



Computer Organization

Lab8 Verilog and EDA tools

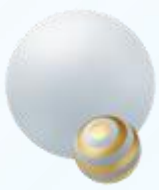


Verilog and EDA tool



Topic

- **Verilog**
 - A kind of **Hardware Description Language**
 - **module, block, statement, operator, data**
 - **suggestion**
- **EDA tools**
 - **vivado(1)**
 - **project, design, testbench**
 - **simulation**
- **Practices**
 - **Instruction analysis in RISC-V32I**



Verilog

- **Design-Under-Test vs Test-Bench**
 - Structured Design(top module, instance module)
- **Block**
 - Combinational, Sequential
- **Statement**
 - Continuous assignment
 - Procedure assignment: Non blocking assignment vs Blocking assignment
 - if - else, case, loop
- **Operator and data**
 - Variable vs Constant
 - Reg vs Wire, Splicing { , }, Number system
- **Verilog suggestion**



DUT vs Testbench

- **DUT is a designed module for circuit 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(s) is(are) instanced and connected in the top module
- **Testbench is build for test circuit 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 a part of Design.** It only runs in FPGA/ASIC EDA, so the **un-synthesizable grammar can be used in testbench**



Module (Structured Design 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
```

Here are 3 pieces of verilog code, Which one is(are) the circuit design, which one is(are) the testbench?

What are the common point(s) and difference(s) between the circuit design and the testbench?

```
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
```



Module (Circuit 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 ..)
 - For example: `not n1(na,a); xor xor1(c,a,b);`

➤ 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
 - For example: `assign z = (x | y) ^ (a&b);`

➤ 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**.



Behavior Modeling(if-else)

“if else” block can represent the priority among 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 (more clear while reading, less latency).

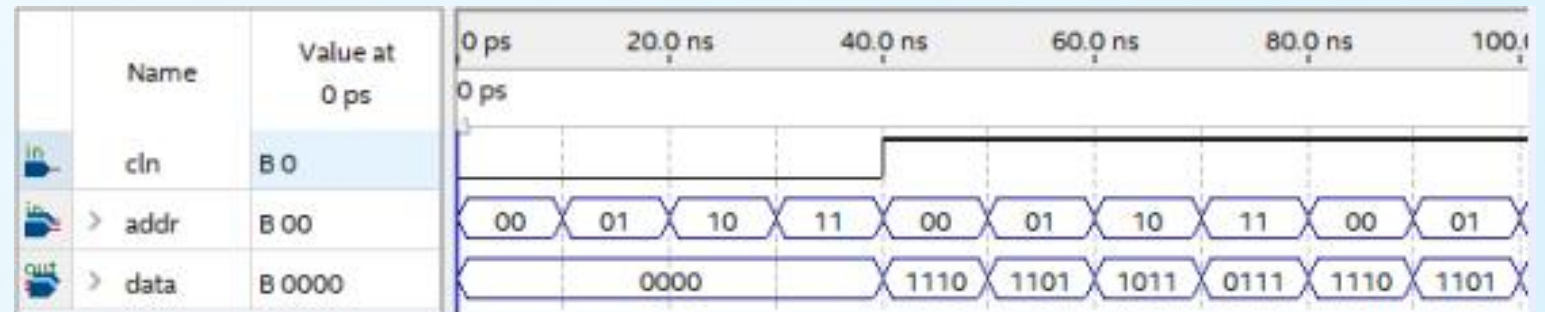


Behavior Modeling(case)

```
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
```

| 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 |



NOTIC:

Without defining 'default' branches and declaring all situations under the "case" , **latches** will be generated while doing the synthesis.

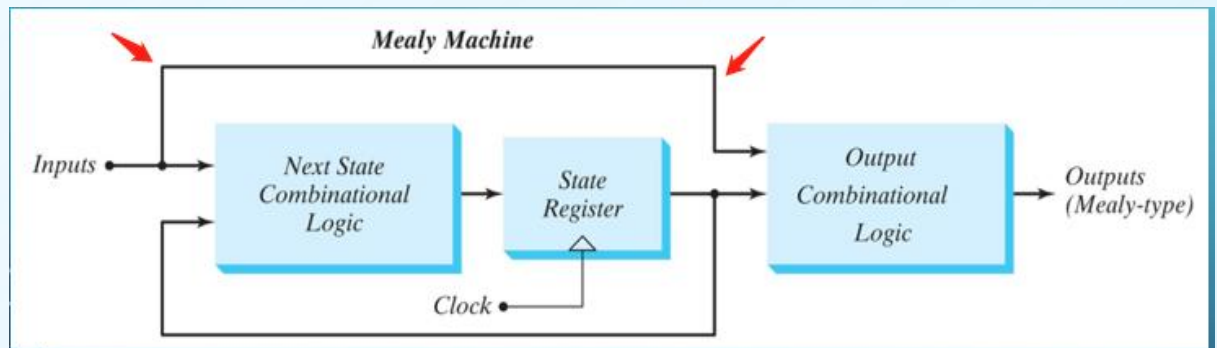
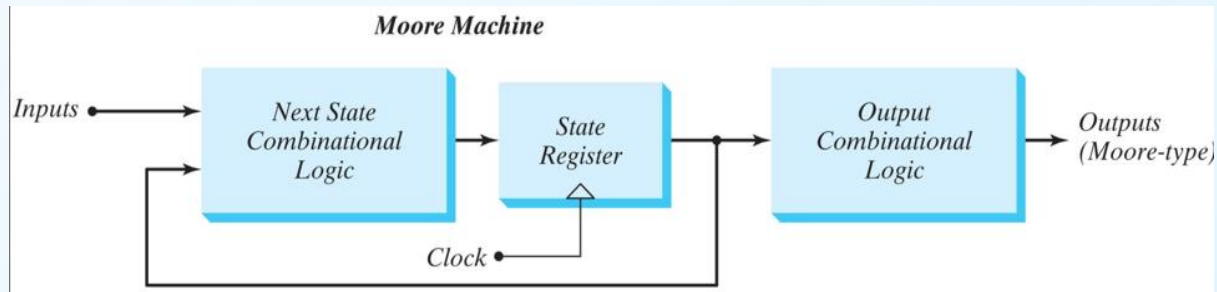


Sequential Circuit: FSM

The piece of verilog code(on the right hand) is a **2-stage** code(using **2 always block** describe the **combinational** logic and **sequential** logic separately).

Does it describe the **Moor-type** FSM or **Mealy-type** FSM?

NOTES: While implement a **Mealy-type** FSM, 1-stage(using 1 always block describe the combinational logic and sequential logic) is **NOT** suggested!!



```
`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
endmodule
```



Constant

- 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 continued

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



Variable(data type)

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

➤ 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

➤ 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)



Variable (data type) continued

Please find the syntax error about the data type in the following pieces of code.

```
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

sim_1 (2 errors)

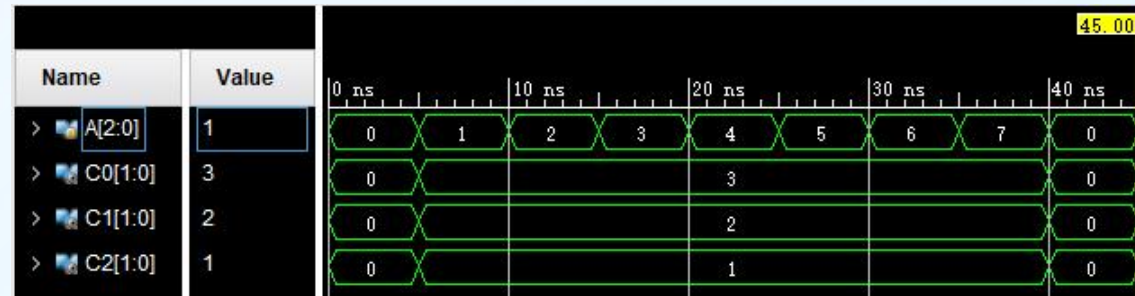
[VRFC 10-529] concurrent assignment to a non-net o1 is not permitted [test.v:29]

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




Memory

```
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
end
endmodule
```



Q1: Does the waveform belongs to the two test?
If not, which one does it belong to?

Q2: While do the following assignment: "{B[0],B[1],B[2]} = 6'b011011; ", what's the value of B[0] ? Is it same as the comments list on the right picture?

```
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
end
endmodule
```



Operator

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

Bit splicing operator { }

- Multiple data or bits of data are separated by commas in order, then using braces to splice them as a whole. e.g.
 - {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}

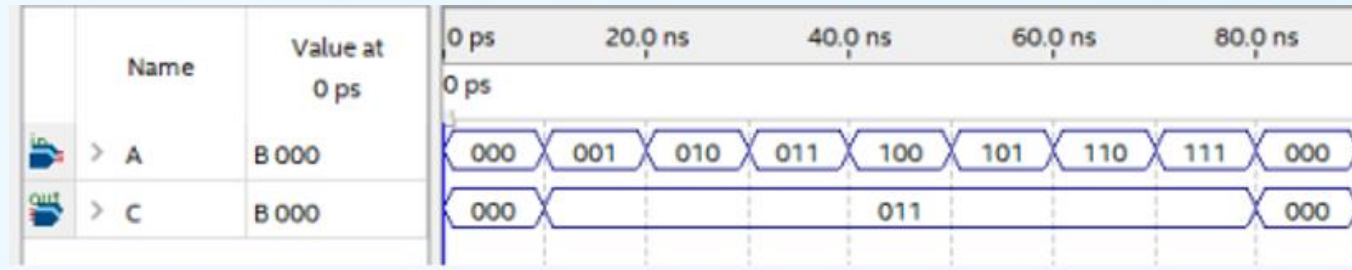


Operator continued

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

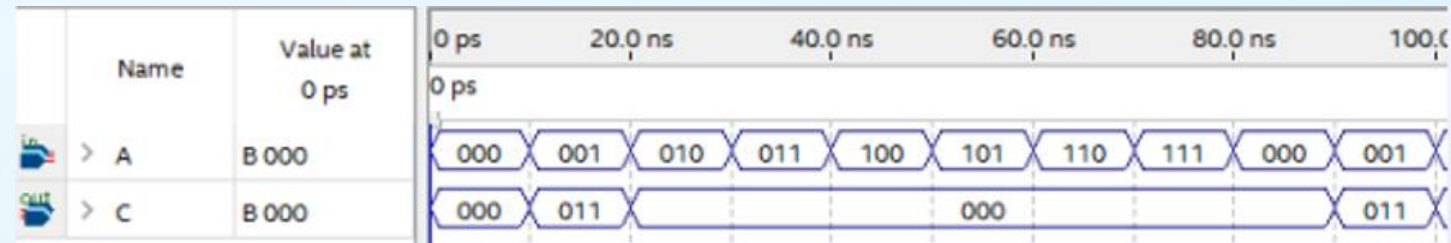
always @(A )
begin
if (A)
C=2'B11;
else
C=2'B00;
end
endmodule
```

Here are two circuits described in verilog and the corresponding waveforms. What' s the difference between two pieces of code?



```
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
```



Tips: When data are used for conditional judgment, **non-zero represent logical truth** and **zero represent logical false**.



Verilog suggestion

- **Non-Synthesizable Verilog** which is **NOT suggested** to use in your design
 - initial; Task, function; System task : \$display, \$monitor, \$strobe, \$finish
 - fork... join; UDP
 - using “#number” as delay
- **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



EDA TOOLS: VIVADO

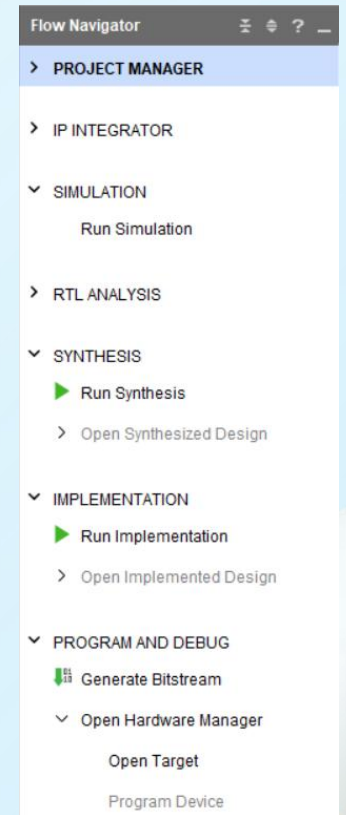
➤ Installation

- It's suggested to recall to pages 5 to 9 of document "Digital design lab1.pdf"

Tips: Digital design lab1.pdf file could be found in the directory "labs/lab8" of course blackboard site

➤ Vivado project

- Vivado files
 - vivado project file, design files, testbench files, constraints files...
- Vivado process flow
 - option1: design, simulation
 - option2: design, simulation, synthesis, implementation, generate bitstream file, open target, program device





Vivado process flow

1. Do the design with verilog (Vivado)

2. Do the simulation to verify the function of the design(Vivado)

3. Do the synthesis , Do the implementation, Generate bit stream file(Vivado)

4. Connect with FPGA chip, Program the chip with bitstream file (Vivado + FPGA chip)

5. Do the test on the programmed FPGA chip (FPGA chip)

**At the very beginning,
a vivado project is needed!**

Vivado project

1. Manage all the files

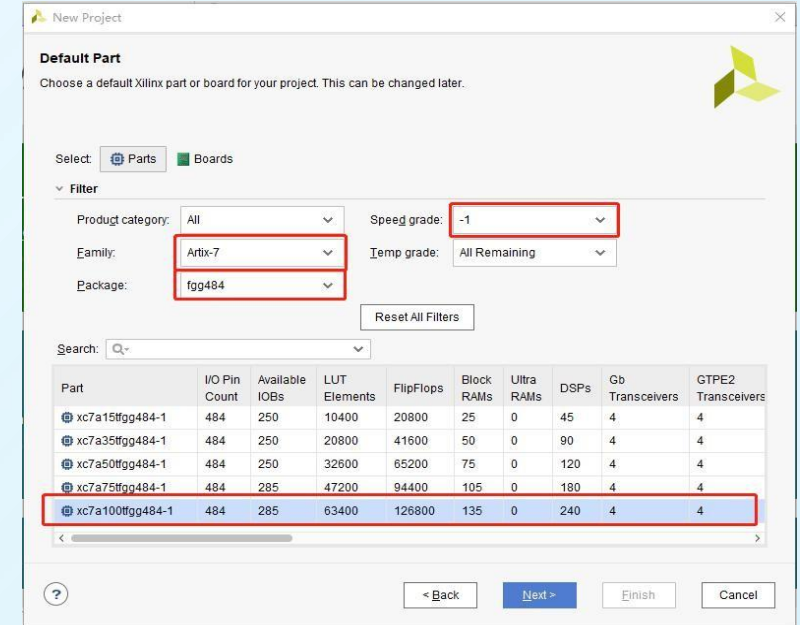
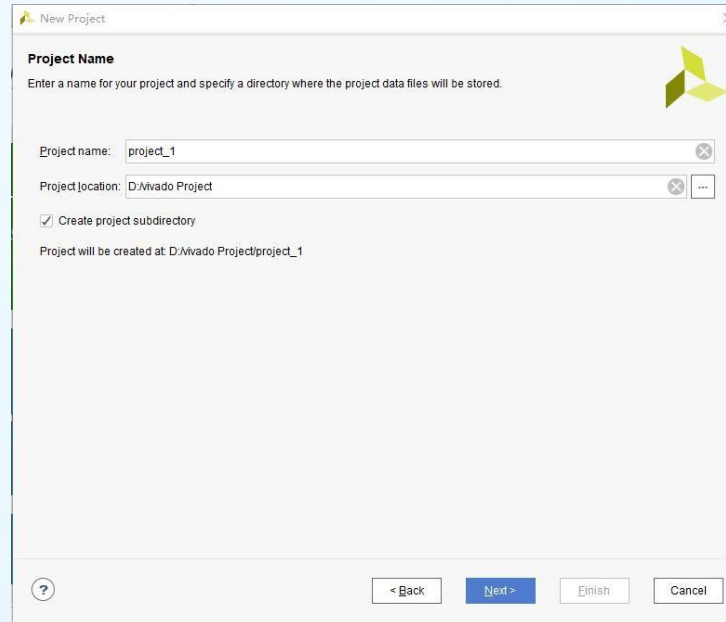
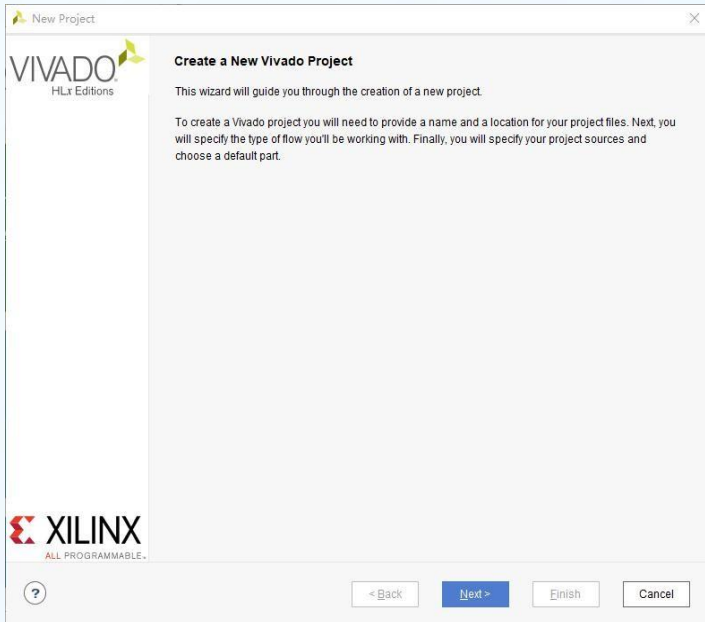
(including design file, simulation file, constraint file and other resource file)

2. Manage the operation flow

3. Connect with FPGA chip

4. Program the FPGA chip

Creat and set a vivado project



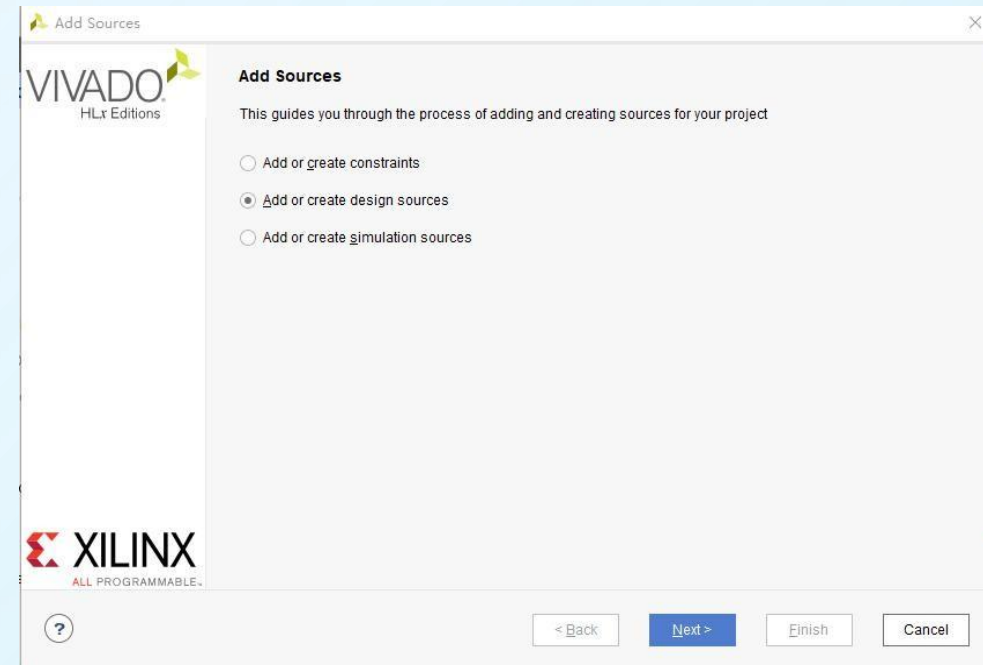
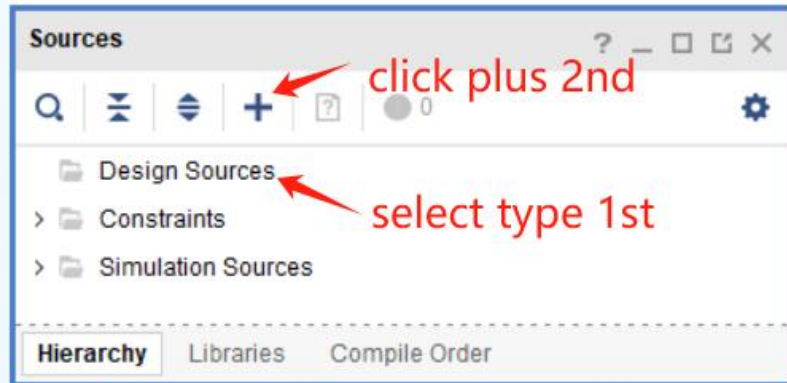
1. Create project

1) Select "rtl type" as project type

2) Select the xilinx board(based on the FPGA chip type embedded in the board), the settings about the xilinx board could be reset after the project is built.

Using VIVADO continued

2. Add files to vivado project design file(s), simulation file(s) and constraint file(s)



Tips: In this experiment, since there is no need to use the development board for testing, only design and simulation files need to be added to the vivado project, no constraint files need to be added.

Using VIVADO continued



3. Following the steps to generate bitstream file.

- 1) Do the **simulation** to verify the Circuit function[**step1**]
- 2) After simulation, a waveform file is generated which records the states of input and output signals.
- 3) If the function of circuit is ok, **Run synthesis**[**step2**] , then **Run implements**[**step3**]
- 4) After implementation is finished, **Generate Bitstream**[**step4**], the generated ".bit" file could be used to program device later.

Tips: If you need to test circuits on the development board, you must set the chip type in the project, add design files and constraint files, then do the synthesise, implemention, and finally generate a bitstream file which is used for programming the FPGA chip embedded on the development board.

In this experiment, as there is no need for testing on the development board, design and simulation files were added to the project for simulation to verify the functionality of the circuit.



Practice 1

- Q1: Please refer to the instruction format of RISC-V32I and using Verilog to achieve the following functions:
 - Build a circuit design module in verilog to analysis the RISC-V32I **instruction**(as inputs), and determine the value of **writeR**, **writeM** (as outputs).
 - The bitwidth of **writeR** is 1, when its value is 1, it indicates a write operation to the Register, and when its value is 0, it indicates no write operation to the register.
 - The bitwidth of **writeM** is 1, when its value is 1, it indicates a write operation to the Memory, and when its value is 0, it indicates no write operation to the Memory
 - Build a testbench and verify through simulation on it to check whether the functionality of the circuit design module is correct.
 - **The test cases should cover at least 6 types of basic instructions of RISC-VI(R, I, S, B, U, J)**

Tips:

- 1) The type of the circuit is a combinational design.
- 2) Using “RISC-V-Reference-Data.pdf” as a reference for the design.



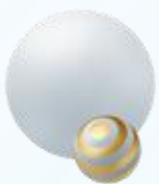
Practice 2

- Q2: Please refer to the instruction format of RISC-V32I and using Verilog to achieve the following functions:
 - Build a circuit design module in verilog to analysis the RISC-V32I instruction(as inputs), and determine the value of imm32(as outputs).
 - Note 1: the immediate data will be sign-extend to a 32-bit register.
 - Note 2: for R-type, you can handle the immediate data as whatever you want.
 - Build a testbench and verify through simulation on it to check whether the functionality of the circuit design module is correct.
 - **The test cases should cover at least 6 types of basic instructions of RISC-VI(R, I, S, B, U, J)**

Tips:

- 1) The type of the circuit is a combinational design.
- 2) Using “RISC-V-Reference-Data.pdf” as a reference for the design.
- 3) If you have done Practice 1 on Lab5, you can complete this practice with slight modifications based on this foundation.

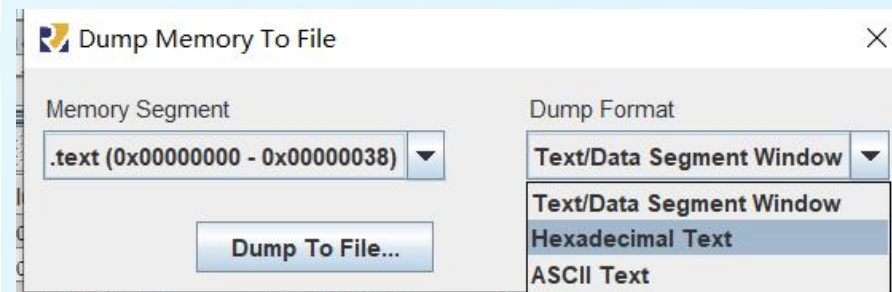
| | | | | | | | | | | | | | | | |
|------------|----|-----------|----|-----|---------|-----|------------|--------|--------|--------|----------|----------|---------|--------|--------|
| 31 | 30 | 25 | 24 | 21 | 20 | 19 | 15 | 14 | 12 | 11 | 8 | 7 | 6 | 0 | |
| funct7 | | | | rs2 | | | rs1 | | funct3 | | rd | | opcode | | R-type |
| imm[11:0] | | | | | | rs1 | | funct3 | | rd | | opcode | | I-type | |
| imm[11:5] | | | | rs2 | | | rs1 | | funct3 | | imm[4:0] | | opcode | | S-type |
| imm[12] | | imm[10:5] | | | rs2 | | | rs1 | | funct3 | | imm[4:1] | imm[11] | opcode | B-type |
| imm[31:12] | | | | | | | | | rd | | | opcode | | U-type | |
| imm[20] | | imm[10:1] | | | imm[11] | | imm[19:12] | | | rd | | opcode | | J-type | |



Tips

1. To build the testcases on the practices, it is suggested to :
 - ✓ 1-1. build a RISC-V assembly source file in which there is 6 types(R,I,S,B,U and J) of the RISC-V32I instructions.
 - ✓ 1-2. Using Rars to assemble the source file, and generate the machine code.
 - ✓ 1-3. Dump the machine code as **Hexadecimal Text**.
 - ✓ 1-4. Open the file generated in step 1-3, copy a line and past it to the testbench as the input of the design circuit.

```
test_instr.asm
1 .data
2 idata: .word 0x12345678
3 .text
4 main:
5 beq x0,x1,here
6 add x0,x0,x0
7 xor x0,x0,x0
8 la t0,idata
9 lb x1,(t0)
```



| | Code | Basic | Source |
|---|------------|------------------------|-------------------|
| 0 | 0x00100c63 | beq x0,x1,0x00000018 | 5: beq x0,x1,here |
| 1 | 0x00000033 | add x0,x0,x0 | 6: add x0,x0,x0 |
| 2 | 0x00004033 | xor x0,x0,x0 | 7: xor x0,x0,x0 |
| 3 | 0x00002297 | auipc x5,2 | 8: la t0,idata |
| 4 | 0xff428293 | addi x5,x5,0xffffffff4 | |
| 5 | 0x00028083 | lb x1,0(x5) | 9: lb x1,(t0) |

```
test_instr_text0 - 记事本
文件(F) 编辑(E) 格式(O) 查看(V)
00100c63
00000033
00004033
00002297
ff428293
00028083
```

```
initial begin
inst = 32'h00100c63;
#10
inst = 32'h00000033;
#10
inst = 32'h00004033;
#10
inst = 32'h00002297;
```