bout = (~x & bin) | (~x & y) | (bin & y);
endmodule

```
- (b)

```

module four_bit_sub(a, b, bin, d, bout);
    input[3:0] a, b;

```

```

    input bin;
    output[3:0] d;
    output bout;

    wire[3:0] bo;

    one_bit_sub s1(a[0], b[0], bin, d[0], bo[1]);
    one_bit_sub s2(a[1], b[1], bo[1], d[1], bo[2]);
    one_bit_sub s3(a[2], b[2], bo[2], d[2], bo[3]);
    one_bit_sub s4(a[3], b[3], bo[3], d[3], bout);
endmodule

```

2.6 (a) `module circuit(A, B, C, D, G);`

```

    input A, B, C, D;
    output G;

```

```

    wire E, F;

```

```

    assign E = A & B;
    assign F = E | C;
    assign G = D & F;

```

```

endmodule

```

(b) `module circuit(A, B, C, D, G);`

```

    input A, B, C, D;
    output reg G;

```

```

    reg E, F;

```

```

    initial begin

```

```

        E <= 0;
        F <= 0;
        G <= 0;

```

```

    end

```

```

    always @(*)

```

```

    begin

```

```

        E <= A & B;
        F <= E | C;
        G <= F & D;

```

```

    end

```

```

endmodule

```

2.7 (a) A changes to 1 at 25 ns, B changes to 1 at 25 ns, C change to 1 at 35 ns

(b) A changes to 1 at 25 ns, B changes to 1 at $20 + \Delta$ ns, C does not change

2.8 (a) A falling-edge triggered D flip-flop with asynchronous active high clear and set

(b) Q = '0', because Clr = 1 has priority.

2.9 `module SR_Latch(S, R, Q, Qn);`

```

    input S, R;
    output reg Q;
    output Qn;

```

```

    initial begin

```

```

        Q <= 0;

```

```

    end

```

```

always @(S, R)
begin
    if(S == 1'b1)
        Q <= 1'b1;
    if(R == 1'b1)
        Q <= 1'b0;
end

assign Qn = ~Q;
endmodule

```

2.10 module MNFF(M, N, CLK, CLRn, Q, Qn);

```

input M, N, CLK, CLRn;
output reg Q;
output Qn;

initial begin
    Q <= 0;
end

always @(CLK, CLRn)
begin
    if(CLRn == 1'b0)
        begin
            Q <= 0;
        end
    else if(CLK == 0)
        begin
            if(M == 0 && N == 0)
                Q <= ~Q;
            else if(M == 0 && N == 1)
                Q <= 1;
            else if(M == 1 && N == 0)
                Q <= 0;
            else if(M == 1 && N == 1)
                Q <= Q;
        end
    end

assign Qn = ~Q;
endmodule

```

2.11 module DDFR(R, S, D, Clk, Q);

```

input R, S, D, Clk;
output reg Q;

initial begin
    Q <= 0;
end

always @(Clk, R, S)
begin
    if(R == 1'b0)
        Q <= 0;
    else if(S == 1'b0)
        Q <= 1;
    else
        Q <= D;
    end
endmodule

```

2.12 (a) `module ITFF(I0, I1, T, R, Q, QN);`
`input I0, I1, T, R;`
`output reg Q;`
`output QN;`

`initial begin`
`Q <= 0;`
`end`

`always @(T, R)`
`begin`
`if(R == 1'b1)`
`#5 Q <= 0;`
`else begin`
`if((I0 == 1'b1 && T == 1'b1) || (I1 == 1'b1 && T == 1'b0))`
`#8 Q <= QN;`
`end`
`end`

`assign QN = ~Q;`
`endmodule`

(b) `add list *`
`add wave *`
`force T 0 0, 1 100 -repeat 200`
`force I1 0 0, 1 50, 0 450`
`force I0 0 0, 1 450`
`run 750 ns`

2.13

ns	Δ	a	b	c	d	e
10	+0	0	0	0	0	0
20	+0	0	0	0	0	1
20	+1	0	7	0	0	1
25	+0	1	7	0	0	1
35	+0	5	7	0	0	1

2.14

ns	Δ	a	b	c	d	e
10	+0	0	0	0	0	0
20	+0	0	0	0	0	1
20	+1	0	7	0	0	1
25	+0	1	7	0	0	1
35	+0	5	7	0	0	1

2.15 i. 5'b10101
 ii. 8'b11010101
 iii. 3'b100

2.16 i. 4'b0000
 ii. 8'b00001010
 iii. 7'b0000101

- 2.17**
- i. 8'h0D
 - ii. 8'hFD
 - iii. 8'h50
 - iv. 8'h50
 - v. 8'h0D
 - vi. 8'hFD
 - vii. 8'h50
 - viii. 8'h50

- 2.18 (a)**
- $A \gg 4 == 2'h0C$
 - $A \ggg 4 == 2'hFC$
 - $A \ll 4 == 8'h70$
 - $A \lll 4 == 8'h70$
- (b)**
- $A \gg 4 == 2'h0C$
 - $A \ggg 4 == 2'h0C$
 - $A \ll 4 == 8'h70$
 - $A \lll 4 == 8'h70$
- (c)**
- $A \gg 4 == 2'h0C$
 - $A \ggg 4 == 2'h0C$
 - $A \ll 4 == 8'h70$
 - $A \lll 4 == 8'h70$
- (d)**
- $A \gg 4 == 8'h0C$
 - $A \ggg 4 == 8'h0C$
 - $A \ll 4 == 8'h70$
 - $A \lll 4 == 8'h70$
- (e)**
- $A \gg 4 == 8'h0C$
 - $A \ggg 4 == 8'h0C$
 - $A \ll 4 == 8'h70$
 - $A \lll 4 == 8'h70$
- (f)**
- $A \gg 4 == 8'h0C$
 - $A \ggg 4 == 8'hFC$
 - $A \ll 4 == 8'h70$
 - $A \lll 4 == 8'h70$
- (g)**
- $A \gg 4 == 8'h0C$
 - $A \ggg 4 == 8'hFC$
 - $A \ll 4 == 8'h70$
 - $A \lll 4 == 8'h70$
- (h)**
- $A \gg 4 == 32'h0FFFFFFC$
 - $A \ggg 4 == 32'hFFFFFFFC$
 - $A \ll 4 == 32'hFFFFFFC70$
 - $A \lll 4 == 32'hFFFFFFC70$

- 2.19**
- i. 8'h0D
 - ii. 8'h0D
 - iii. 8'h50
 - iv. 8'h50
 - v. 8'h0D

- vi. 8'h0D
- vii. 8'h50
- viii. 8'h50

- 2.20
- i. 8'h0D
 - ii. 8'h0D
 - iii. 8'h50
 - iv. 8'h50
 - v. 8'h0D
 - vi. 8'h0D
 - vii. 8'h50
 - viii. 8'h50

2.21 The synthesized hardware is a 4-bit shift register.

2.22 The synthesized hardware is a single flip-flop.

2.23 Both modules are synthesized to 4-bit shift registers. There are no differences between the two shift registers.

2.24 (a) D1 = 5, D2 = 1. The values of D1 and D2 swap.

(b) D1 = 1, D2 = 1. The values of D1 and D2 do not swap.

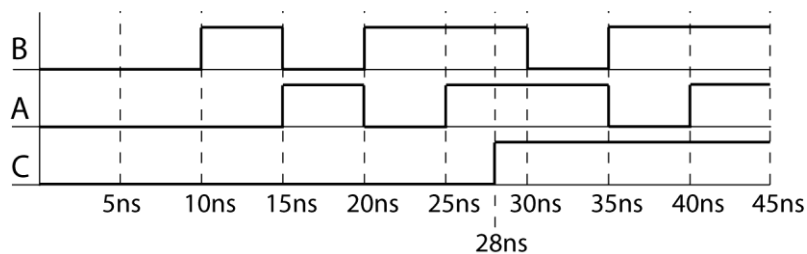
(c) iii

2.25 a; y must be in the sensitivity list, otherwise *sum* and *carry* will not update from changes to y

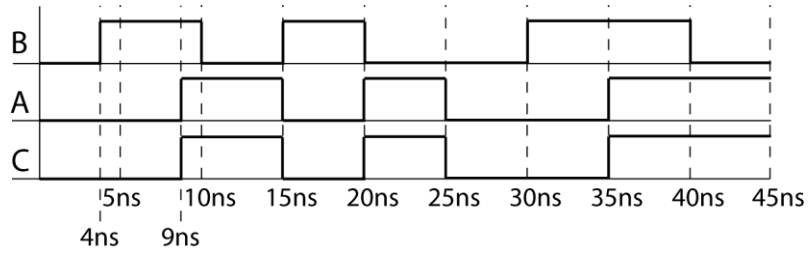
2.26

ns	Δ	a	b	c	d	e	f
0	+0	0	0	0	0	0	0
5	+0	0	0	0	1	0	0
5	+1	1	0	0	1	0	0
5	+2	1	1	1	1	0	0
6	+0	1	1	1	0	0	0
10	+0	1	1	1	0	1	0
10	+1	0	1	1	0	1	0
10	+2	0	0	0	0	1	0

2.27



2.28



2.29 (a)

ns	a	b	c
0	1	0	0
4	1	1	0
5	1	1	1
10	1	0	1
15	1	1	0
20	1	0	1
25	1	0	0
30	1	1	0
35	1	1	1
40	1	0	1
45	1	0	0

(b)

ns	a	b	c
0	1	0	0
4	1	1	0
5	1	1	1
10	1	0	1
15	1	1	0
20	1	0	1
25	1	0	0
30	1	1	0
35	1	1	1
40	1	0	1
45	1	0	0

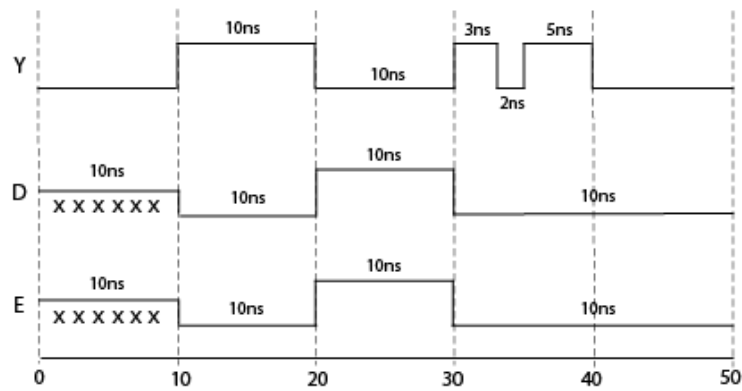
(c)

ns	a	b	c
0	1	0	0
4	1	1	0
9	1	1	1
10	1	0	1
15	1	1	0
20	1	0	1
25	1	0	0
30	1	1	0
35	1	1	1
40	1	0	1
45	1	0	0

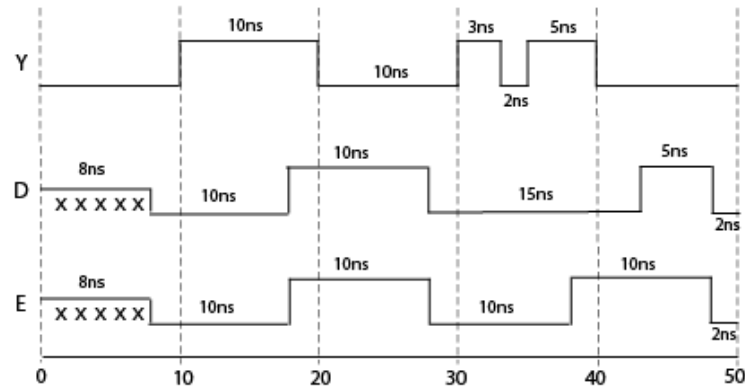
(d)

ns	a	b	c
0	1	0	0
4	1	1	0
10	1	0	0
15	1	1	0
20	1	0	1
25	1	0	0
30	1	1	0
35	1	1	1
40	1	0	1
45	1	0	0

2.30



2.31

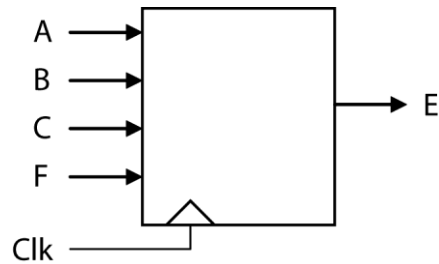


2.32

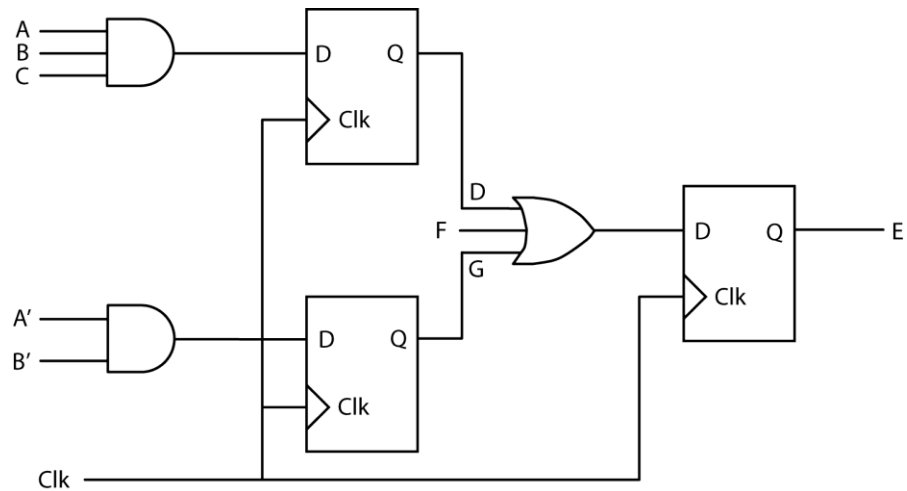
ns	Δ	a	b	c	d
4	+0	0	0	0	0
5	+0	1	0	0	0
10	+0	1	1	0	0
10	+1	0	1	0	0
11	+0	0	1	0	1
12	+0	0	1	1	1
15	+0	0	0	1	1

- 2.33 (a) 6'b111011
 (b) 3'b001
 (c) 3'b001
 (d) 1'b0
 (e) 3'b111

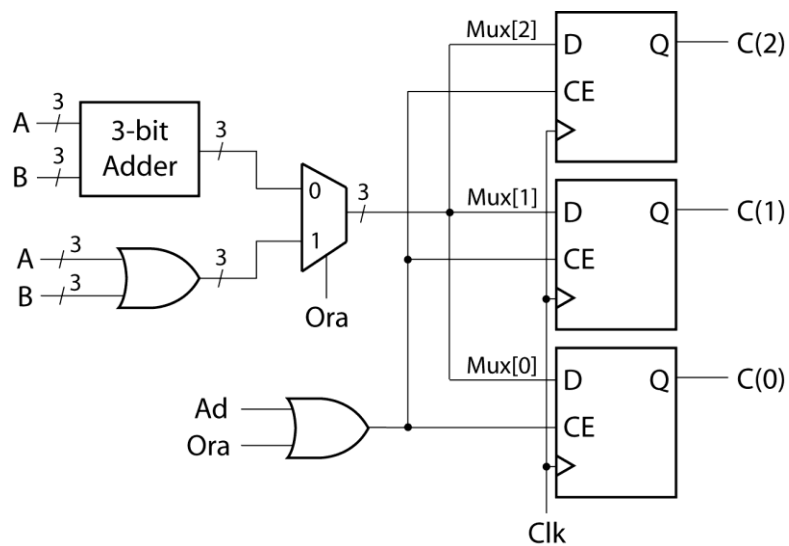
2.34 (a)



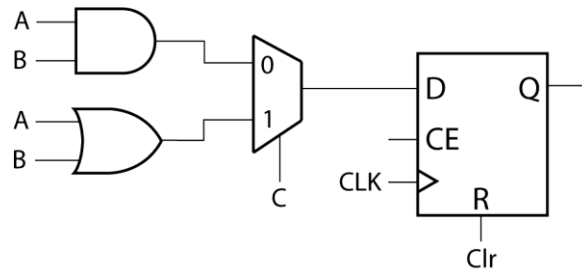
(b)



2.35



2.36



Clr is asynchronous, whereas C affects a synchronous input to the D flip-flop.

2.37 (a) `assign #10 F = (C == 0) ? ((D==0)? ~A: B) : ((D==0)? ~B: 0);`

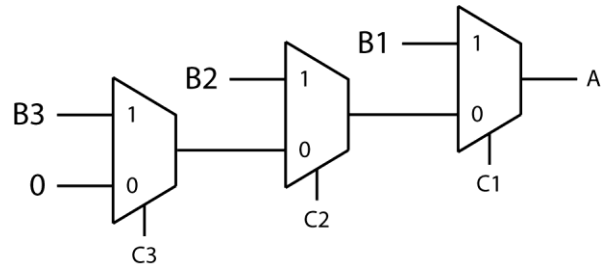
(b) `always @(*)
begin
 if(C==0 && D==0)
 #10 F = ~A;
 else if(C==0 && D==1)
 #10 F = B;
 else if(C==1 && D==0)
 #10 F = ~B;
 else
 #10 F = 0;
end`

(c) `always @(*)
begin
 case(sel)
 0: #10 F = ~A;
 1: #10 F = B;
 2: #10 F = ~B;
 3: #10 F = 0;
 endcase
end`

2.38 (a) `module 1:
always @(C, B1, B2, B3)
begin
 if (C == 1)
 A <= B1;
 else if (C == 2)
 A <= B2;
 else if (C == 3)
 A <= B3;
 else
 A <= 0;
end

module 2:
assign A = (C==1)? B1 : ((C==2)? B2 : ((C==3)? B3 : 0));`

(b)



2.39 (a)

```
module SR_Latch(S, R, P, Q);
    input S, R;
    output P, Q;

    assign Q = (S)? 1 : ((R)? 0 : Q);
    assign P = ~Q;

endmodule
```

(b)

```
assign Q = S | (~R & Q);
assign P = ~Q;
```

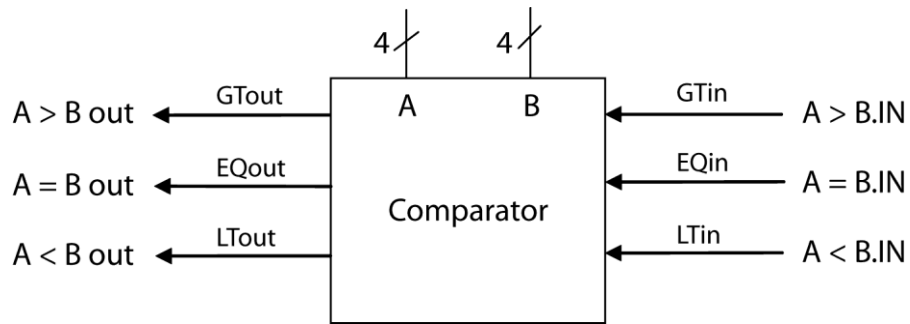
(c)

```
assign Q = ~(R | P);
assign P = ~(S | Q);
```

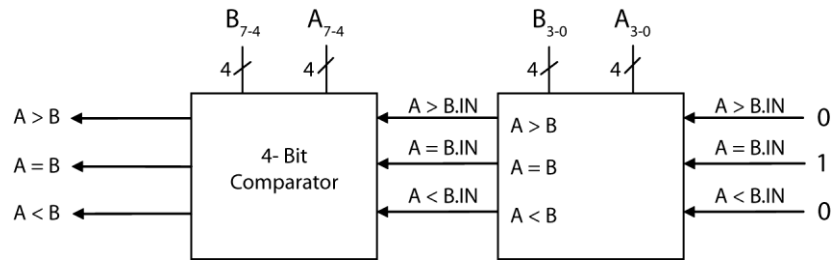
- 2.40
- i. 8'b00010100
 - ii. 8'b00010100
 - iii. 8'b11111100
 - iv. 8'b11111100
 - v. 8'b00010100
 - vi. 8'b00010100

- 2.41
- i. 32'hFFFFFF5B
 - ii. 32'hFFFFFF5B
 - iii. 32'h0000015B
 - iv. 32'h0000015B
 - v. 32'h0000005B
 - vi. 32'h0000005B

2.42 (a)



(b)



(c) `module comp4bit(A, B, EQin, GTin, LTin, EQout, GTout, LTout);
input[3:0] A, B;
input EQin, GTin, LTin;
output reg EQout, GTout, LTout;`

```
initial begin  
    EQout = 0;  
    GTout = 0;  
    LTout = 0;  
end  
  
always @(A, B, EQin, GTin, LTin)  
begin  
    if(A > B) begin  
        EQout <= 0;  
        GTout <= 1;  
        LTout <= 0;  
    end  
    else if(A < B) begin  
        EQout <= 0;  
        GTout <= 0;  
        LTout <= 1;  
    end  
    else if(GTin == 1) begin  
        EQout <= 0;  
        GTout <= 1;  
        LTout <= 0;  
    end  
    else if(LTin == 1) begin  
        EQout <= 0;  
        GTout <= 0;  
        LTout <= 1;  
    end  
    else begin  
        EQout <= 1;  
        GTout <= 0;  
        LTout <= 0;  
    end  
end  
endmodule
```

(d) `module comp8bit(A, B, EQi, GTi, LTi, EQ, GT, LT);
input[7:0] A, B;
input EQi, GTi, LTi;
output EQ, GT, LT;

wire LowEQ, LowGT, LowLT;

comp4bit C1(A[3:0], B[3:0], EQi, GTi, LTi, LowEQ, LowGT, LowLT);
comp4bit C2(A[7:4], B[7:4], LowEQ, LowGT, LowLT, EQ, GT, LT);
endmodule`

```

2.43 module shift_reg(SI, EN, CK, SO);
    input SI, EN, CK;
    output SO;
    reg[15:0] register;

    initial begin
        register <= 0;
    end

    always @(posedge CK)
    begin
        if(EN == 1)
            register <= {SI, register[15:1]};
        end

    assign SO = register[0];
endmodule

```

```

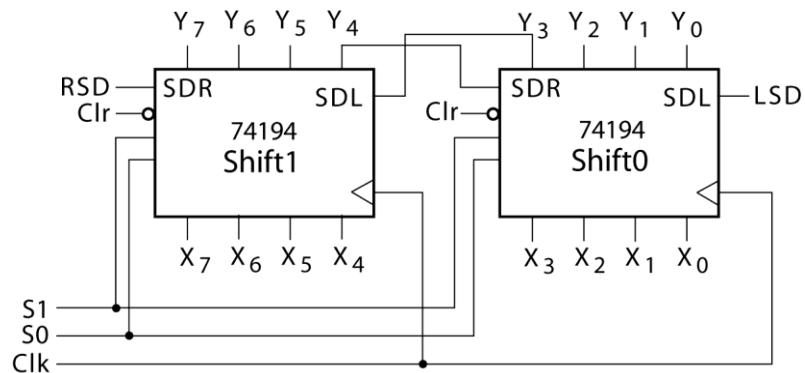
2.44 (a) module shift74194(D, S, SDR, SDL, CLRb, CLK, Q);
    input[3:0] D;
    input[1:0] S;
    input SDR, SDL, CLRb, CLK;
    output reg [3:0] Q;

    initial begin
        Q <= 0;
    end

    always @(CLK, CLRb)
    begin
        if(CLRb == 0)
            Q <= 4'b0000;
        else if(CLK == 1)
            begin
                case(S)
                0: Q <= Q;
                1: Q <= {Q[2:0], SDL};
                2: Q <= {SDR, Q[3:1]};
                3: Q <= D;
                endcase
            end
        end
    endmodule

```

(b)



```

module bit8shift(X, S, RSD, LSD, CLRb, CLK, Y);
    input[7:0] X;
    input[1:0] S;
    input RSD, LSD, CLRb, CLK;
    output[7:0] Y;

    shift74194 S1(X[3:0], S, Y[4], LSD, CLRb, CLK, Y[3:0]);
    shift74194 S2(X[7:4], S, RSD, Y[3], CLRb, CLK, Y[7:4]);
endmodule

```

2.45 (a)

```

module Counter(D, CLK, CLR, ENT, ENP, UP, LOAD, Q, CO);
    input[3:0] D;
    input CLK, CLR, ENT, ENP, UP, LOAD;
    output reg[3:0] Q;
    output CO;

    initial begin
        Q = 0;
    end

    assign CO = ((ENT == 1) && ((UP == 1 && (Q == 4'b1001)) ||
        (UP == 0 && (Q == 4'b0000))));

    always @(CLK, CLR)
    begin
        if(CLR == 0)
            Q <= 0;
        else if(CLK == 1)
            begin
                if(LOAD == 0)
                    Q <= D;
                else if(ENT == 1 && ENP == 1 && UP == 0) begin
                    if(Q == 0)
                        Q <= 4'b1001;
                    else
                        Q <= Q - 1;
                end
                else if(ENT == 1 && ENP == 1 && UP == 1) begin
                    if(Q == 4'b1001)
                        Q <= 0;
                    else
                        Q <= Q + 1;
                end
            end
        end
    end
endmodule

```

(b)

```

module Century_Counter(Din1, Din2, CLK, CLR, ENT, ENP, UP, LOAD,
Count, CO);
    input [3:0] Din1, Din2;
    input CLK, CLR, ENT, ENP, UP, LOAD;
    output [7:0] Count;
    output CO;

    wire [3:0] Qout1, Qout2;
    wire Carry1, Carry2;

    Counter ct1(Din1, CLK, CLR, ENT, ENP, UP, LOAD, Qout1, Carry1);
    Counter ct2(Din2, CLK, CLR, ENT, Carry1, UP, LOAD, Qout2,
Carry2);

```

```

    assign Count = {Qout2, Qout1};
    assign CO = Carry2;
endmodule

```

The block diagram is similar to Figure 2-45 with an "Up" input added to each counter.

(c)

```

add wave *
force Din2 4'b1001
force Din1 4'b1000
force CLK 0 0 ns, 1 50 ns -repeat 100 ns
force CLR 1 0 ns, 0 1000 ns
force LOAD 0 0 ns, 1 100 ns
force ENT 1 0 ns, 0 400 ns, 1 600 ns
force ENP 1
force UP 1 0 ns, 0 500 ns
run 1200 ns

```

- 2.46 Students should look on the web for 74HC192 data sheet. CLR is active high. LOADB is active low. Counting up happens when UP has a rising edge and DOWN=1. Counting down happens when DOWN has a rising edge and UP=1. CARRY indicates terminal count in the up direction, i.e. 9. BORROW indicates terminal count in the down direction, i.e. 0.

Operating Mode	CLR	LOADB	UP	DOWN	D	Q	Borrow	Carry
Clear	1	X	X	0	XXXX	0000	0	1
	1	X	X	1	XXXX	0000	1	1
Load	0	0	X	X	XXXX	Q = D	1*	1*
Count Up	0	1	↑	1	XXXX	Q = Q + 1	1	1**
Count Down	0	1	1	↑	XXXX	Q = Q - 1	1**	1

* when loading, if the input is 0 and down = 0, borrow will be 0. If the input is 9 and up = 0, carry will be 0

** Borrow = 0 when the counter is in state 0 and down = 0. Carry = 0 when the counter is in state 9 and up = 0.

```

module count74HC192(DOWN, UP, CLR, LOADB, BORROW, CARRY, D, Q);
    input DOWN, UP, CLR, LOADB;
    input[3:0] D;
    output BORROW, CARRY;
    output reg[3:0] Q;

    initial begin
        Q = 0;
    end

    always @(DOWN, UP, CLR, LOADB)
    begin
        if(CLR == 1)
            Q <= 0;
        else if(LOADB == 0)
            Q <= D;
        else if(DOWN == 1) begin
            @(posedge UP)
            if(Q == 4'b1001)
                Q <= 0;
            else
                Q <= Q + 1;
        end
        else if(UP == 1) begin
            @(posedge DOWN)

```

```

        if(Q == 0)
            Q <= 4'b1001;
        else
            Q <= Q - 1;
        end
    end
end

assign BORROW = (DOWN == 0 && Q == 0)? 0 : 1;
assign CARRY = (UP == 0 && Q == 4'b1001)? 0 : 1;
endmodule

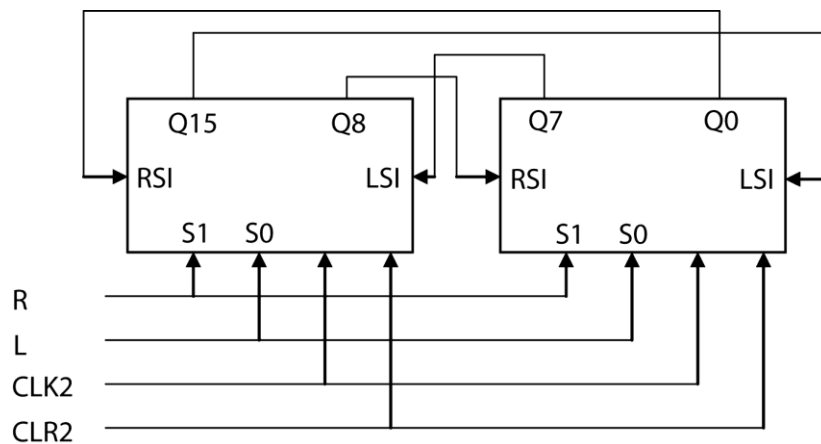
```

2.47 (a) **module** shift8(Q, D, CLR, CLK, S0, S1, LSI, RSI);
input [7:0] D;
output reg [7:0] Q;
input CLR, CLK, S0, S1, LSI, RSI;

initial begin
 Q = 0;
end

always @(CLK, CLR)
begin
if(CLR == 1)
 Q <= 0;
else if(CLK == 1) **begin**
if(S0 == 1 && S1 == 1)
 Q <= D;
else if(S0 == 0 && S1 == 1)
 Q <= {RSI, Q[7:1]};
else if(S0 == 1 && S1 == 0)
 Q <= {Q[6:0], LSI};
else
 Q <= Q;
end
end
end
endmodule

(b)



Note: D is not shown in the diagram.

(c) **module** shiftreg(QQ, DD, CLK2, CLR2, L, R);
input [15:0] DD;
input CLK2, CLR2, L, R;

```

        output[15:0] QQ;

        shift8 SR1(QQ[15:8], DD[15:8], CLR2, CLK2, L, R, QQ[7], QQ[0]);
        shift8 SR2(QQ[7:0], DD[7:0], CLR2, CLK2, L, R, QQ[15], QQ[8]);
    endmodule

```

2.48 **module** countQ1(clk, Ld8, Enable, S5, Q);
 input clk, Ld8, Enable;
 output S5;
 output[3:0] Q;

 reg[3:0] Qint;

 initial begin
 Qint = 0;
 end

 always @(posedge clk)
 begin
 if(Ld8 == 1)
 Qint <= 4'b1000;
 else if(Enable == 1)
 begin
 if(Qint == 4'b0011)
 Qint <= 4'b1000;
 else
 Qint <= Qint - 1;
 end
 end

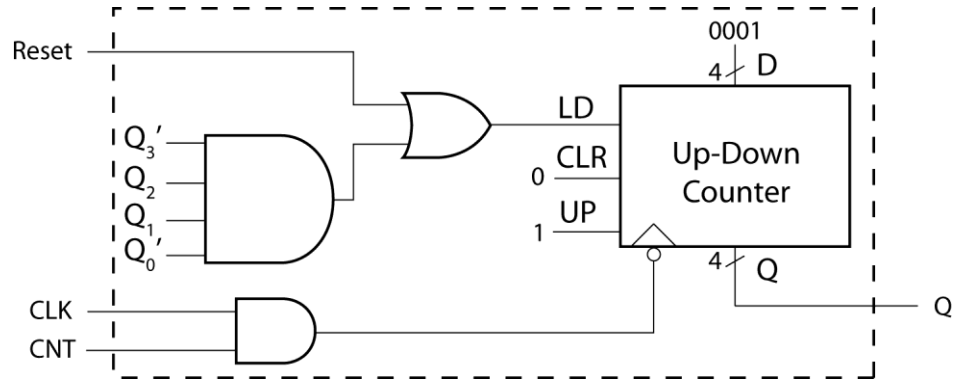
 assign S5 = (Qint == 4'b0101)? 1 : 0;
 assign Q = Qint;
 endmodule

2.49 **(a)** **module** up_down(CLK, CLR, LD, UP, D, Q);
 input CLK, CLR, LD, UP;
 input[3:0] D;
 output reg[3:0] Q;

 initial begin
 Q = 0;
 end

 always @(negedge CLK)
 begin
 if(CLR == 1)
 Q <= 4'b0000;
 else if(LD == 1)
 Q <= D;
 else if(UP == 1)
 Q <= Q + 1;
 else
 Q <= Q - 1;
 end
 endmodule

(b)



(c)

```

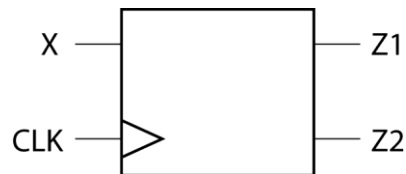
module modulo6(CLK, Reset, CNT, Q);
    input CLK, Reset, CNT;
    output [3:0] Q;
    wire load, clock;

    assign load = Reset | (~Q[0] & Q[1] & Q[2] & ~Q[3]);
    assign clock = CLK & CNT;

    up_down U1(clock, 1'b0, load, 1'b1, 4'b0001, Q);
endmodule

```

2.50 (a)



(b)

Present State	Next State		X = 0		X = 1	
	X = 0	X = 1	Z1	Z2	Z1	Z2
S0	S0	S1	1	0	0	0
S1	S1	S2	0	1	0	1
S2	S2	S3	0	1	0	1
S3	S0	S1	0	0	1	0

2.51 The following solutions utilize the solution for 1.13.

```

(a) module P2_51a(X, CLK, S, V);
    input X, CLK;
    output S, V;

    reg [2:0] StateTable0 [5:0];
    reg [2:0] StateTable1 [5:0];
    reg [1:0] OutTable0 [5:0];
    reg [1:0] OutTable1 [5:0];

    reg [2:0] State;
    wire [2:0] NextState;

```

```

initial begin
    StateTable0[0] <= 1; StateTable1[0] <= 1;
    StateTable0[1] <= 2; StateTable1[1] <= 4;
    StateTable0[2] <= 3; StateTable1[2] <= 3;
    StateTable0[3] <= 0; StateTable1[3] <= 0;
    StateTable0[4] <= 3; StateTable1[4] <= 5;
    StateTable0[5] <= 0; StateTable1[5] <= 0;
    OutTable0[0] <= 2'b00; OutTable1[0] <= 2'b10;
    OutTable0[1] <= 2'b10; OutTable1[1] <= 2'b00;
    OutTable0[2] <= 2'b00; OutTable1[2] <= 2'b10;
    OutTable0[3] <= 2'b00; OutTable1[3] <= 2'b10;
    OutTable0[4] <= 2'b10; OutTable1[4] <= 2'b00;
    OutTable0[5] <= 2'b10; OutTable1[5] <= 2'b01;
    State <= 0;
end

    assign NextState = (X==0)? StateTable0[State] :
StateTable1[State];
    assign S = (X==0)? OutTable0[State][1] : OutTable1[State][1];
    assign V = (X==0)? OutTable0[State][0] : OutTable1[State][0];

    always @(negedge CLK)
    begin
        State <= NextState;
    end
endmodule

```

example simulation commands:

```

add wave *
force CLK 1 0 ns, 0 10 ns -repeat 20 ns
force X 1 0 ns, 0 15 ns, 1 35 ns, 0 75 ns, 1 95 ns, 0 175 ns
run 240 ns

```

(b)

```

module P2_51b(X, CLK, S, V);
    input X, CLK;
    output S, V;

    reg Q1, Q2, Q3;

    initial begin
        Q1 <= 0;
        Q2 <= 0;
        Q3 <= 0;
    end

    always @(negedge CLK)
    begin
        Q1 <= (~Q1 & Q3);
        Q2 <= (~Q2 & ~Q3) | (X & ~Q1 & Q2);
        Q3 <= (~Q1 & Q3) | (Q2 & ~Q3);
    end

    assign S = (X & ~Q2) | (~X & Q2);
    assign V = (X & Q1 & Q2);
endmodule

```

Read each set of outputs after 1/4 clock period before the falling edge of the clock but no later than the falling edge of the clock.

```

(c)  module P2_51c(X, CLK, S, V);
      input X, CLK;
      output S, V;

      wire Q1, Q2, Q3;
      wire XN, Q1N, Q2N, Q3N;
      wire D1, D2, D3;
      wire A1, A2, A3, A4, A5, A6;

      Inverter I1(X, XN);
      And2 G1(Q1N, Q3, D1);
      And2 G2(Q2N, Q3N, A1);
      And3 G3(X, Q1N, Q2, A2);
      Or2 G4(A1, A2, D2);
      And2 G5(Q1N, Q3, A3);
      And2 G6(Q2, Q3N, A4);
      Or2 G7(A3, A4, D3);
      And2 G8(X, Q2N, A5);
      And2 G9(XN, Q2, A6);
      Or2 G10(A5, A6, S);
      And3 G11(X, Q1, Q2, V);
      DFF DFF1(D1, CLK, Q1, Q1N);
      DFF DFF2(D2, CLK, Q2, Q2N);
      DFF DFF3(D3, CLK, Q3, Q3N);
  endmodule

```

See Section 2.15 for the definition of the `DFF` component. The `And3`, `And2`, `Or2`, and `Inverter` components are all similar to the `Nand3` component given on pages 109-110 (section 2.15).

2.52 The following solutions utilize the solution for 1.14.

```

(a)  module P2_52a(X, CLK, D, B);
      input X, CLK;
      output reg D, B;
      reg[2:0] State, NextState;

      initial begin
        State <= 0;
        NextState <= 0;
      end

      always @(State, X)
      begin
        case(State)
          0:begin
            if(X == 0)
            begin
              D <= 0;
              B <= 0;
              NextState <= 1;
            end
            else begin
              D <= 1;
              B <= 0;
              NextState <= 1;
            end
          end
          1:begin
            if(X == 0)
            begin
              D <= 1;

```

```

        B <= 0;
        NextState <= 2;
    end
    else begin
        D <= 0;
        B <= 0;
        NextState <= 3;
    end
end
2: begin
    if(X == 0)
    begin
        D <= 1;
        B <= 0;
        NextState <= 4;
    end
    else begin
        D <= 0;
        B <= 0;
        NextState <= 5;
    end
end
3: begin
    if(X == 0)
    begin
        D <= 0;
        B <= 0;
        NextState <= 5;
    end
    else begin
        D <= 1;
        B <= 0;
        NextState <= 5;
    end
end
4: begin
    if(X == 0)
    begin
        D <= 1;
        B <= 1;
        NextState <= 0;
    end
    else begin
        D <= 0;
        B <= 0;
        NextState <= 0;
    end
end
5: begin
    if(X == 0)
    begin
        D <= 0;
        B <= 0;
        NextState <= 0;
    end
    else begin
        D <= 1;
        B <= 0;
        NextState <= 0;
    end
end
endcase
end

```

```

    always @(negedge CLK)
    begin
        State <= NextState;
    end
endmodule

```

example simulation commands:

```

add wave *
force CLK 1 0 ns, 0 10 ns -repeat 20 ns
force X 1 0 ns, 0 15 ns, 1 35 ns, 0 75 ns, 1 95 ns, 0 175 ns
run 240 ns

```

(b)

```

module P2_52b(X, CLK, D, B);
    input X, CLK;
    output D, B;

    reg Q1, Q2, Q3;

    initial begin
        Q1 <= 0;
        Q2 <= 0;
        Q3 <= 0;
    end

    always @(negedge CLK)
    begin
        Q1 <= (~Q1 & ~Q3) | (~X & Q1 & ~Q2);
        Q2 <= (~Q2 & Q3);
        Q3 <= ~Q2 & (Q3 | Q1);
    end

    assign D = (~X & Q1) | (X & ~Q1 & Q3);
    assign B = ~X & Q1 & Q2;
endmodule

```

Read each set of outputs after 3/4 clock period before the falling edge of the clock but no later than the falling edge of the clock.

(c)

```

module PC_52c(X, CLK, D, B);
    input X, CLK;
    output D, B;
    wire A1, A2, A3;
    wire Q1, Q2, Q3;
    wire Q1N, Q2N, Q3N, XN, One;
    parameter I = 1;

    Inverter I1(X, XN);
    Nand2 G1(XN, Q2N, A1);
    JKFF FF1(I, I, Q3N, A1, CLK, Q1, Q1N);
    JKFF FF2(I, I, Q3, I, CLK, Q2, Q2N);
    JKFF FF3(I, I, Q1, Q2, CLK, Q3, Q3N);
    Nand2 G2(XN, Q1, A2);
    Nand3 G3(X, Q1N, Q3, A3);
    Nand2 G4(A2, A3, D);
    And3 G5(XN, Q1, Q2, B);
endmodule

```

The Nand2, And3, and Inverter components are similar to the Nand3 component in Section 2.15. The JKFF component is similar to the DFF component in Section 2.15.

```

2.53 module moore_mach(X1, X2, Clk, Z);
    input X1, X2;
    input Clk;
    output Z;

    reg[1:0] state;

    initial begin
        state <= 1;
    end

    always @(negedge Clk)
    begin
        case(state)
        1: begin
            if((X1 ^ X2) == 1)begin
                #10 state <= 2;
            end
        end
        2: begin
            if(X2 == 1)begin
                #10 state <= 1;
            end
        end
        default: begin
            end
        endcase
    end

    assign #10 Z = state[1];
endmodule

```

```

2.54 module P_54(x1, x2, clk, z1, z2);
    input x1, x2, clk;
    output z1, z2;

    reg[1:0] state, next_state;

    initial begin
        state <= 1;
        next_state <= 1;
    end

    always @(state, x1, x2)
    begin
        case(state)
        1: begin
            if({x1,x2} == 2'b00)
                #10 next_state <= 3;
            else if({x1,x2} == 2'b01)
                #10 next_state <= 2;
            else
                #10 next_state <= 1;
        end
        2: begin
            if({x1,x2} == 2'b00)
                #10 next_state <= 2;
            else if({x1,x2} == 2'b01)
                #10 next_state <= 1;
            else
                #10 next_state <= 3;
        end
    end
endmodule

```

```

end
3: begin
    if({x1,x2} == 2'b00)
        #10 next_state <= 1;
    else if({x1,x2} == 2'b01)
        #10 next_state <= 2;
    else
        #10 next_state <= 3;
    end
endcase
end

always @(negedge clk)
begin
    #5 state <= next_state;
end

assign #10 z1 = (state == 2)? 1: 0;
assign #10 z2 = (state == 3)? 1: 0;
endmodule

```

2.55 (a) *nextstate* is not always assigned a new value in the conditional statements, i.e. else clauses are not specified. Therefore, a latch will be created to hold *nextstate* to its old value.

(b) The latch output would have the most recent value of *nextstate*.

(c)

```

always @(state, X)
begin
    case(state)
    0: begin
        if(X == 1)
            nextstate <= 1;
        else
            nextstate <= 0;
        end
    1: begin
        if(X == 0)
            nextstate <= 2;
        else
            nextstate <= 1;
        end
    2: begin
        if(X == 1)
            nextstate <= 0;
        else
            nextstate <= 2;
        end
    endcase
end

```

(d) Yes, unconditionally set *nextstate* to a default value at the beginning of the always block

2.56 The nonblocking assignments must be changed to blocking assignments. Otherwise *sel* will not update for current use. *sel* updates only at the end of the process so the case statement will get the wrong value.

2.57

ns	Δ	A	B	D
0	+0	0	0	0
5	+0	1	0	0
15	+0	1	0	1
15	+1	1	1	1
25	+0	1	1	0
25	+1	1	0	0
35	+0	1	0	1
35	+1	1	1	1
40	+0	0	1	1

2.58 Rising-edge triggered toggle flip-flop (T-flip-flop), with asynchronous active-high clear signal

2.59 (a) **module** ROM4_3(ROMin, ROMout);
input[3:0] ROMin;
output[2:0] ROMout;

reg[2:0] ROM16X3 [15:0];

initial begin
ROM16X3[0] <= 3'b000;
ROM16X3[1] <= 3'b001;
ROM16X3[2] <= 3'b001;
ROM16X3[3] <= 3'b010;
ROM16X3[4] <= 3'b001;
ROM16X3[5] <= 3'b010;
ROM16X3[6] <= 3'b010;
ROM16X3[7] <= 3'b011;
ROM16X3[8] <= 3'b001;
ROM16X3[9] <= 3'b010;
ROM16X3[10] <= 3'b010;
ROM16X3[11] <= 3'b011;
ROM16X3[12] <= 3'b010;
ROM16X3[13] <= 3'b011;
ROM16X3[14] <= 3'b011;
ROM16X3[15] <= 3'b100;
end

assign ROMout = ROM16X3[ROMin];
endmodule

(b) **module** P_59(A, count);
input[11:0] A;
output[3:0] count;

wire[2:0] B,C,D;

ROM4_3 R1(A[11:8], B);
ROM4_3 R2(A[7:4], C);
ROM4_3 R3(A[3:0], D);

assign count = {1'b0, B} + C + D;
endmodule

(c)

A	Count	D	C	B
111111111111	1100	100	100	100
010110101101	0111	011	010	010
100001011100	0101	010	010	001

2.60

a	b	c	y ₇	y ₆	y ₅	y ₄	y ₃	y ₂	y ₁	y ₀
0	0	0	0	0	0	0	0	0	0	1
0	0	1	0	0	0	0	0	0	1	0
0	1	0	0	0	0	0	0	1	0	0
0	1	1	0	0	0	0	1	0	0	0
1	0	0	0	0	0	1	0	0	0	0
1	0	1	0	0	1	0	0	0	0	0
1	1	0	0	1	0	0	0	0	0	0
1	1	1	1	0	0	0	0	0	0	0

```
module decoder(A, B, C, Y);
    input A,B,C;
    output[7:0] Y;
    wire[2:0] index;
    reg[7:0] ROM[0:7];

    initial begin
        ROM[0] <= 8'b00000001;
        ROM[1] <= 8'b00000010;
        ROM[2] <= 8'b00000100;
        ROM[3] <= 8'b00001000;
        ROM[4] <= 8'b00010000;
        ROM[5] <= 8'b00100000;
        ROM[6] <= 8'b01000000;
        ROM[7] <= 8'b10000000;
    end

    assign index = {A,B,C};
    assign Y = ROM[index];
endmodule
```

2.61

```
(a) always
begin
    MAX = A[0];
    for (i = 0; i < 20; i = i + 1) begin
        if(A[i] > MAX)
            MAX = A[i];
    end
end
```

```
(b) always
begin
    MAX = A[0];
    i = 1;
    while (i < 20) begin
        if(A[i] > MAX)
            MAX = A[i];
        i = i + 1;
    end
end
```

```

2.62 module tester;
    reg CLK;
    reg [0:11] X;
    reg [0:11] Z;

    initial begin
        X = 12'b011011011100;
        Z = 12'b100110110110;
        CLK = 1;
    end

    reg Xin;
    wire Zout;
    integer i;

    always
        #50 CLK = ~CLK;

    Mealy M1(Xin, CLK, Zout);

    always
    begin
        for(i = 0; i < 12; i = i + 1) begin
            @(posedge CLK)
                #10 Xin = X[i];
                #80 // wait to read output
                if( Zout != Z[i]) begin
                    $display("Error");
                    $stop;
                end
            end
            $display("sequence correct");
            $stop;
        end
    endmodule

```

```

2.63 module TestExcess3;
    reg[3:0] XA[1:10];
    reg[3:0] ZA[1:10];
    reg X, CLK;
    wire Z;
    integer i;
    integer j;

    initial begin
        X = 0;
        CLK = 0;
        XA[1] = 4'b0000;
        XA[2] = 4'b0001;
        XA[3] = 4'b0010;
        XA[4] = 4'b0011;
        XA[5] = 4'b0100;
        XA[6] = 4'b0101;
        XA[7] = 4'b0110;
        XA[8] = 4'b0111;
        XA[9] = 4'b1000;
        XA[10] = 4'b1001;
        ZA[1] = 4'b0011;
        ZA[2] = 4'b0100;
        ZA[3] = 4'b0101;
        ZA[4] = 4'b0110;
        ZA[5] = 4'b0111;
        ZA[6] = 4'b1000;
    end

```

```

        ZA[7] = 4'b1001;
        ZA[8] = 4'b1010;
        ZA[9] = 4'b1011;
        ZA[10] = 4'b1100;
    end

    always
        #50 CLK <= ~CLK;

    Code_Converter C1(X, CLK, Z);

    always
    begin
        for(i = 1 ; i <= 10; i = i + 1)
        begin
            for(j= 0; j <= 3; j = j + 1)
            begin
                X = XA[i][j];
                @(posedge CLK);
                #(25);
                if(ZA[i][j] != Z) begin
                    $display("sequence incorrect");
                    $stop;
                end
            end
        end
        $display("all sequences correct");
        $stop;
    end
endmodule

2.64 module testbench;
    wire S5;
    reg clk, Ld8, Enable;
    wire[3:0] Q;

    initial begin
        clk = 1;
        Ld8 = 1;
        Enable = 0;
        #100
        Ld8 = 0;
        Enable = 1;
        #500 Enable = 0;
        #200 Enable = 1;
        #1000 Enable = 0;
    end

    always
        #50 clk <= ~clk;

    always @(posedge S5)
        $display($time);

    countQ1 C1(clk, Ld8, Enable, S5, Q);
endmodule

2.65 module testSMQ1(correct);
    output reg correct;
    reg clk, X;
    integer i;
    wire Z;
    reg[1:5] answer;

```

```

initial begin
    answer[1] = 1;
    answer[2] = 1;
    answer[3] = 0;
    answer[4] = 1;
    answer[5] = 0;
    clk = 0;
    X = 1;
    #100 X = 0;
    #200 X = 1;
end

always
    #50 clk <= ~clk;

SMQ1 S1(X, clk, Z);

always
begin
    for(i = 1; i <= 5; i = i + 1)
    begin
        @(posedge clk);
        correct = (answer[i] == Z);
        if(correct == 0)
            $display($time);
        #10;
    end
    $stop;
end
endmodule

```

