Lecture #2: Verilog HDL

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EE183 Design Process

- Understand problem and generate block diagram of solution
- Code block diagram in verilog HDL
- Synthesize verilog
- Create verification script to test design
- Run static timing tool to make sure timing is met
- Design is mapped, placed, routed, and *.bit file is created download to FPGA
Module is basic verilog construct

module synchronizer (in, out, clk);
    parameter SIZE = 1;
    input [SIZE-1:0] in;
    input clk;
    output [SIZE-1:0] out;
    wire [SIZE-1:0] x;

dff #(SIZE) dff_1(.d(in[SIZE-1:0]), .clk(clk), .q(x[SIZE-1:0]));

dff #(SIZE) dff_2(.d(x[SIZE-1:0]), .clk(clk), .q(out[SIZE-1:0]));
endmodule

Lexical Conventions

- The lexical conventions are close to the programming language C++.
- Comments are designated by // to the end of a line or by /* to */ across several lines.
- Keywords, e.g., module, are reserved and in all lower case letters.
- The language is case sensitive, meaning upper and lower case letters are different.
- Spaces are important in that they delimit tokens in the language.
Number specification

- Numbers are specified in the traditional form of a series of digits with or without a sign but also in the following form:
  - <size><base format><number>
    - where <size> contains decimal digits that specify the size of the constant in the number of bits. The <size> is optional. The <base format> is the single character ‘ followed by one of the following characters b, d, o and h, which stand for binary, decimal, octal and hex, respectively. The <number> part contains digits which are legal for the <base format>. Some examples:
      - 4'b0011 // 4-bit binary number 0011
      - 5'd3   // 5-bit decimal number
      - 32'hdeadbeef // 32 bit hexadecimal number

Bitwise/Logical Operators

- Bitwise operators operate on the bits of the operand or operands.
  - For example, the result of A & B is the AND of each corresponding bit of A with B. Operating on an unknown (x) bit results in the expected value. For example, the AND of an x with a FALSE is an FALSE. The OR of an x with a TRUE is a TRUE.

<table>
<thead>
<tr>
<th>Operator</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>~</td>
<td>Bitwise negation</td>
</tr>
<tr>
<td>&amp;</td>
<td>Bitwise AND</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>^</td>
<td>Bitwise XOR</td>
</tr>
<tr>
<td>~&amp;</td>
<td>Bitwise NAND</td>
</tr>
<tr>
<td>~</td>
<td></td>
</tr>
<tr>
<td><del>^ or ^</del></td>
<td>Equivalence (Bitwise NOT XOR)</td>
</tr>
</tbody>
</table>
Miscellaneous Operators

- { , } Concatenation of nets
  - Joins bits together with 2 or more comma-separated expressions, e.g., \{A[0], B[1:7]\} concatenates the zeroth bit of A to bits 1 to 7 of B.

- << Shift left (Multiplication by power of 2)
  - Vacated bit positions are filled with zeros, e.g., A = A << 2; shifts A two bits to left with zero fill.

- >> Shift right (Division by power of 2)
  - Vacated bit positions are filled with zeros.

- ?: Conditional (Creates a MUX)
  - Assigns one of two values depending on the conditional expression. E.g., A = C > D ? B+3 : B-2; means if C greater than D, the value of A is B+3 otherwise B-2.

Unary Reduction Operators

- Unary reduction operators produce a single bit result from applying the operator to all of the bits of the operand. For example, &A will AND all the bits of A.
  - Operator Name
  - & AND reduction
  - | OR reduction
  - ^ XOR reduction
  - ~& NAND reduction
  - ~| NOR reduction
  - ~^ XNOR reduction

- I have never used these, if you find a realistic application, let me know… 😊
Continuous Assignment

• assign out = in1 & in2;
  - Amazingly enough creates an “and” gate!
  - Anytime right hand side (RHS) changes, left hand side (LHS) is updated
  - LHS must be a “wire”

Procedural Assignments

• We will only use them to define combinational logic
  - as a result, blocking (=) and nonblocking assignment (<=) are the same

• Example:
  reg out;
  always @(in1 or in2)
  begin
    out = in1 & in2;
  end

LHS must be of type reg
Does NOT mean this is a DFF

All input signals must be in sensitivity list

Begin and End define a block in Verilog
If-Else Conditional
Procedural Assignment

- Just a combinational logic mux
- Every if must have matching else or state element will be inferred—why?
  
  always @(control or in)
  begin
    if (control == 1'b1)
      out = in;
  end

- Watch nestings—make life easy, always use
  begin…end

Logical Operators

- Logical operators operate on logical operands and return a logical value, i.e., TRUE(1) or FALSE(0).
  - Used typically in if and while statements.
    - Do not confuse logical operators with the bitwise Boolean operators. For example, `!` is a logical NOT and `~` is a bitwise NOT. The first negates, e.g., `!(5 == 6)` is TRUE. The second complements the bits, e.g., `~{1,0,1,1}` is 0100.
  
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Relational Operators

- Relational operators compare two operands and return a logical value, i.e., TRUE(1) or FALSE(0)—what do these synthesize into?
  - If any bit is unknown, the relation is ambiguous and the result is unknown—it should never happen!

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<tr>
<td>&gt;</td>
<td>Greater than</td>
</tr>
<tr>
<td>&gt;=</td>
<td>Greater than or equal</td>
</tr>
<tr>
<td>&lt;</td>
<td>Less than</td>
</tr>
<tr>
<td>&lt;=</td>
<td>Less than or equal</td>
</tr>
<tr>
<td>==</td>
<td>Logical equality</td>
</tr>
<tr>
<td>!=</td>
<td>Logical inequality</td>
</tr>
</tbody>
</table>

Case Statement Procedural Assignment

module mux4_to_1 (out, i0, i1, i2, i3, s1, s0);
output out;
input i0, i1, i2, i3;
input s1, s0;
reg out;
always @(s1 or s0 or i0 or i1 or i2 or i3)
begin
  case ({s1, s0})
    2'b00: out = i0;
    2'b01: out = i1;
    2'b10: out = i2;
    2'b11: out = i3;
    default: out = 1'bx;
  endcase
end
endmodule

Note how all nets that are inputs to the always block are specified in the sensitivity list.

Make sure all 2^n cases are covered or include a “default:” statement or else state elements will be inferred.

X is don’t care.
After initial synchronous reset there should never be any X’s in your design.
So how do I get D-FlipFlops?

- Use 183lib.v to instantiate them
  - dff, dffr, dffre
- These are the **only** state elements (except for CoreGen RAMs) allowed in your design

Dffre guts

// dffre: D flip-flop with active high enable and reset
// Parametrized width; default of 1
module dffre (d, en, r, clk, q);
  parameter WIDTH = 1;
  input en;
  input r;
  input clk;
  input [WIDTH-1:0] d;
  output [WIDTH-1:0] q;
  reg [WIDTH-1:0] q;
  always @(posedge clk)
    if (r)
      q <= {WIDTH{1'b0}};
    else if (en)
      q <= d;
    else q <= q;
endmodule

Only change LHS on "posedge clk"
Note that if statement is missing an else
Replicator Operator.

How cute!! :)

8
No Behavioral Code

- No “initial” statements
  - Often used to reset/initialize design
- No system tasks
  - “$” commands (i.e., “$display()”)
- For both, use Xilinx simulator and scripts

Use Case Statement for FSM

- Instantiate state elements as dffX
- Put next state logic in always @() block
  - Input is curstate (.q of dffX) and other inputs
  - Output is nextstate which goes to .d of dffX
  - Use combined case and if statements
    - “If” good for synchronous resets and enables
- Synthesis tools auto-magically minimizes all combinational logic.
  - Three cheers for synthesis!! 😊
8-bit Counter

module counter_8 (clk, reset, en, cntr_q);
    input clk;
    input reset;
    input en;
    output [7:0] cntr_q;

    reg [7:0] cntr_d;
    wire [7:0] cntr_q;

    // Counter next state logic
    always @(cntr_q)
        begin
            cntr_d = cntr_q + 8‘b1;
        end

    // Counter state elements
    dffe #(8) cntr_reg (.clk(clk), .r(reset), .en(en), .d(cntr_d), .q(cntr_q));

endmodule

CoreGen

- **Tools → Design Entry → Core Generator**
  - Useful info appears in “language assistant”—Read it!
- **Only use this for memories for now**
  - Do you need anything else??
    - I really cannot think of anything now
- **Caveat: Block Memory does not simulate correctly with initial values.**
  - Must create gate netlist by completing synthesis and implementation.
  - Simulate by loading time_sim.edn into Simulator