

A decorative graphic on the left side of the slide, consisting of a network of white lines and circles on a blue gradient background. The lines and circles resemble a circuit board or a digital network, with some lines ending in small circles.

DIGITAL DESIGN

LAB14 COUNTER, VERILOG SUMMARY, TIPS FOR DEBUG

2024 FALL TERM @ CSE . SUSTECH

LAB14

- Counter
 - Ring Counter
 - Johnson Counter
- Tips1: Debug
- Tips2: Verilog Summary

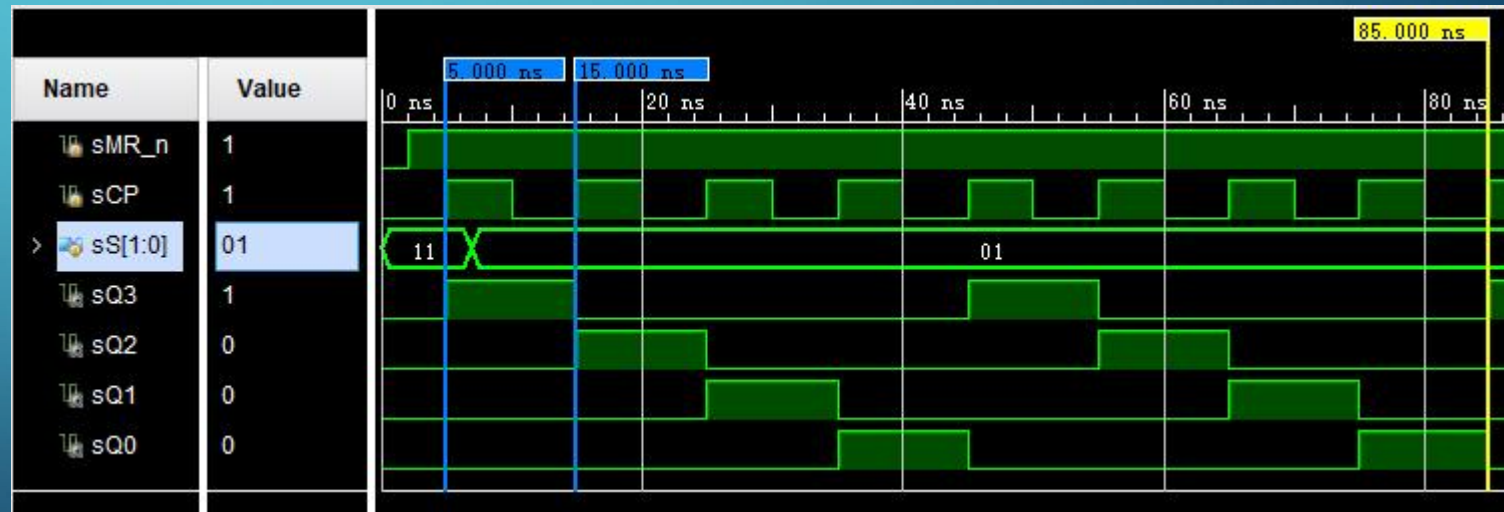
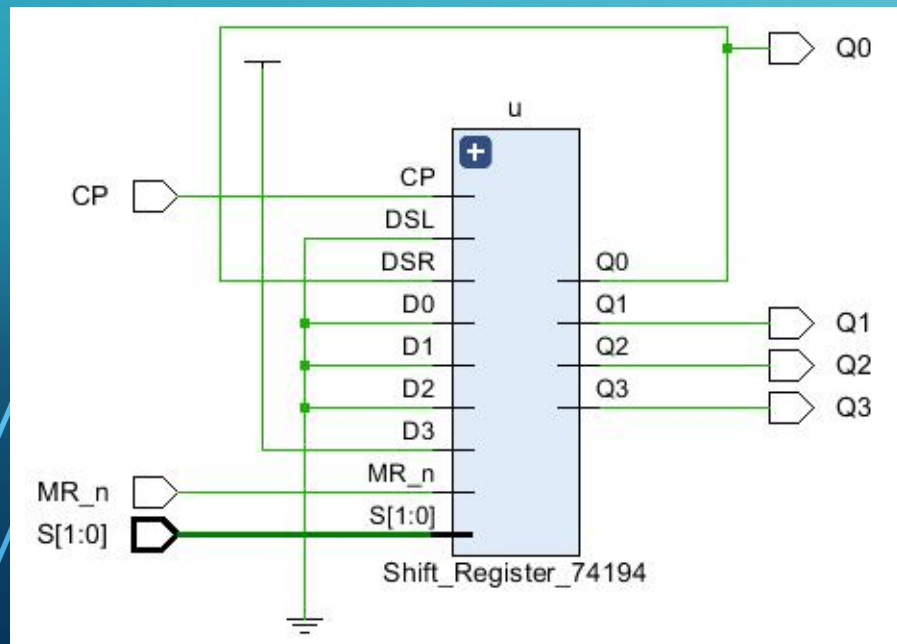
COUNTER

- In digital logic and computing, a **counter** is a device which stores (and sometimes displays) the number of times a particular event or process has occurred, often in relationship to a clock signal. The most common type is a sequential digital logic circuit with an input line called the *clock* and multiple output lines. The values on the output lines represent a number in the binary or BCD number system. Each pulse applied to the clock input increments or decrements the number in the counter.
- A counter circuit is usually constructed of a number of flip-flops connected in cascade. Counters are a very widely used component in digital circuits, and are manufactured as separate integrated circuits and also incorporated as parts of larger integrated circuits

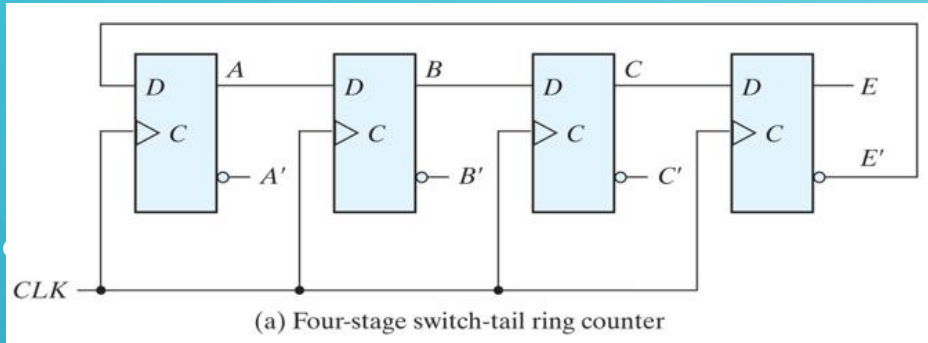
RING COUNTER—USING 74194

OPERATING MODES	INPUTS							OUTPUTS			
	CP	$\overline{\text{MR}}$	S ₁	S ₀	D _{SR}	D _{SL}	D _a	Q ₀	Q ₁	Q ₂	Q ₃
reset (clear)	X	L	XXXXX					LLLL			
hold ("do nothing")	X	H	I	I	X	X	X	q ₀	q ₁	q ₂	q ₃
shift left	↑	H	h	I	X	I	X	q ₁	q ₂	q ₃	L
	↑	H	h	I	X	h	X	q ₁	q ₂	q ₃	H
shift right	↑	H	I	h	I	X	X	L	q ₀	q ₁	q ₂
	↑	H	I	h	h	X	X	H	q ₀	q ₁	q ₂
parallel load	↑	Hh		h	X	X	d _a	d ₀	d ₁	d ₂	d ₃

sequence number	Q ₃	Q ₂	Q ₁	Q ₀
1	1	0	0	0
2	0	1	0	0
3	0	0	1	0
4	0	0	0	1

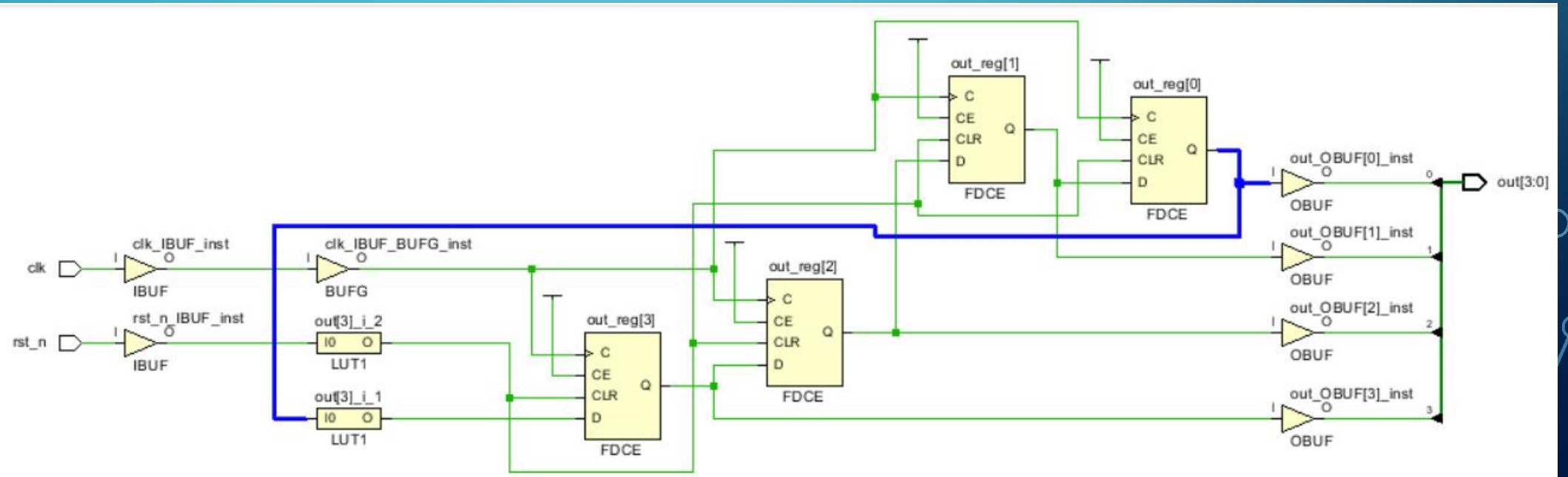


JOHNSON-COUNTER(1)



```
module johoson_counter(
input clk,rst_n,output reg [3:0] out);
always @(posedge clk,negedge rst_n) begin
    if(~rst_n)
        out<=4'b0;
    else
        out<={~out[0],out[3:1]};
end
endmodule
```

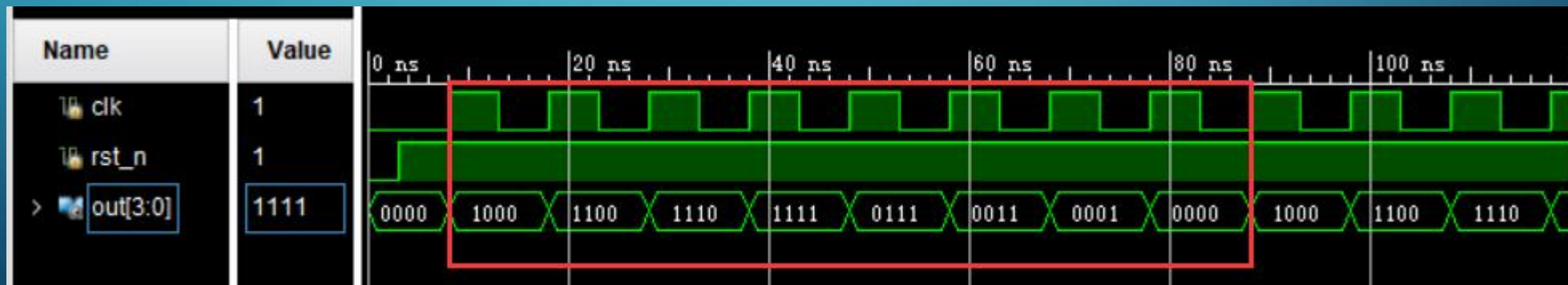
Cell Properties	
out[3]_i_1	
I0	O=!I0
0	1
1	0



JOHNSON-COUNTER(2)

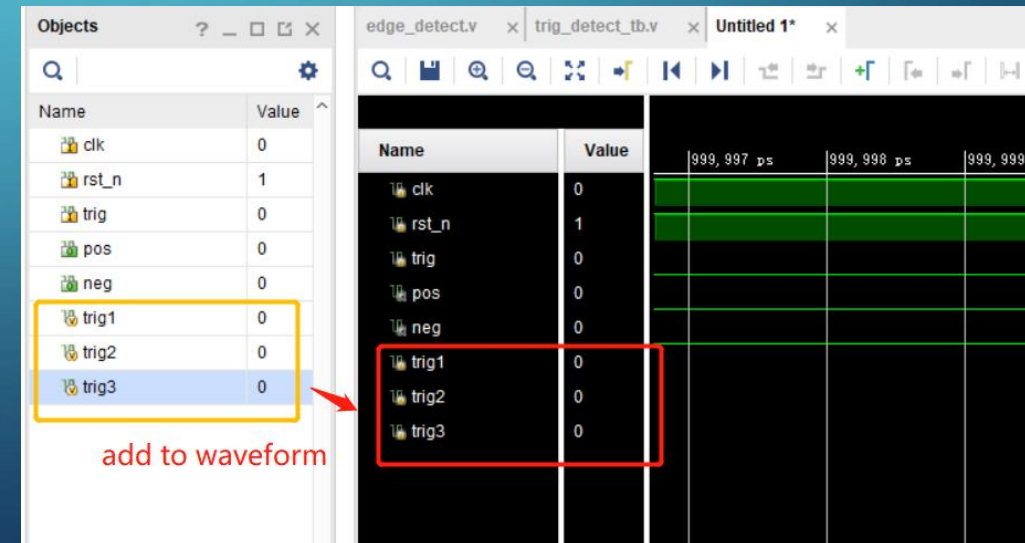
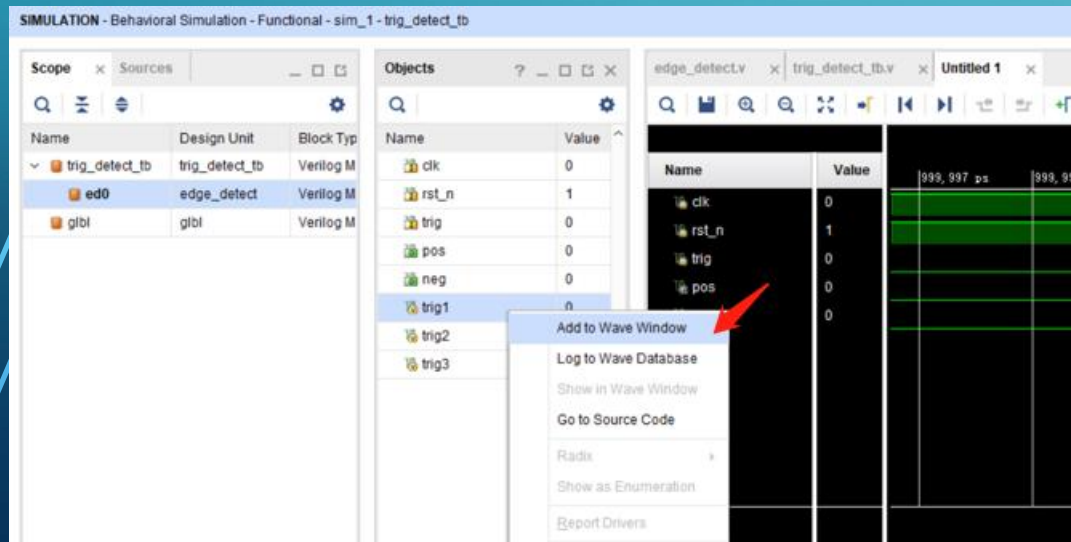
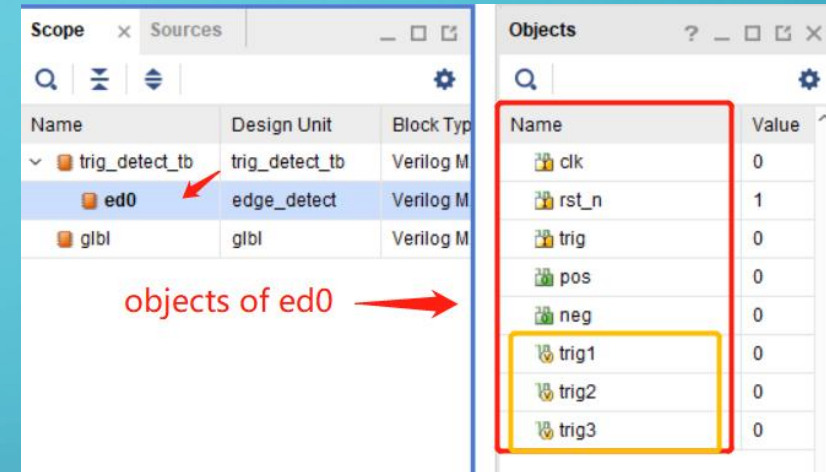
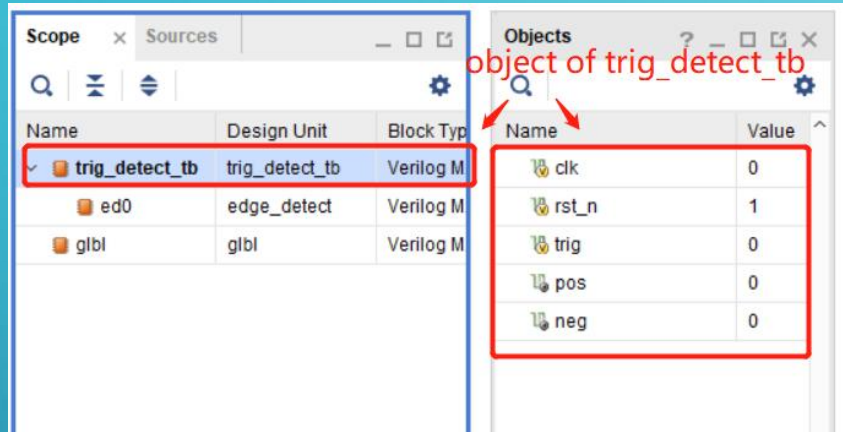
```
module johoson_counter(  
input clk, rst_n, output reg [3:0] out);  
always @(posedge clk, negedge rst_n) begin  
    if (~rst_n)  
        out <= 4'b0;  
    else  
        out <= {~out[0], out[3:1]};  
    end  
endmodule
```

```
module johnsonCounterTb();  
reg clk, rst_n;  
wire [3:0] out;  
johoson_counter jc1(clk, rst_n, out);  
initial begin  
    clk = 1'b0;  
    rst_n = 1'b0;  
    #3 rst_n = 1'b1;  
    forever #5 clk = ~clk;  
    #160 $finish;  
end  
endmodule
```



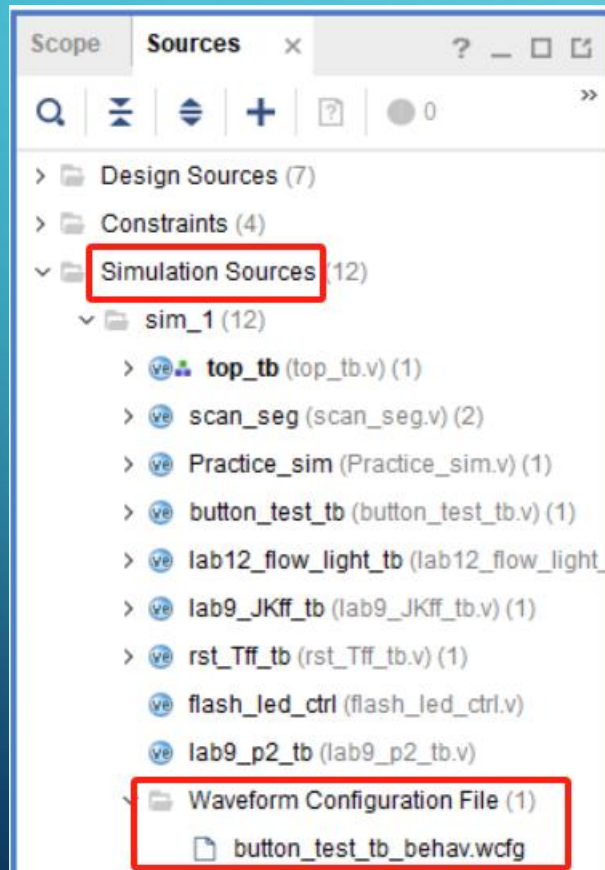
DEBUG BY SIMULATION(1)

- Step1: add intral signal to waveform if needed



DEBUG BY SIMULATION(2)

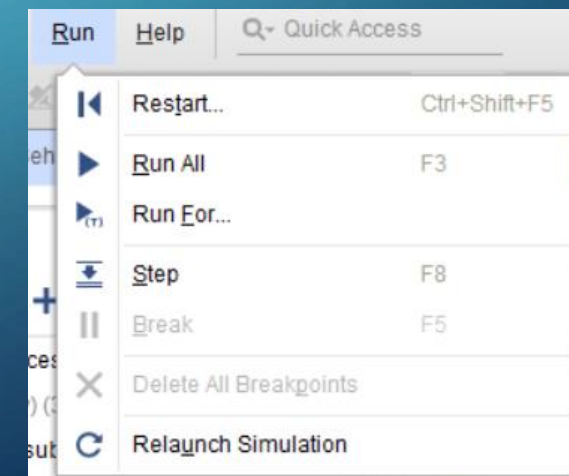
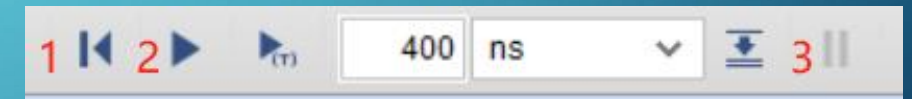
- Step2: run the simulation again
 - method 1: save the waveform as wcfg file and add it to the project, the simulation will rerun as the wcfg file specified.



- method 2: restart the simulation without save the modification on the waveform.
 - Restart -> specify the simulation time -> Run For the specified time



- Restart -> Run All , then "Break" as needed.



VERILOG SUMMARY(1)

- **Design-Under-Test vs Test-Bench**

- **Structured design**

- (top module , instance modules)

- **Block**

- Combinational, Sequential

- **Statement**

- continuous assignment
- Unblock assignment vs block assignment
- If else, case, loop

- **Variable vs Constant**

- reg vs wire
- Splicing { , }
- Number system

VERILOG SUMMARY(2)

- **Non-Synthesizable Verilog** which is **NOT suggested** to use in your design
 - initial
 - Task, function
 - System task : \$display, \$monitor, \$strobe, \$finish
 - fork... join
 - UDP

VERILOG SUMMARY(3)

- **Suggested**

- Using an asynchronous reset to make your system go to initial state
- Using case instead of embedded 'if-else' to avoid unwanted priority and longer delay

- **NOT suggested**

- Embedded 'if-else'
- Two different edge trigger for one always block
- (!!!) **a signal/port is assigned in more than one always block** (it won't report error while synthesized but its behavior maybe wrong after synthesize)
- Mix-use blocking assignment and non-blocking assignment in one always block

DUT VS TESTBENCH

- DUT is a designed module with input and output ports
 - While do the design, non-synthesizable grammar means can't be convert to circuit, is NOT suggested!
 - DUT may be a top module using structured design which means the sub module is instanced and connected in the top module
- Testbench is used for test DUT with NO input and output ports
 - Instance the DUT, bind its ports with variable, set the states of variable which bind with inputs and check the states of variable which bind with outputs
 - Testbench is NOT part of Design, it only runs in FPGA/ASIC EDA, so the un-synthesizable grammar can be used in testbench

MODULE (STRUCTURED LEVEL VS TESTBENCH)

```
module multiplexer_153(out,c0,c1,c2,c3,a,b,g1n);
input c0,c1,c2,c3;
input a,b;
input g1n;
output reg [3:0] out;

always @(*)
if(1'b0==g1n)
    case({b,a})
        2'b00:out=4'b1110;
        2'b01:out=4'b1101;
        2'b10:out=4'b1011;
        2'b11:out=4'b0111;
    endcase
else
    out = 4'b1111;
endmodule
```

```
module multiplexer_153_2(out1,out2,c10,c11,c12,c13,a1,b1,g1n,
    c20,c21,c22,c23,a2,b2,g2n);
input c10,c11,c12,c13,a1,b1,g1n,c20,c21,c22,c23,a2,b2,g2n;
output out1,out2;

multiplexer_153 m1(
    .g1n(g1n),
    .a(a1),
    .b(b1),
    .c0(c10),
    .c1(c11),
    .c2(c12),
    .c3(c13),
    .out(out1)
);

multiplexer_153 m2(
    .g1n(g2n),
    .a(a2),
    .b(b2),
    .c0(c20),
    .c1(c21),
    .c2(c22),
    .c3(c23),
    .out(out2)
);

endmodule
```

```
module lab3_df_sim( );
    reg simx,simy;
    wire simq1,simq2,simq3;
    lab3_df u_df(
        .x(simx), .y(simy), .q1(simq1), .q2(simq2), .q3(simq3) );

    initial
    begin
        simx=0;
        simy=0;

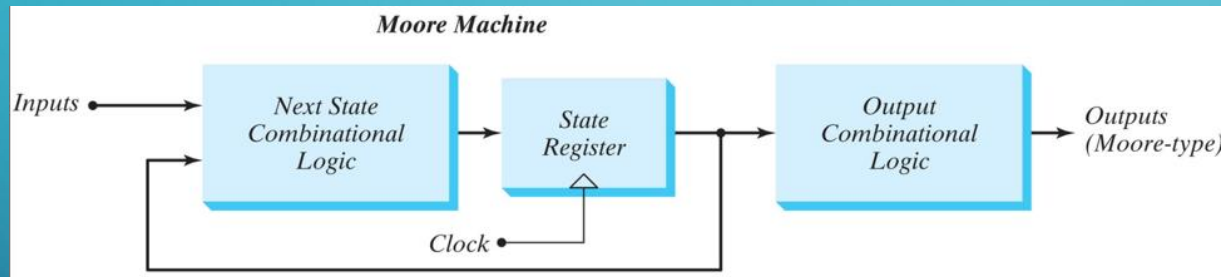
        #10
        simx=0;
        simy=1;

        #10
        simx=1;
        simy=0;

        #10
        simx=1;
        simy=1;

    end
endmodule
```

FSM AND VERILOG



```
`timescale 1ns / 1ps
///////////////////////////////////////////////////
module moore_2b(input clk,rst_n,x_in,output[1:0] state,next_state);
    reg [1:0] state,next_state;
    parameter S0=2'b00,S1=2'b01,S2=2'b10,S3=2'b11;
    always @(posedge clk,negedge rst_n) begin
        if(~rst_n)
            state <= S0;
        else
            state <= next_state;
    end
    always @(state,x_in) begin
        case(state)
            S0: if(x_in) next_state = S1; else next_state = S0;
            S1: if(x_in) next_state = S2; else next_state = S1;
            S2: if(x_in) next_state = S3; else next_state = S2;
            S3: if(x_in) next_state = S0; else next_state = S3;
        endcase
    end
end
endmodule
```

MODULE DESIGN

- Gate level
 - Implementation from the perspective of gate-level structure of the circuit, Using gates as components, connecting pins of gates
 - using logical and bitwise operators or original primitive(not , or , and , xor , xnor ..)
- Data streams
 - Implementation from the perspective of data processing and flow
 - Using continuous assignment, pay attention to the correlation between signals, the difference between logical and bitwise operators
- Behavior level
 - Implementation from the perspective of the Behavior of Circuits
 - Implemented in the always statement block
 - The variable which is assigned in the always block Must be Reg type.

IF – ELSE IN BEHAVIOR MODELING

'if else' block can represent the priority between signals

From the overall structure, from top to bottom, priority decreases in turn

```
module updown_counter(D,CLK,CR,LD,UP,Q)
input [3:0]D;
input CLK,CR,LD,UP;
output reg [3:0] Q;

always @(posedge CLK )
if(!CR)
Q=0;
else if(!LD)
Q=D;
else if(UP)
Q=Q+1;
else
Q=Q-1;
endmodule
```



NOTIC:

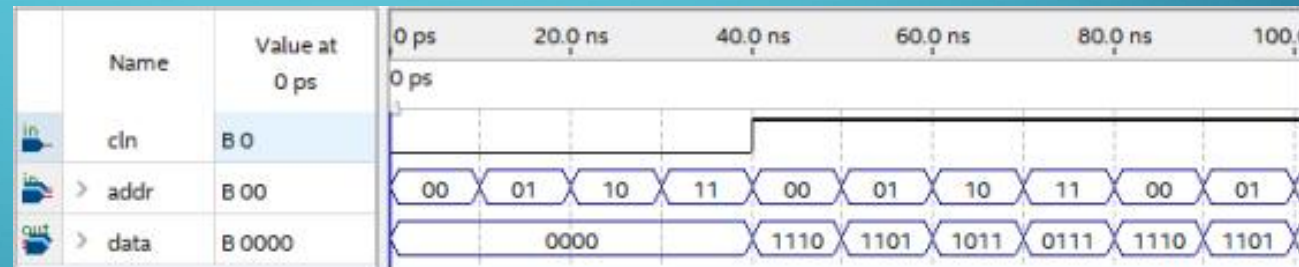
- 1) If there is no 'else' branch in the statement, latches will be generated while doing the synthesis.
- 2) Nested 'if-else' is NOT suggested, 'case' is suggested as an alternative.

CASE IN BEHAVIOR MODELING

case	0	1	x	z
0	1	0	0	0
1	0	1	0	0
x	0	0	1	0
z	0	0	0	1

```
module decoder(cIn,data,addr);
input cIn;
input [1:0] addr;
output reg [3:0] data;

always @(cIn or addr )
begin
if(0==cIn)
data=4'b0000;
else
case(addr)
2'b00:data=4'b1110;
2'b01:data=4'b1101;
2'b10:data=4'b1011;
2'b11:data=4'b0111;
endcase
end
endmodule
```



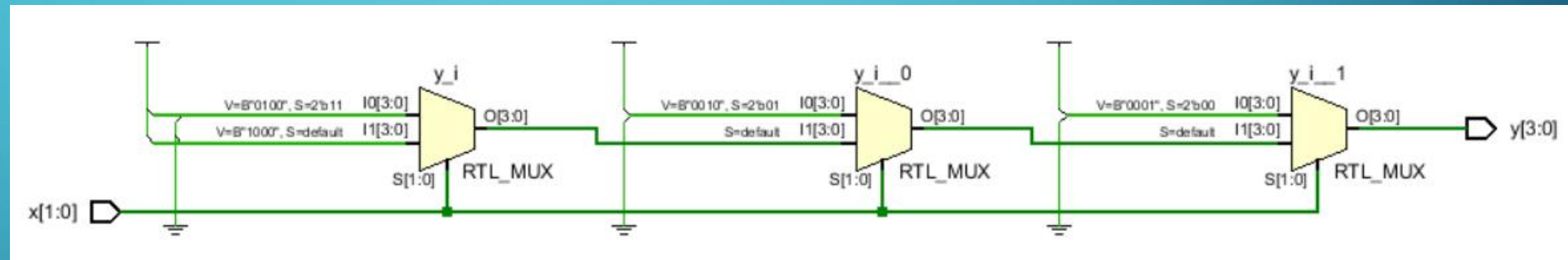
NOTIC:

Without defining default branches and NOT all situations is cleared under the “case”, latches will be generated while doing the synthesis.

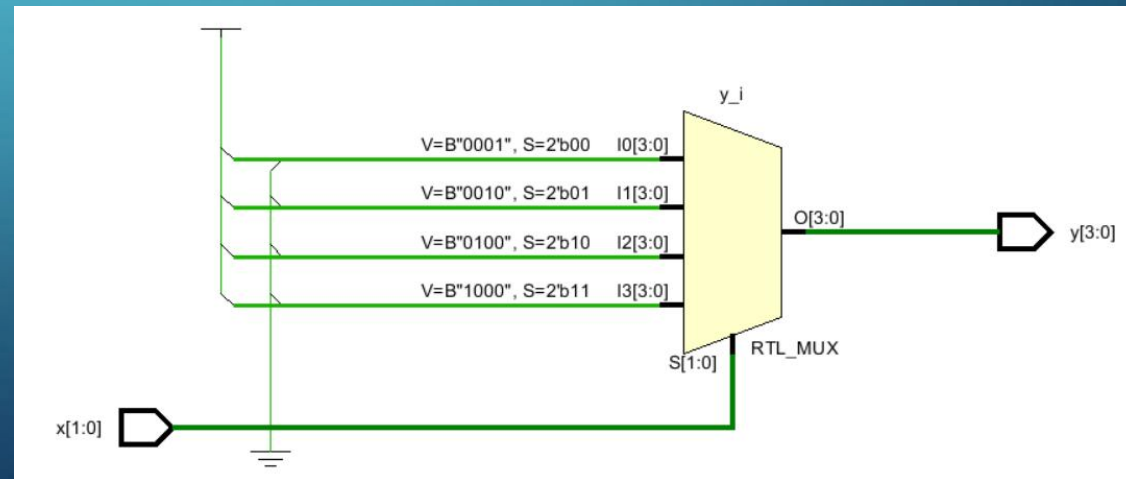
VERILOG (BE CAREFUL WITH EMBEDDED IF-ELSE)

- Embedded 'if-else' circuit brings priority and more latency compared to 'case'

```
always @*  
  if( 2'b00 == x)  
    y = 4'b0001;  
  else if( 2'b01 == x)  
    y = 4'b0010;  
  else if( 2'b11 == x)  
    y = 4'b0100;  
  else  
    y = 4'b1000;
```



```
always @*  
  case(x)  
    2'b00: y=4'b0001;  
    2'b01: y=4'b0010;  
    2'b10: y=4'b0100;  
    2'b11: y=4'b1000;  
  endcase
```



LOOP IN BEHAVIOR MODELING

- Loop is NOT used much in design, for its comprehensiveness is not very good.
- Loop is most often used in testbench to specify signal behavior:

```
repeat(12)
  begin
    Cin = 1'b0;
    Cin = #40000 1'b1;
    # 40000;
  end
```

STATEMENT

- Assignment

- Continuous assign (MUST to a wire variable)

- `assign A = 1'b0 ;` `//A MUST be defined as a wire`

- Block assign(used in initial or always block, MUST to a reg variable, usually in combinational block)

- `always @ *`

- `A = 1'b0;` `//A MUST be defined as a reg`

- `initial`

- `A = 1'b0;` `//A MUST be defined as a reg`

- Un-block assign (used in initial or always block, MUST to a reg variable , usually in sequential block)

- `always @(posedge clk)`

- `A <= 1'b0 ;` `//A MUST be defined as a reg`

CONSTANT(1)

- Expression
 - <bit width>'<numerical system expression><number in the numerical system >
 - numerical system expression
 - B / b : Binary
 - O / o : Octal
 - D / d : decimal
 - H / h : hexadecimal
 - '<numerical system expression><number in the numerical system >
 - The default value of bit width is based on the machine-system(at least 32 bit)
 - <number> : default in decimal
 - The default value of bit width is based on the machine-system(at least 32 bit)

CONSTANT(2)

- x(uncertain state) and z (High resistivity state)
 - The default value of a wire variable is Z before its assignment
 - The default value of a reg variable is X before its assignment
- negative value
 - Minus sign must be ahead of bit-width
 - -4'd3 (is ok) while 4'd-3 is illegal
- underline
 - Can be used between number but can NOT be in the bit width and numerical system expression
 - 8'b0011_1010 (is ok) while 8'_b_0011_1010(is illegal)

CONSTANT(3)

- Parameter (symbolic constants)
 - Used for improve the Readability and maintainability
 - Declare an identifier on a constant
 - Parameter `p1=expression1,p2=expression2,..;`

VARIABLE (1)

- Variable

- Changeable while process

- Wire

- Net
 - Can 't store info, must be driven (such as continuous assignment)
 - The input and output port of module is wire by default
 - Can NOT be the type of left-hand side of assignment in initial or always block

```
wire a;  
wire [7:0] b;  
wire [4:1] c,d;
```


VARIABLE (2)

- Reg
 - **MUST** be the type of left-hand side of assignment in initial or always block
 - The default initial value of reg is an indefinite value X. Reg data can be assigned positive values and negative values.
 - When a reg data is an operand in an expression, its value is treated as an unsigned value, that is, a positive value.
 - For example, when a 4-bit register is used as an operand in an expression, if the register is assigned -1. When performing operations in an expression. It is considered to be a complement representation of + 15 (- 1)

WIRE VS REG

```
module sub_wr();  
  input reg in1,in2;  
  output out1;  
  output out2;  
endmodule
```

Error: Port in1 is not defined
Error: Non-net port in1 cannot be of mode input
Error: Port in2 is not defined
Error: Non-net port in2 cannot be of mode input

```
module sub_wr(in1,in2,out1,out2);  
  input in1,in2;  
  output out1;  
  output reg out2;  
  
  assign in1 = 1'b1;  
  
  initial begin  
    in2 = 1'b1;  
  end  
endmodule
```

Error: procedural assignment to a non-register in2 is not permitted, left-hand side should be reg/integer/time/genvar

```
23 module test_wire_reg(  
24   );  
25   wire i1,i2;  
26   reg o1,o2;  
27   sub_wr s1(i1,i2,o1,o2);  
28 endmodule  
29  
30 module sub_wr(in1,in2,out1,out2);  
31   input in1,in2;  
32   output out1;  
33   output reg out2;  
34
```

[Synth 8-685] variable 'o1' should not be used in output port connection [test_wire_reg.v:27]

MEMORY

- Memory can be seen as a set of registers with the same bit width.

Modeling memory by building arrays of reg variables, and addressing each unit of the array by array index

- Definition:

```
reg [n-1:0] memory name [m-1:0]; // there are m unit in memory, the size of each unit in the memory is n .
```

- Notes:

- A n-bit register can be assigned in an assignment statement, but a full memory CAN NOT.
- If you need to read and write a storage unit in memory, you must specify the address of the unit in memory.

```
reg [2:0] Mema [4:0]; // define a memory named Mema which has 5 memory units, each with a bit width of 3 bits.
```

```
Mema [1]= 3'b101; // assign 3'b101 to Mema [1] unit in Mema
```

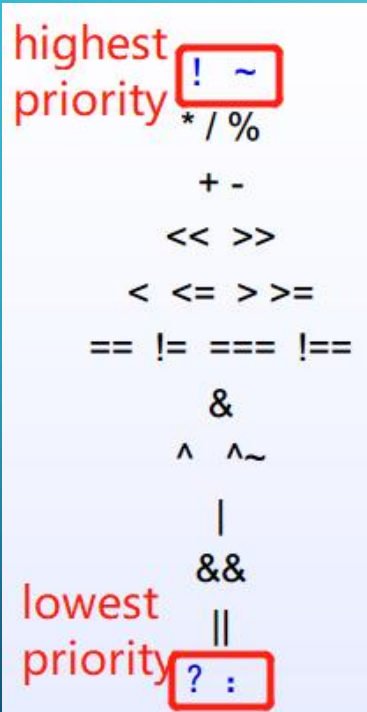
MEMORY (DEMO)

```
module test(  
    A, C0, C1, C2  
);  
    input [2:0] A;  
    output [1:0] C0, C1, C2;  
    reg [1:0] B [2:0];  
    assign {C0, C1, C2} = {B[0], B[1], B[2]};  
    always @(A)  
    if(A)  
    begin  
        B[0] = 2'b11;  
        B[1] = 2'b10;  
        B[2] = 2'b01;  
    end  
    else  
    begin  
        B[0] = 2'b00;  
        B[1] = 2'b00;  
        B[2] = 2'b00;  
    end  
endmodule
```

```
module test(  
    A, C0, C1, C2  
);  
    input [2:0] A;  
    output [1:0] C0, C1, C2;  
    reg [1:0] B [2:0];  
    assign {C0, C1, C2} = {B[0], B[1], B[2]};  
    always @(A)  
    if(A)  
    begin  
        {B[0], B[1], B[2]} = 6'b011011;  
        /*B[0] = 2'b11;  
        B[1] = 2'b10;  
        B[2] = 2'b01;*/  
    end  
    else  
    begin  
        {B[0], B[1], B[2]} = 6'b0;  
        /*B[0] = 2'b00;  
        B[1] = 2'b00;  
        B[2] = 2'b00;*/  
    end  
endmodule
```

		45.000									
		0 ns		10 ns		20 ns		30 ns		40 ns	
>	A[2:0]	0	1	2	3	4	5	6	7	0	
>	C0[1:0]	0				3				0	
>	C1[1:0]	0				2				0	
>	C2[1:0]	0				1				0	

OPERATOR(1)



A vertical list of operators categorized by priority. At the top, 'highest priority' is written in red. At the bottom, 'lowest priority' is written in red. Operators are listed from top to bottom: `! ~` (boxed in red), `* / %`, `+ -`, `<< >>`, `< <= > >=`, `== != === !==`, `&`, `^ ^~`, `|`, `&&`, `||`, and `? :` (boxed in red).

highest priority	<code>! ~</code>
	<code>* / %</code>
	<code>+ -</code>
	<code><< >></code>
	<code>< <= > >=</code>
	<code>== != === !==</code>
	<code>&</code>
	<code>^ ^~</code>
	<code> </code>
	<code>&&</code>
lowest priority	<code> </code>
	<code>? :</code>

- Bit splicing operator `{ }`

multiple data or bits of data are separated by commas in order, then using braces to splice them as a whole.

Such as: `{ a, B[1:0], w, 2'b10 }` // Equivalent to `{ a, B[1], B[0], w, 1'b1, 1'b0 }`

- Repetition can be used to simplify expressions

`{ 4 {w} }` // Equivalent to `{ w, w, w, w }`

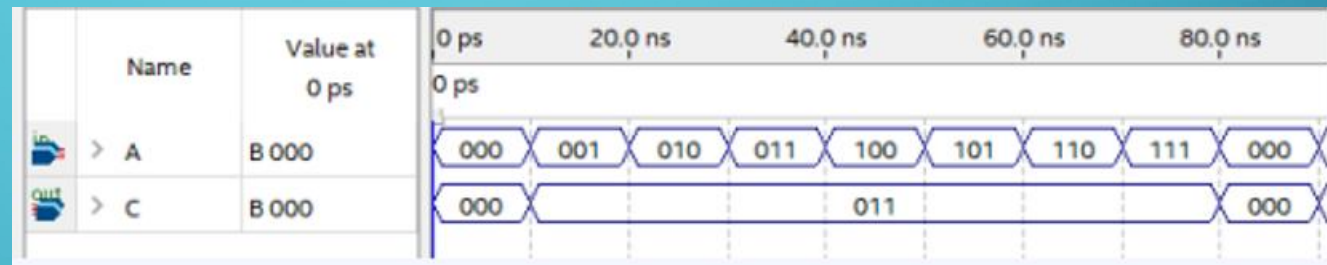
`{ b, {2 {x, y} } }` // Equivalent to `{ b, x, y, x, y }`

OPERATOR(2)

When numeric values are used for conditional judgment, non-zero values represent logical truth and zero values represent logical false.

```
module test_bool(A,C);
input [2:0]A;
output reg [2:0]C;

always @(A )
begin
    if(A)
    C=2'b11;
    else
    C=2'b00;
end
endmodule
```



```
module test_bool(A,C);
input [2:0]A;
output reg [2:0]C;

always @(A )
begin
    if(A==1)
    C=2'b11;
    else
    C=2'b00;
end
endmodule
```

