

# 271/471 Verilog Tutorial

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## Introduction

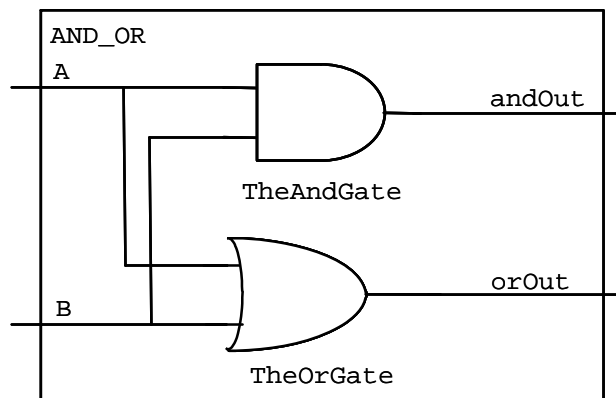
The following tutorial is intended to get you going quickly in circuit design in Verilog. It isn't a comprehensive guide to System Verilog, but should contain everything you need to design circuits for your class.

If you have questions, or want to learn more about the language, I'd recommend Vahid and Lysecky's *Verilog or Digital Design*.

## Modules

The basic building block of Verilog is a module. This is similar to a function or procedure in C/C++/Java in that it performs a computation on the inputs to generate an output. However, a Verilog module really is a collection of logic gates, and each time you call a module you are creating that set of gates.

An example of a simple module:



```
// Compute the logical AND and OR of inputs A and B.
module AND_OR(andOut, orOut, A, B);
    output andOut, orOut;
    input A, B;

    and TheAndGate (andOut, A, B);
    or TheOrGate (orOut, A, B);
endmodule
```

We can analyze this line by line:

```
// Compute the logical AND and OR of inputs A and B.
```

The first line is a comment, designated by the //. Everything on a line after a // is ignored. Comments can appear on separate lines, or at the end of lines of code.

```
module AND_OR(andOut, orOut, A, B);
```

```
output andOut, orOut;
input A, B;
```

The top of a module gives the name of the module (AND\_OR in this case), and the list of signals connected to that module. The subsequent lines indicate that the first two binary values (andOut and orOut) are generated by this module, and are output from it, while the next two (A, B) are inputs to the module.

```
and TheAndGate (andOut, A, B);
or TheOrGate (orOut, A, B);
```

This creates two gates: An AND gate, called “TheAndGate”, with output andOut, and inputs A and B; An OR gate, called “TheOrGate”, with output orOut, and inputs A and B. The format for creating or “instantiating” these gates is explained below.

```
endmodule
```

All modules must end with an endmodule statement.

## **Basic Gates**

Simple modules can be built from several different types of gates:

```
buf <name> (OUT1, IN1); // Sets output equal to input
not <name> (OUT1, IN1); // Sets output to opposite of input
```

The <name> can be whatever you want, but start with a letter, and consist of letters, numbers, and the underscore “\_”. Avoid keywords from Verilog (i.e. “module”, “output”, etc.).

There are multi-input gates as well, which can each take two or more inputs:

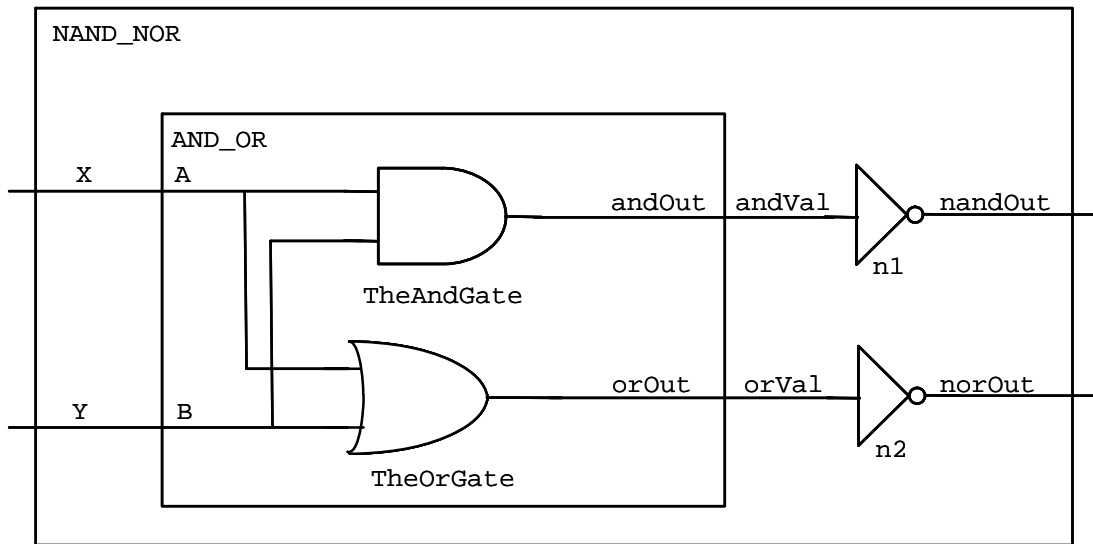
```
and <name> (OUT, IN1, IN2); // Sets output to AND of inputs
or <name> (OUT, IN1, IN2); // Sets output to OR of inputs
nand <name> (OUT, IN1, IN2); // Sets to NAND of inputs
nor <name> (OUT, IN1, IN2); // Sets output to NOR of inputs
xor <name> (OUT, IN1, IN2); // Sets output to XOR of inputs
xnor <name> (OUT, IN1, IN2); // Sets to XNOR of inputs
```

If you want to have more than two inputs to a multi-input gate, simply add more. For example, this is a five-input and gate:

```
and <name> (OUT, IN1, IN2, IN3, IN4, IN5); // 5-input AND
```

## **Hierarchy**

Just like we build up a complex software program by having procedures call subprocedures, Verilog builds up complex circuits from modules that call submodules. For example, we can take our previous AND\_OR module, and use it to build a NAND\_NOR:



```
// Compute the logical AND and OR of inputs A and B.
module AND_OR(andOut, orOut, A, B);
    output andOut, orOut;
    input A, B;

    and TheAndGate (andOut, A, B);
    or TheOrGate (orOut, A, B);
endmodule

// Compute the logical NAND and NOR of inputs X and Y.
module NAND_NOR(nandOut, norOut, X, Y);
    output nandOut, norOut;
    input X, Y;
    wire andVal, orVal;

    AND_OR aoSubmodule (.andOut(andVal), .orOut(orVal),
                        .A(X), .B(Y));
    not n1 (nandOut, andVal);
    not n2 (norOut, orVal);
endmodule
```

Notice that in the NAND\_NOR procedure, we now use the AND\_OR module as a gate just like the standard Verilog “and”, “not”, and other gates. That is, we list the module’s name, what we will call it in this procedure (“aoSubmodule”), and the outputs and inputs:

```
AND_OR aoSubmodule (.andOut(andVal), .orOut(orVal),
                    .A(X), .B(Y));
```

Note that unlike C/C++/Java where we use the order of parameters to indicate which caller values connect to which submodule ports, in Verilog we explicitly name the ports. That is, when we say:

```
.andOut (andVal)
```

We mean that the “andVal” wires in the caller module are connected to the “andOut” wires in the called submodule. This explicit naming tends to avoid mistakes, especially when someone adds or deletes ports inside the submodule. Note that every signal name in each module is distinct. That is, the same name can be used in different modules independently. In fact, if the caller module wants to hook a wire to a port of a submodule with the same name, there’s a shorthand for that. For example, if we had the call:

```
AND_OR aoSubmodule (.andOut(andOut), .orOut(orVal),
                    .A(A), .B(B));
```

We could write that alternatively as:

```
AND_OR aoSubmodule (.andOut, .orOut(orVal), .A, .B);
```

This hooks andOut in the caller to andOut of the submodule, as well as A to A and B to B.

Just as we had more than one not gate in the NAND\_NOR module, you can also call the same submodule more than once. So, we could add another AND\_OR gate to the NAND\_NOR module if we chose to – we simply have to give it a different name (like “n1” and “n2” on the not gates). Each call to the submodule creates new gates, so three calls to AND\_OR (which creates an AND gate and an OR gate in each call) would create a total of  $2 \times 3 = 6$  gates.

One new statement in this module is the “wire” statement:

```
wire andVal, orVal;
```

This creates what are essentially local variables in a module. In this case, these are actual wires that carry the signals from the output of the AND\_OR gate to the inverters.

Note that we chose to put the not gates below the AND\_OR in this procedure. The order actually doesn’t matter – the calls to the modules hooks gates together, and the order they “compute” in doesn’t depend at all on their placement order in the code – all execute in parallel anyway. Thus, we could swap the order of the “not” and “AND\_OR” lines in the module freely.

## ***True and False***

Sometimes you want to force a value to true or false. We can do that with the numbers “0” = false, and “1” = true. For example, if we wanted to compute the AND\_OR of false and some signal “foo”, we could do the following:

```
AND_OR aoSubmodule (.andOut(andVal), .orOut(orVal),
                    .A(0), .B(foo));
```

## ***Delays***

Normally Verilog statements are assumed to execute instantaneously. However, Verilog does support some notion of delay. Specifically, we can say how long the basic gates in a circuit take to execute with the # operator. For example:

```
// Compute the logical AND and OR of inputs A and B.
module AND_OR(andOut, orOut, A, B);
    output andOut, orOut;
    input A, B;
```

```

    and #5 TheAndGate (andOut, A, B);
    or #10 TheOrGate (orOut, A, B);
endmodule

```

This says that the and gate takes 5 “time units” to compute, while the or gate is twice as slow, taking 10 “time units”. Note that the units of time can be whatever you want – as long as you put in consistent numbers.

## ***Defining constants***

Sometimes you want to have named constants - variables whose value you set in one place and use throughout a piece of code. For example, setting the delay of all units in a module can be useful. We do that as follows:

```

// Compute the logical AND and OR of inputs A and B.
module AND_OR(andOut, orOut, A, B);
    output andOut, orOut;
    input A, B;
    parameter delay = 5;

    and #delay TheAndGate (andOut, A, B);
    or #delay TheOrGate (orOut, A, B);
endmodule

```

This sets the delay of both gates to the value of “delay”, which in this case is 5 time units. If we wanted to speed up both gates, we could change the value in the parameter line to 2.

## ***Parameterized Design***

Parameters can also be inputs to designs, that allow the caller of the module to set the size of features of that specific instance of the module. So, if we have a module such as:

```

module adder #(parameter WIDTH=5) (out, a, b);
    output [WIDTH-1:0] out;
    input  [WIDTH-1:0] a, b;

    assign out = a + b;
endmodule

```

This defines a parameter “WIDTH” with a default value of 5 – any instantiation of the adder module that does not specify a width will have all of the internal variable widths set to 5. However, we can also instantiate other widths as well:

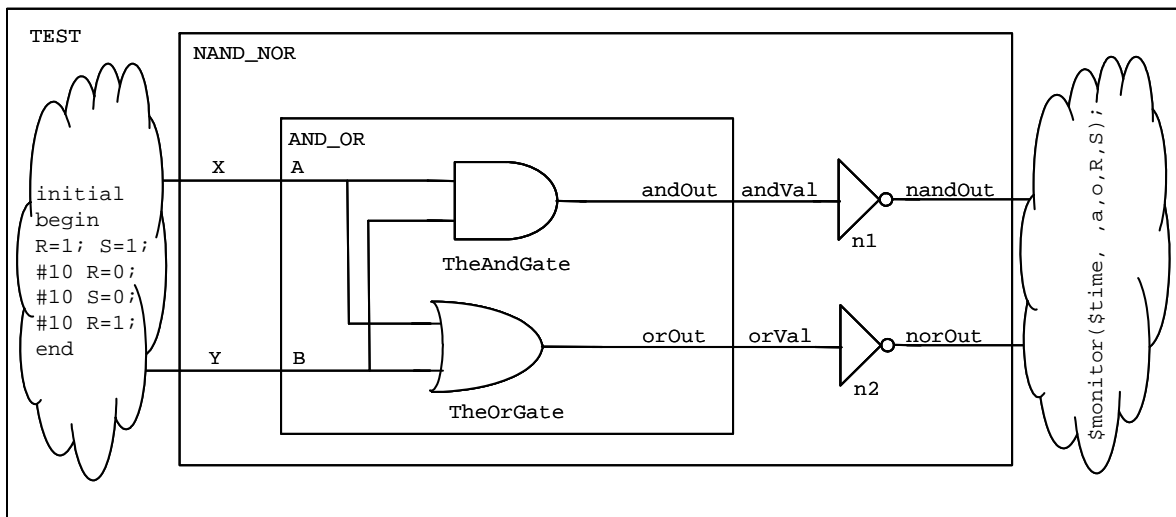
```

// A 16-bit adder
adder #(.WIDTH(16)) add1 (.out(o1), .a(a1), .b(b1));
// A default-width adder, so 5-bit
adder add2 (.out(o2), .a(a2), .b(b2));

```

## ***Test benches***

Once a circuit is designed, you need some way to test it. For example, we’d like to see how the NAND\_NOR circuit we designed earlier behaves. To do this, we create a test bench. A test bench is a module that calls your unit under test (UUT) with the desired input patterns, and collects the results. For example consider the following:



```
// Compute the logical AND and OR of inputs A and B.
module AND_OR(andOut, orOut, A, B);
    output andOut, orOut;
    input A, B;

    and TheAndGate (andOut, A, B);
    or TheOrGate (orOut, A, B);
endmodule

// Compute the logical NAND and NOR of inputs X and Y.
module NAND_NOR(nandOut, norOut, X, Y);
    output nandOut, norOut;
    input X, Y;
    wire andVal, orVal;

    AND_OR aoSubmodule (.andOut(andOut), .orOut(orVal),
                        .A(A), .B(B));
    not n1 (nandOut, andVal);
    not n2 (norOut, orVal);
endmodule

module NAND_NOR_testbench; // No ports!
    reg X, Y;
    wire nandOut, norOut;

    initial begin // Stimulus
        X = 1; Y = 1; #10;
        X = 0;           #10;
        Y = 0; #10;
        X = 1;           #10;
    end
endmodule
```

```
end
```

```
NAND_NOR dut (.nandOut, .norOut, .X, .Y);
```

```
endmodule
```

The code to notice is that of the module “NAND\_NOR\_testbench”. It instantiates one copy of the NAND\_NOR gate, called “dut” (device under test). All the inputs to the dut are declared “reg”, while the outputs are declared “wire”. The inputs are declared “reg” so that they will have memory, remembering the last value assigned to them – this is important to allow us to use the “initial” block for stimulus.

In order to provide test data to the dut, we have a stimulus block:

```
initial begin // Stimulus
    X = 1; Y = 1; #10;
    X = 0;           #10;
        Y = 0; #10;
    X = 1;           #10;
end
```

The code inside the “initial” statement is only executed once. It first sets X and Y to true. Then, due to the “#10” the system waits 10 time units, keeping X and Y at the assigned values. We then set X to false. Since Y wasn’t changed, it remains at true. Again we wait 10 time units, and then we change Y to false (X remains at false). If we consider the entire block, the inputs XY go through the pattern 11 -> 01 -> 00 -> 10, which tests all input combinations for this circuit. Other orders are also possible. For example we could have done:

```
initial begin // Stimulus
    X = 0; Y = 0; #10;
        Y = 1; #10;
    X = 1; Y = 0; #10;
        Y = 1; #10;
end
```

This goes through the pattern 00 -> 01 -> 10 -> 11. In fact, there’s a shorthand for doing this format:

```
integer i;
initial begin // Stimulus
    for(i=0; i<4; i++) begin
        {X,Y} = i; #10;
    end
end
```

We use the fact that integers are encoded in binary, and the binary values go through the pattern 000, 001, 010, 011, 100, 101, ... If you want to put N binary signals through all combinations of inputs, then use the same code, but replace the upper limit of 4 with the integer whose value is  $2^N$ .

## ***Register Transfer Level (RTL) Code***

In the earlier sections, we showed ways to do structural designs, where we tell the system exactly how to perform the design. In RTL code we instead state what we want, and allow the Verilog system to automatically determine how to do the computation.

Note: in RTL it is easy to forget how the hardware actually works, and pretend it's just C or Java. This is a great way to design AWFUL hardware. Because of this, we will give you stylized ways of using the constructs, which will guide you towards better versions. Our introductory logic class spends a lot of time showing what hardware is generated from various Verilog structures – think about the hardware your Verilog actually requires!

In each of these cases, RTL code is done in an “always” block. Anything whose value is set in RTL code should be declared as “reg”. Also, the always statement should be followed by a sensitivity list – generally `@(*)`, which is shorthand for “re-evaluate this chunk of logic whenever any of the inputs it depends on changes”.

### ***Begin-end***

Begin and end statements merge together multiple statements into one, like the “{ }” braces in C and Java. For statements below such as “if-then-else” and “case”, you can use begin and end to merge together multiple statements.

### ***If-then-else***

```
reg V1, V2;
always @(*) begin
    if (A == 1) begin
        V1 = 1;
        V2 = 0;
    end else if (A == 0 & B == 1) begin
        V1 = 1;
        V2 = 1;
    end else begin
        V1 = 0;
        V2 = 0;
    end
end
```

You can set the output of a wire based upon the value of other signals. The if-then-else is similar to software programming languages. Note however that you should make sure that all signals are defined in all cases (i.e. it would be a problem to delete either V1 or V2 from any of these clauses).

If you think through this code, it is equivalent to a logic function. For example, V1 is true only when  $A == 1$ , or when  $A == 0$  and  $B == 1$ . This is equivalent to  $V1 = A + (\text{not}(A) * B) = A + B$ . Similarly  $V2 = \text{not}(A) * B$ .

### ***case***

As we move to multi-bit signals, that can take on values more than just 0 and 1, the case statement becomes quite useful. The variable to be considered is placed in the “case ()” statement, and then different values are listed, with the associated action. For example, in the code below when the “state” variable is equal to 0, HEX is set to 0, while if the “state” variable is equal to 1, HEX is set to 1, and so on. There must also always be a “default” case, which is used when no other case matches. Also, like the if-then-else



statement, any variable set in any part of the case statement should be set in all states. That is, dropping HEX from any of the “state” value lines would be incorrect.

In this code we use “1'bX” to indicate a 1-bit binary don't care in the default case, allowing the Verilog system to use Don't Cares in the minimization.

```
reg HEX;
always @(*) begin
    case (state)
        0: HEX = 0;
        1: HEX = 1;
        2: HEX = 1;
        3: HEX = 0;
        4: HEX = 1;
        default: HEX = 1'bX;
    endcase
end
```

## ***Sequential Logic***

In combinational logic we start an always block with “always @(\*)”, which means the logic output is recomputed every time any of the inputs changes. For sequential logic, we need to introduce a clock, which will require a somewhat different always statement:

```
// D flip-flop w/synchronous reset
module D_FF (q, d, reset, clk);
    output q;
    input d, reset, clk;
    reg q; // Indicate that q is stateholding

    always @(posedge clk) // Hold val until clock edge
        if (reset)
            q <= 0; // On reset, set to 0
        else
            q <= d; // Otherwise out = d
endmodule
```

Most of this should be familiar. The new part is the “always @(posedge clk)”.

For sequential circuits, we want to have signals that remember their prior value until it is overwritten. We do this by the “reg” statement, which declares a variable that remembers the last value written to it – an implicit flip-flop. This came in handy before in making testbenches, since we usually want to set up the inputs to remember their last setting, until we change it. Here, the variable “q” in the D\_FF module remembers the value written to it on the last important clock edge.

We capture the input with the “always @(posedge clk)”, which says to only execute the following statement statements at the instant you see a positive edge of the clk. That means we have a positive edge-triggered flip-flop. We can build a negative edge-triggered flip-flop via “always @(negedge clk)”.

## **Assignment styles: = vs. <=**

Verilog includes two different types of ways to assign values to variables: = vs. <=. They are subtly different:

- = The assignment occurs immediately. A subsequent line will see the new value. So, a = b; c = a; will set both a and c to the value contained in b.
- <= The value to be assigned is computed immediately, but the assignment itself is delayed until all simultaneously executing code has been evaluated. So, a<=b; b<=a; will swap the values of a and b. However, a<=b; c<= a; will set a to the value of b, and c to the old value of a (the value before the value of b is written to a).

The two kinds of assignment can be confusing, and mixing them in one “always” block is a recipe for disaster. However, things are much easier if you obey the following rules:

1. Inside always @(posedge clk) blocks use <= for everything (except the iteration variable in a for loop).
2. For assign statements and always @(\*) blocks use = for everything.
3. Avoid complex logic in always @(posedge clk) blocks – instead, compute complex logic in always @(\*) blocks, and then just have statements like “ps <= ns” in always @(posedge clk) blocks.

## **Clocks**

A sequential circuit will need a clock. We can make the test bench provide it with the following code:

```
reg clk;
parameter PERIOD = 100; // 2*period = length of clock
                        // Make the clock LONG to test

initial clk = 0;
always #(PERIOD/2) clk = ~clk;
```

This code would be put into the testbench code for your system, and all modules that are sequential will take the clock as an input.

## **Declaring Multi-bit Signals**

So far we have seen “wire” and “reg” statements that create single-bit signals (i.e. they are just 0 or 1). Often you’d like to represent multi-bit wires (for example, a 3-bit wire that can represent values 0..7). We can do this type of operation with the following declarations:

```
wire [2:0] foo; // a 3-bit signal (a bus)
reg [15:0] bar; // a 16-bit stateholding value
```

These statements set up a set of individual wires, which can also be treated as a group. For example, the “wire [2:0] foo;” declares a 3-bit signal, which has the MSB (the  $2^2$ ’s place) as foo[2], the LSB (the  $2^0$ ’s place) as foo[0], and a middle bit of foo[1].

The individual signals can be used just like any other binary value in Verilog. For example, we could do:

```
and a1(foo[2], foo[0], c);
```

This AND's together c and the 1's place of foo, and puts the result in the 4's place of foo.

Multi-bit signals can also be passed together to a module:

```
module random(bus1, bus2);
    output [31:0] bus1;
    input [19:0] bus2;
    wire c;

    another_random ar1(.c, .bus2, .bus1);
endmodule
```

This module connects to two multi-bit signals (32 and 20 bits respectively), and passes both of them to another module "another\_random", which also connects to a single-bit wire c.

### **Multi-bit Signals – Common Error**

When you are declaring multi-bit signals, you may get a warning message like:

*"Warning! Port sizes differ in port connection (port 2) [Verilog-PCDPC]"*

look for something like the following in your code:

```
input [31:0] d, reset, clk;
```

What that line does is declare 3 32-bit values. That is, d is [31:0] AND reset is [31:0] AND clk is [31:0]

What you actually want is:

```
input [31:0] d;
input reset, clk;
```

Which declares d to be a 32-bit value, and reset and clk are 1-bit values.

### **Multi-bit Constants**

In test benches and other places, you may want to assign a value to a multi-bit signal.

You can do this in several ways, shown in the following code:

```
reg [15:0] test;
initial begin // stimulus
    test = 12;
    #(10) test = 16'h1f;
    #(10) test = 16'b01101;
end
```

The 16-bit variable test is assigned three different values. The first is in decimal, and represents twelve. The second is a hexadecimal number (specified by the 'h) 1f, or 16+15 = 31. The last is a binary number (specified by the 'b) 01101 = 1+4+8 = 13. In each case the value is assigned, in the equivalent binary, to the variable test. Unspecified bits are padded to 0. So, the line:

```
test = 12;
```

is equivalent to:

```
test = `b00000000000001100;
```

It sets test[2] and test[3] to 1, and all other bits to 0.

### ***For Loops for Multi-bit Signals***

Sometimes when we need to reorganize signals in a bus, a FOR loop can be helpful, particularly with mathematical calculations for the indexes.

```
reg [7:0] LEDG;
integer i;

always @(*) begin
    for (i=0; i<8; i=i+1)
        LEDG[7-i] = GPIO_0[28+i];
    for (i=0; i<10; i=i+1)
        LEDR[9-i] = GPIO_0[18+i];
end
```

In this code we set LEDG[7] = GPIO\_0[28], LEDG[6] = GPIO\_0[29], etc.

### ***Multi-Dimensional Buses***

Sometimes it can be useful to have structures with more than one dimension – for example, we might want to hold 16 8-bit values. Verilog allows you to define multiple sets of indexes for a variable:

```
reg [7:0] string [15:0];
```

Notice that we have put one dimension in front of the variable, and another behind – we can actually pick to put any number of dimensions before, and any number after. The rule you should use is that dimensions to the left of the variable name (the [7:0] above) should be the bits of a value (we wanted 8-bit values in the string), and the dimensions to the right of the variable name (the [15:0]) should refer to different elements. Thus, if instead of 16x8-bit values, we wanted a 16x8 grid of 1-bit entries, we would define it as:

```
reg bitField [15:0][7:0];
```

To index a value, you move left-to-right through the indices, but the indices to the right of the variable appear BEFORE the indices to the left of the variable. For example, the following code sets all the bits of a 4-dimensions bus to 0:

```
reg [7:0][3:0] vals [15:0][9:0];
integer i, j, k, l;

always @(*)
    for(i=0; i <= 15; i++)
        for(j=0; j<=9; j++)
            for(k=0; k<=7; k++)
                for(l=0; l<=3; l++)
                    vals[i][j][k][l] = 1'b0;
```

### ***Subsets***

Sometimes you want to break apart multi-bit values. We can do that by selecting a subset of a value. For example, if we have

```
wire [31:0] foo;
initial foo[3:1] = 3'b101;
```

This would set  $\text{foo}[3] = 1$ ,  $\text{foo}[2] = 0$ , and  $\text{foo}[1] = 1$ . All other bits of  $\text{foo}$  will not be touched. We could also use the same form to take a subset of a multi-bit wire and pass it as an input to another module.

Note that this subdividing can be done to save you work in creating large, repetitive structures. For example, consider the definition of a simple 16-bit register built from a base `D_FF` unit:

```
module D_FF16(q, d, clk);
    output [15:0] q;
    input [15:0] d;
    input clk;

    D_FF d0 (.q(q[0]), .d(d[0]), .clk);
    D_FF d1 (.q(q[1]), .d(d[1]), .clk);
    ...
    D_FF d15(.q(q[15]), .d(d[15]), .clk);
endmodule
```

with the 16 separate `D_FF` lines there's a good likelihood you'll make a mistake somewhere. For a 32-bit register it's almost guaranteed. We can do it a bit more safely by repeatedly breaking down the problem into pieces. For example, write a 4-bit register, and use it to build the 16-bit register:

```
module D_FF4(q, d, clk);
    output [3:0] q;
    input [3:0] d;
    input clk;

    D_FF d0(.q(q[0]), .d(d[0]), .clk);
    D_FF d1(.q(q[1]), .d(d[1]), .clk);
    D_FF d2(.q(q[2]), .d(d[2]), .clk);
    D_FF d3(.q(q[3]), .d(d[3]), .clk);
endmodule

module D_FF16(q, d, clk);
    output [15:0] q;
    input [15:0] d;
    input clk;

    D_FF4 d0( .q(q[3:0]), .d(d[3:0]), .clk);
    D_FF4 d1( .q(q[7:4]), .d(d[7:4]), .clk);
    D_FF4 d2( .q(q[11:8]), .d(d[11:8]), .clk);
    D_FF4 d3( .q(q[15:12]), .d(d[15:12]), .clk);
endmodule
```

## ***Concatenations***

Sometimes instead of breaking apart a bus into pieces, you instead want to group things together. Anything inside `{}`'s gets grouped together. For example, if we want to swap the low and high 8 bits of an input to a `D_FF16` we could do:

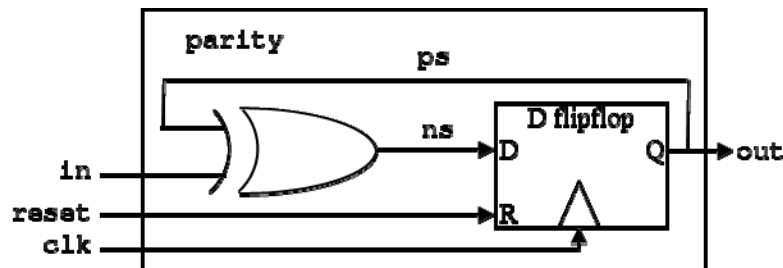
```
wire [15:0] data, result;
```

```
D_FF16 d1(.q(result), .d({data[7:0], data[15:8]}), .clk);
```

Pretty much anything can go into the concatenation – constants, subsets, buses, single wires, etc.

### ***Example Finite State Machine***

Here's an example of a simple sequential circuit, with all of its gory details. Note that this circuit computes parity – the output is true when the circuit has seen an odd number of trues on its input.



```
// Parity example
```

```
module parity (out, in, reset, clk);
    output out;
    input in, reset, clk;
    reg ps, ns;
```

```
    always @(*)
        ns = ps ^ in;
```

```
    always @(posedge clk)
        if (reset)
            ps <= 0;
        else
            ps <= ns;
```

```
    assign out = ps;
endmodule
```

```
module parity_testbench;
    reg in, reset, clk;
    wire out;
```

```
    parameter period = 100;
```

```
    parity dut (.in, .reset, .clk, .out);
```

```

initial clk = 1;
always begin
    #(period/2);
    clk = ~clk;
end

initial begin
    reset <= 1; in <= 0; @(posedge clk);
    reset <= 0;          @(posedge clk);
                        in <= 1; @(posedge clk);
                        in <= 0; @(posedge clk);
                        in <= 1; @(posedge clk);
                        in <= 0; @(posedge clk);
                        in <= 1; @(posedge clk);
                        in <= 0; @(posedge clk);
                        in <= 1; @(posedge clk);
    $stop();
end

endmodule

```

### ***Advanced Features – assert statements***

As you design larger systems, you will often have assumptions you'd like to make sure are true. For example, you may have a parameterized module, but there are only a few legal values of that parameter. Or, you may have a module that assumes the inputs obey certain requirements. You could check this via simulation, but as the design gets larger you are more and more likely to miss things.

The solution to this is the “assert” statement, that in simulation will raise an error whenever the value inside the assertion is false. So, if we have a parameter with only a few legal values, we can test it with an assertion inside the module:

```

initial assert(WIDTH>1 && WIDTH<=19);

```

If we require that at least one input to a unit must always be true, we can test it with an always-running assertion:

```

always @(posedge clk)
    assert(reset || a != 3'b000 || b);

```

### ***Advanced Features – generate statements***

Earlier in this tutorial we showed how to build a 16-bit register by using a hierarchy of modules, one that does a 4-bit register, and another that uses 4 of these 4-bit registers to build a 16-bit register. If we want to make a completely parameterized version, where the size can be any length at all, we can use a generate statement. Generate allows us to

put submodule calls and other logic within “for” loops and “if” statements, allowing the logic to decide the number of modules actually instantiated. Note that any iteration variables must be declared “genvar”, and any for loops or if statements must have a begin – end block with a label (an identifier, such as “eachDff” in the code below).

```
module DFF_VAR #(parameter WIDTH=8) (q, d, clk);
    output [WIDTH-1:0] q;
    input  [WIDTH-1:0] d;
    input                clk;

    initial assert(WIDTH>0);

    genvar i;

    generate
        for(i=0; i<WIDTH; i++) begin : eachDff
            D_FF dff (.q(q[i]), .d(d[i]), .clk);
        end
    endgenerate
endmodule
```

Note that for the case of the register, one could just use a parameter and the FSM format to do the same thing:

```
module DFF_VAR #(parameter WIDTH=8) (q, d, clk);
    output reg [WIDTH-1:0] q;
    input  [WIDTH-1:0] d;
    input                clk;

    initial assert(WIDTH>0);

    always @(posedge clk)
        q <= d;
endmodule
```

But, the register is a simple way to show the power of generate statements, which can be useful in some situations that often cannot be handled in any other way.

foo.