

EECS 151/251A

Discussion 3

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9/14, 9/15 and 9/20

About Me (Zhaokai Liu)

- 5th year PhD student advised by Bora
- Research in mixed-signal design, ADC, analog circuit automation, ...
- Took this class 4 years ago

- Office hour
 - Friday 2-3pm



Agenda

- Administrivia
- Verilog
- Simulating Verilog

Administrivia

- Homework ³~~2~~ due 11:59pm, Friday, 9/17⁴
- Homework ⁴~~3~~ out this Thursday

Verilog

Exercise: Fix the Errors (not in HW) ②

(par... N)

```

module this_is_wrong_1(
    input a,
    input b, ②
    input reg rst
); ④ reg
    wire x;
    always @(a or b) begin ③
        assign x = a + b;
    end
    always @(rst) begin
        assign x = 1'b0;
    end
endmodule

```

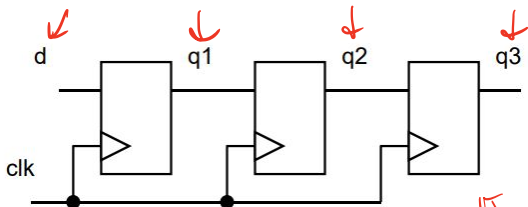
```

module this_is_wrong_2(
    input [N-1:0] a,
    input b, ②
    output reg c
);
    wire [N:0] x; ④
    genvar i;
    generate
        for (i=0; i<N; i=i+1) begin
            SubMod submod(.in0(a[i]), .in1(x[i]), .out(x[i+1]));
        end
    endgenerate

    assign c = x[N];
endmodule

```

Race Conditions: Synthesis vs. Simulation



Want: a register pipeline

Determine:

1. Does it **synthesize** correctly?
2. Does it **simulate** correctly?
 Note: always blocks may simulate in any order
3. Is it good coding practice?

Candidate #1:

```
always @(posedge clk) begin
  q1 = d;
  q2 = q1;
  q3 = q2;
end
```

Handwritten notes: YNN, a box around the assignment statements, and a diagram of a pipeline with three stages labeled a1, a2, a3.

Candidate #2:

```
always @(posedge clk) begin
  q3 = q2;
  q2 = q1;
  q1 = d;
end
```

Handwritten notes: YYN, a box around the assignment statements, and a diagram of a pipeline with three stages labeled a1, a2, a3.

★ Candidate #3:

```
always @(posedge clk) begin
  q1 <= d;
  q2 <= q1;
  q3 <= q2;
end
```

Handwritten notes: YYN, a box around the assignment statements, and a diagram of a pipeline with three stages labeled a1, a2, a3.

Candidate #4:

```
always @(posedge clk) q1 = d;
always @(posedge clk) q2 = q1;
always @(posedge clk) q3 = q2;
```

Handwritten notes: YNN, a box around the assignment statements, and a diagram of a pipeline with three stages labeled a1, a2, a3.

Candidate #5:

```
always @(posedge clk) q3 = q2;
always @(posedge clk) q2 = q1;
always @(posedge clk) q1 = d;
```

Handwritten notes: YNN, a box around the assignment statements, and a diagram of a pipeline with three stages labeled a1, a2, a3.

Candidate #6:

```
always @(posedge clk) q1 <= d;
always @(posedge clk) q2 <= q1;
always @(posedge clk) q3 <= q2;
```

Handwritten notes: YYN, a box around the assignment statements, and a diagram of a pipeline with three stages labeled a1, a2, a3.

Simulating Verilog

Adder

We can test RTL via simulation before putting it on the FPGA or fabricating an ASIC
Let's see a 32 bit adder.

```
module adder(  
    input [31:0] a,  
    input [31:0] b,  
    output [31:0] c  
);  
    assign c = a + b;  
endmodule
```

or

```
module adder(a, b, c);  
    input [31:0] a, b;  
    output [31:0] c;  
    assign c = a + b;  
endmodule
```

- The adder module is **synthesizable**. It can be implemented on ASIC (gates, optimized by compiler) or FPGA (LUTs)
- Note that 32-bit a + 32-bit b produces a **33-bit** result, which is truncated to 32-bit when assigning to c
- In the test bench, we will refer to the adder module as DUT (design under test)

Testbench

```
module adder_tester();  
  { reg [31:0] a, b;  
    wire [31:0] c;  
→ adder dut(.a(a), .b(b), .c(c)); // device under test  
  // ... initial block of adder_tester  
endmodule
```

- The `adder_tester` module is **not synthesizable**. It is executed by an *RTL simulator*
- Note we have created reg nets to drive the DUT's inputs, and wire nets to sense the DUT's outputs
- Testbench is super important! Make sure you have covered the circumstances as many as possible. Basically you can do nothing with the bugs on a tape-out chip

Testbench initial block

```
initial begin t = 0
    a = 32'd1;
    b = 32'd2;
    #1; // wait for 1
timestep
    if (c != 32'd3) begin
        $display("FAILED");
    end
    a = 32'd5;
    b = 32'd10;
    #1;
    if (c != 32'd15) begin
        $display("FAILED");
    end
    $finish();
end
```

- The initial block defines the 'entry point' of the simulator. It executes only once at time zero
- The code in initial block runs sequentially, just like other languages (C, python)
- The input signals are driven using blocking (=) assignments
- #(n) is used to advance simulation time by n timesteps.
- \$display and \$finish are system functions

Timescales and timesteps

``timescale 1ns/10ps`
``timescale (simulation time step)/(simulation time resolution)`

Handwritten annotations: Red arrows point from the title to the `1ns` and `10ps` in the first code line. A red circle is drawn around `10ps`. To the right, handwritten red text shows `36ps` with a downward arrow pointing to `40ps`.

- ``timescale` declaration is at the top of each testbench
- Simulation time step defines how much time is advanced when running #1
- Simulation time resolution defines the smallest amount of time can be advanced
- In the example, `#1 = 1ns`; `#0.01` is the smallest possible delay

Delay

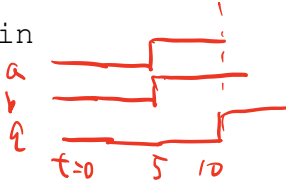
```
reg [7:0] r;  
reg a, b;  
wire c, d;  
initial begin  
    a = 0;  
    b = 1;  
    #1 r = 8'd20;  
    r = #1 8'b0001_0100;  
end  
  
assign #3 c = a & b;  
and #3 (d, a, b);  
// an AND gate with 3 timestep  
delay
```

- Delay at LHS: Everything happens after the time step
- Delay at RHS: RHS is evaluated first, and assigned to the left at the end of that time step
- Pay attention if blocking/non-blocking assignments are both used (not recommended)

Blocking vs Non-blocking + Delay

initial begin

```
a <= 0;
b <= 0;
q <= 0;
```



```
#5 a = 1;
b = 1;
```

```
#5 q <= a & b; @ t=10
end
```

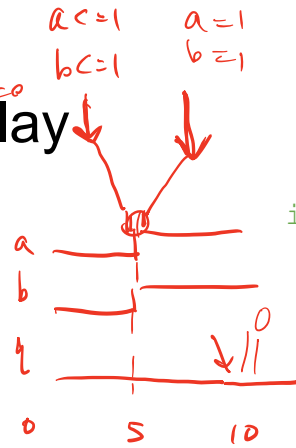
/* Output:

```
t=0: a=0, b=0, q=0
t=5: a=1, b=1, q=0
t=10: a=1, b=1, q=1
```

*/

initial begin

```
a <= 0;
b <= 0;
q <= 0;
```



```
#5 a <= 1;
b <= 1;
```

```
q <= #5 a & b; @ t=5
end
```

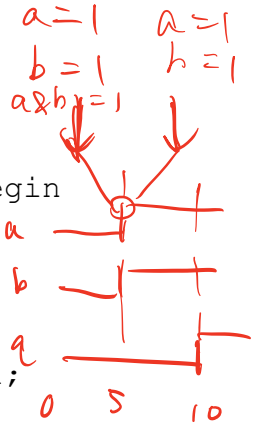
/* Output:

```
t=0: a=0, b=0, q=0
t=5: a=1, b=1, q=0
No change after t=5!
```

*/

initial begin

```
a <= 0;
b <= 0;
q <= 0;
```



```
#5 a (=) 1;
b (=) 1;
```

```
q <= #5 a & b;
end
```

/* Output:

```
t=0: a=0, b=0, q=0
t=5: a=1, b=1, q=0
t=10: a=1, b=1, q=1
```

*/

- [This article](#) is helpful for understanding!

Adder Demo

<https://www.edaplayground.com/x/fHwj>

Exhaustive Testing Demo

A small adder can be tested exhaustively by using nested for loops.

<https://www.edaplayground.com/x/JEZg>

Randomized Testing Demo

A large adder can't be tested exhaustively since it would take too much time. Instead test it using random stimulus.

<https://www.edaplayground.com/x/mEVz>

4-state Signals in Verilog

0
1
X
Z

```
module counter(input clk);  
    reg [3:0] count;  
    always @(posedge clk) begin  
        count <= count + 'd1;  
    end  
endmodule
```

- All *registers* begin with an initial value of 'x' in simulation unless otherwise specified
- Every signal in Verilog has 4 potential states: 0, 1, 'x' (unknown), 'z' (high-impedance/unconnected)
- We can set initial values of *registers* with `initial count = 0`
- Initial values are synthesizable on some FPGAs but not on ASICs, so using a `reset` is recommended

Simulation Constructs

```
@(posedge signal);
@(posedge signal);
//wait for 2 rising edges of signal
```



```
repeat (10) @(negedge clk);
//wait for 10 falling edge of clk
```



```
reg clk;
initial clk = 0;
always #(10) clk <= ~clk;
// an easy way to create a clock in testbench
```



always #(15) clk2 <= clk2; (c → 0 →)

\$display

```
$display("Wire x in decimal is %d", x);  
$display("Wire x in binary is %b", x);  
//Similar to printf() in C
```

```
module x(input clk, input valid, input data);  
    always @(posedge clk) begin  
        if (valid) $display("Data is %d", data);  
    end  
endmodule  
// $ display can be used inside RTL as well
```

$a = 0$;

#5 $a = 1$;

$a = 1$

\$display (a);

#5 $a = 0$;

#5 $a = 1$;

\$display (a);

$a = 0$

\$display (a);

$a = 1$

Counter Demo

Run through the counter testbench. Deal with unknown values, initialize registers, add a reset. Use \$display in the DUT.

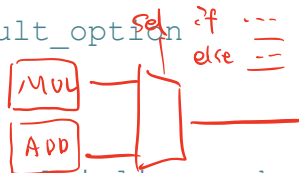
<https://www.edaplayground.com/x/mmHN>

Generate Macros

```
→ genvar i;  
generate for (i = 0; i < n; i = i + 1) begin  
    full_adder u0(.a(a[i]), .b(b[i]), .cin(c[i]), .s(s[i]), .cout(c[i+1]));  
end  
endgenerate
```

parameter mult_option ...

```
// there is a module parameter named mult_option  
→ generate if (mult_option == 1)  
    assign z = x * y;  
else  
    assign z = x + y; // will you see a multiplier and an adder on the hardware  
endgenerate // at the same time?
```



- Generate macros (generate for and generate if) can be used to programmatically instantiate hardware

2D Regs + Memories

[7]

// A memory structure that has eight 32-bit elements

reg [31:0] mem [7:0];

mem[2]

C = 32'b0

// The 3rd 32-bit element

[15]

mem[5][7:0]

// The lowest Byte (8-bit) of the 6th 32-bit element