

Verilog for Testbenches

Verilog for Testbenches

- ◆ Big picture: Two main Hardware Description Languages (HDL) out there
 - **VHDL**
 - Designed by committee on request of the DoD
 - Based on Ada
 - **Verilog**
 - Designed by a company for their own use
 - Based on C
- ◆ Both now have IEEE standards
- ◆ Both are in wide use

Overall Module Structure

```
module name (args...);  
begin  
  parameter ...; // define parameters  
  input ...;    // define input ports  
  output ...;   // define output ports  
  wire ...;    // internal wires  
  reg ...;     // internal or output regs  
  // the parts of the module body are  
  // executed concurrently  
  <module/primitive instantiations>  
  <continuous assignments>  
  <procedural blocks (always/initial)>  
endmodule
```

Overall Module Structure

```
module NAND2 (Y, A, B);  
begin  
  parameter ...; // define parameters  
  input A, B;    // define input ports  
  output Y;     // define output ports  
  wire ...;    // internal wires  
  reg ...;     // internal or output regs  
  // the parts of the module body are  
  // executed concurrently  
  <module/primitive instantiations>  
  assign Y = ~(A & B);  
  <procedural blocks (always/initial)>  
endmodule
```

Overall Module Structure

```
module NAND2 (Y, A, B);
  begin
    parameter ...; // define parameters
    input A, B;    // define input ports
    output Y;     // define output ports
    wire ...;    // internal wires
    reg ...;     // int. or output regs
    // the parts of the module body are
    // executed concurrently
    <module/primitive instantiations>
    assign #10 Y = ~(A & B);
    <procedural blocks (always/initial)>
  endmodule
```

Overall Module Structure

```
module NAND2 (Y, A, B);
  begin
    parameter ...; // define parameters
    input A, B;    // define input ports
    output Y;     // define output ports
    wire ...;    // internal wires
    reg ...;     // int. or output regs
    // the parts of the module body are
    // executed concurrently
    nand _i1 (Y, A, B);
    <continuous assignments>
    <procedural blocks (always/initial)>
  endmodule
```

Overall Module Structure

```
module NAND2 (Y, A, B);
begin
  parameter ...; // define parameters
  input A, B;    // define input ports
  output Y;     // define output ports
  wire ...;     // internal wires
  reg ...;      // int. or output regs
  // the parts of the module body are
  // executed concurrently
  <module/primitive instantiations>
  <continuous assignments>
  always @ (A or B)
    #10 Y = ~(A & B);
endmodule
```

Overall Module Structure

```
module NAND2 (Y, A, B);
begin
  parameter delay = 10; // define parameters
  input A, B;          // define input ports
  output Y;           // define output ports
  // the parts of the module body are
  // executed concurrently
  <module/primitive instantiations>
  <continuous assignments>
  always @ (A or B)
  begin
    #delay Y = ~(A & B);
  end
endmodule
```

Assignments

- ◆ Continuous assignments to **wire** vars
 - **assign variable = exp;**
 - Always at the “top level” of the module
 - In the concurrent execution section
 - Results in combinational logic

Assignments

- ◆ Procedural assignment to **reg** vars
 - Always inside procedural blocks
 - Meaning “always” or “initial” blocks
 - blocking **variable = exp;**
 - non-blocking **variable <= exp;**
 - Can result in combinational or sequential logic

Block Structures

- ◆ Two types:
 - **always** // repeats until simulation is done
begin
...
end
 - **initial** // executed once at beginning of simulation
begin
...
end

Data Types

- ◆ **reg** and **wire** are the main variable types
- ◆ Possible values for **wire** and **reg** variables:
 - **0**: logic 0, false
 - **1**: logic 1, true
 - **X**: unknown logic value
 - **Z**: High impedance state
- ◆ **integer**, **time**, and **real** are used in behavioral modeling, and in simulation (*not synthesis*)

Registers

- ◆ Abstract model of a data storage element
- ◆ A **reg** holds its value from one assignment to the next
 - The value “sticks”
- ◆ Register type declarations
 - `reg a; // a scalar register`
 - `reg [3:0] b; // a 4-bit vector register`

Wires (nets)

- ◆ **wire** variables model physical connections
- ◆ They don't hold their value
 - They must be driven by a “driver” (a gate output or a continuous assignment)
 - Their value is Z if not driven
- ◆ Wire declarations
 - `wire d; \\ a scalar wire`
 - `wire [3:0] e; \\ a 4-bit vector wire`

Memories

- ◆ Verilog models memory as an array of **regs**
- ◆ Each element in the memory is addressed by a single array index
- ◆ Memory declarations:
 - \\ a 256 word 8-bit memory (256 8-bit vectors)
`reg [7:0] imem[0:255];`
 - \\ a 1k word memory with 32-bit words
`reg [31:0] dmem[0:1023];`

Accessing Memories

```
reg [7:0] imem[0:255]; // 256 x 8 memory
reg [7:0] foo;         // 8-bit reg
reg [2:0] bar, baz;   // 3-bit regs

foo = imem[15]; // get word 15 from imem
bar = foo[6:4]; // extract 3 bits from foo
baz = bar;     // assign all 3 bits of baz
```


Other types

- ◆ Integers:
 - `integer i, j; \` declare two scalar ints
 - `integer k[0:7]; \` an array of 8 ints
- ◆ `$time` - returns simulation time
 - Useful inside `$display` and `$monitor` commands...

Number Representations

- ◆ Two forms are available:
 - Simple decimal numbers: 45, 123, 49039...
 - `<size>'<base><number>`
 - base is d, h, o, or b
 - size is number of bits (not digits!)
- ◆ `4'b1001` // a 4-bit binary number
- ◆ `8'h2fe4` // an 8-bit hex number

Relational Operators

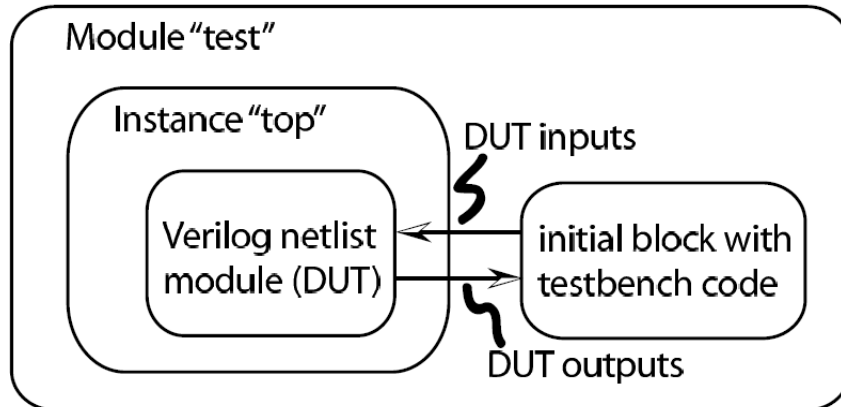
- ◆ $A < B$, $A > B$, $A \leq B$, $A \geq B$, $A == B$, $A != B$
 - The result is 0 if the relation is false, 1 if the relation is true, X if either of the operands has any X's in the number
- ◆ $A === B$, $A !== B$
 - These require an exact match of numbers, X's and Z's included

Relational Operators

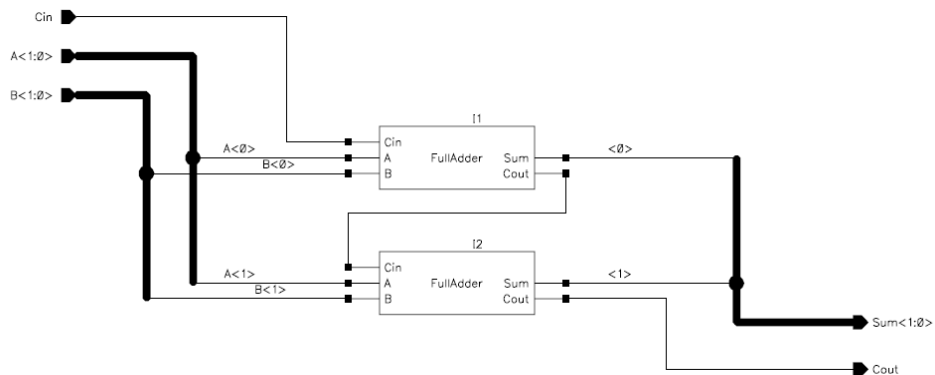
- ◆ $!$, $\&\&$, $||$
 - Logical NOT, AND, OR of expressions
 - e.g. `if (!(A == 5) && (B != 2))`
- ◆ \sim , $\&$, $|$, \wedge
 - bitwise NOT, AND, OR, and XOR
 - e.g. `Y = ~(A & B);`
- ◆ `{a, b[3:0]}` // example of concatenation

Testbench Template

- ◆ Testbench template generated by Cadence



DUT schematic (twoBitAdd)



Testbench Template

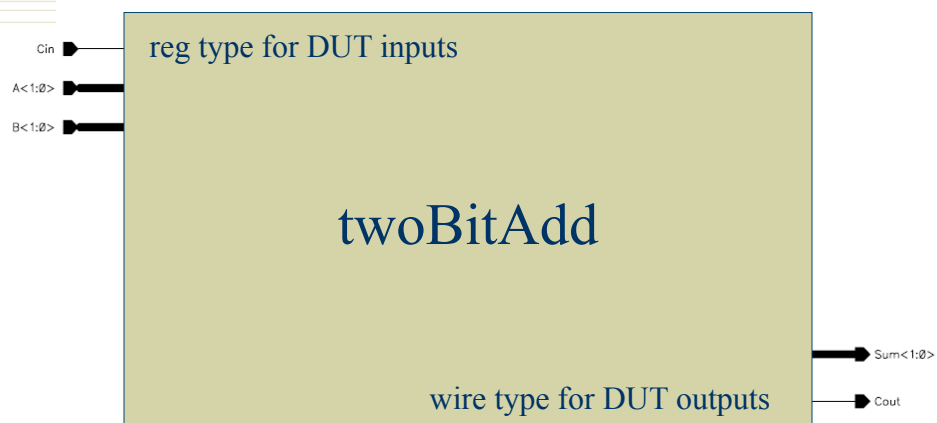
```
`timescale 1ns / 100ps
module test;

  wire  Cout;
  reg   Cin;
  wire [1:0]  Sum;
  reg  [1:0]  A;
  reg  [1:0]  B;

  twoBitAdd top(Cout, Sum, A, B, Cin);

  `include "testfixture.verilog"
endmodule
```

DUT schematic



testfixture.verilog

- ◆ Again, template generated by Cadence

```
// Verilog stimulus file.  
// Please do not create a module in this file.  
  
// Default verilog stimulus.  
  
initial  
begin  
  
    A[1:0] = 2'b00;  
  
    B[1:0] = 2'b00;  
  
    Cin = 1'b0;  
  
end
```

Testbench code

- ◆ All your test code will be inside an initial block!
 - Or, you can create new procedural blocks that will be executed concurrently
 - Remember the structure of the module
 - If you want new temp variables you need to define those outside the procedural blocks
 - DUT inputs and outputs have been defined in the template
 - DUT inputs are **reg** type
 - DUT outputs are **wire** type

Basic Testbench

```
initial
begin
  a[1:0] = 2'b00;
  b[1:0] = 2'b00;
  cin = 1'b0;
  $display("Starting...");
  #20
  $display("A = %b, B = %b, c = %b, Sum = %b, Cout = %b", a, b, cin, sum, cout);
  if (sum != 0) $display("ERROR: Sum should be 00, is %b", sum);
  if (cout != 0) $display("ERROR: cout should be 0, is %b", cout);
  a = 2'b01;
  #20
  $display("A = %b, B = %b, c = %b, Sum = %b, Cout = %b", a, b, cin, sum, cout);
  if (sum != 0) $display("ERROR: Sum should be 01, is %b", sum);
  if (cout != 0) $display("ERROR: cout should be 0, is %b", cout);
  b = 2'b01;
  #20
  $display("A = %b, B = %b, c = %b, Sum = %b, Cout = %b", a, b, cin, sum, cout);
  if (sum != 0) $display("ERROR: Sum should be 10, is %b", sum);
  if (cout != 0) $display("ERROR: cout should be 0, is %b", cout);
  $display("...Done");
  $finish;
end
```

\$display, \$monitor

- ◆ \$display(format-string, args);
 - like a printf
 - \$fdisplay goes to a file...
 - \$fopen and \$fclose deal with files
- ◆ \$monitor(format-string, args);
 - Wakes up and prints whenever args change
 - Might want to include \$time so you know when it happened...
 - \$fmonitor is also available...

Conditional, For

- ◆ If (<expr>) <statement> else <statement>
 - else is optional and binds with closest previous if that lacks an else
 - if (index > 0)
if (rega > regb)
result = rega;
else result = regb;
- ◆ For is like C
 - for (initial; condition; step)
 - for (k=0; k<10; k=k+1)
<statement>;

No k++ syntax
in Verilog...

for

```
parameter MAX_STATES 32;
integer state[0:MAX_STATES-1];
integer i;
initial
begin
  for(i=0; i<32 ; i=i+2)
    state[i] = 0;
  for(i=1; i<32; i=i+2)
    state[i] = 1;
end
```

while

- ◆ A while loop executes until its condition is false

```
count = 0;
while (count < 128)
begin
    $display("count = %d", count);
    count = count + 1;
end
```

repeat

- ◆ repeat for a fixed number of iterations

```
parameter cycles = 128;
integer count;
initial
begin
    count = 0;
    repeat(cycles)
    begin
        $display("count = %d", count);
        count = count+1;
    end
end
```


Nifty Testbench

```
reg [1:0] ainarray [0:4]; // define memory arrays to hold input and result
reg [1:0] binarray [0:4];
reg [2:0] resultsarray [0:4];
integer i;
initial begin
  $readmemb("ain.txt", ainarray); // read values into arrays from files
  $readmemb("bin.txt", binarray);
  $readmemb("results.txt", resultsarray);
  a[1:0] = 2'b00; // initialize inputs
  b[1:0] = 2'b00;
  cin = 1'b0;
  $display("Starting...");
  #10 $display("A = %b, B = %b, c = %b, Sum = %b, Cout = %b", a, b, cin, sum, cout);
  for (i=0; i<=4; i=i+1) // loop through all values in the memories
  begin
    a = ainarray[i]; // set the inputs from the memory arrays
    b = binarray[i];
    #10 $display("A = %b, B = %b, c = %b, Sum = %b, Cout = %b", a, b, cin, sum, cout);
    if ({cout,sum} != resultsarray[i])
      $display("Error: Sum should be %b, is %b instead", resultsarray[i],sum); // check results
    end
  $display("...Done");
  $finish;
end
```

Another Nifty Testbench

```
integer i,j,k;
initial
begin
  A[1:0] = 2'b00;
  B[1:0] = 2'b00;
  Cin = 1'b0;
  $display("Starting simulation...");
  for(i=0;i<=3;i=i+1)
  begin for(j=0;j<=3;j=j+1)
    begin for(k=0;k<=1;k=k+1)
      begin
        #20 $display("A=%b B=%b Cin=%b, Cout-Sum=%b%b", A, B, Cin, Cout, S);
        if ({Cout,S} != A + B + Cin)
          $display("ERROR: CoutSum should equal %b, is %b", (A + B + Cin), {Cin,S});
          Cin=~Cin; // invert Cin
        end
        B[1:0] = B[1:0] + 2'b01; // add 1 to the B input
      end
      A = A+1; // shorthand notation for adding
    end
  $display("Simulation finished... ");
end
```

Another Example

```
initial begin // executed only once
    a = 2'b01; // initialize a and b
    b = 2'b00;
end
always begin // execute repeatedly until simulation completes
    #50 a = ~a; // reg a inverts every 50 units
end
always // execute repeatedly
begin // until simulation completes
    #100 b = ~b // reg b inverts every 100 units
end
```

What's wrong with this code?

Another Example

```
initial begin // executed only once
    a = 2'b01; // initialize a and b
    b = 2'b00;
    #200 $finish; // make sure the simulation finishes!
end
always begin // execute repeatedly until simulation completes
    #50 a = ~a; // reg a inverts every 50 units
end
always // execute repeatedly
begin // until simulation completes
    #100 b = ~b // reg b inverts every 100 units
end
```