Verification Continuum™

Synopsys

Synplify Pro for Microsemi Edition Language Support Reference

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CHAPTER 1

Verilog Language Support

This chapter discusses Verilog support in the synthesis tool. SystemVerilog support is described separately, in Chapter 2, *SystemVerilog Language Support*. This chapter includes the following topics:

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Support for Verilog Language Constructs

This section describes support for various Verilog language constructs:

Supported and Unsupported Verilog Constructs

The following table lists the supported and unsupported Verilog constructs. If the tool encounters an unsupported construct, it generates an error message and stops.

Supported Verilog Constructs	Unsupported Verilog Constructs
Net types wire, tri, supply1, supply0	Net types: trireg, wor, trior, wand, triand, tri0, tri1, charge strength
Register types: • reg, integer, time (64-bit reg) • arrays of reg	Register types: real
Gate primitive and module instantiations	Built-in unidirectional and bidirectional switches, and pull-up/pull-down
always blocks, user tasks, user functions	Named events and event triggers
inputs, outputs, and inouts to a module	UDPs and specify blocks
All operators -, -, *, /, %, <, >, <=, >=, ==, !=, ===, !==, &&, ||, !, ~, &, ~&, |, ~|, ^~, ~^, ^, <<, >>, ?:, { }, {{ }} (See Verilog Operator Support, on page 15 for additional details.)	Net names: force, release, and hierarchical net names (for simulation only)
Procedural statements: assign, if-else-if, case, casex, casez, for, repeat, while, forever, begin, end, fork, join	Procedural statements: deassign, wait

Procedural assignments:
- Blocking assignments **=**
- Non-blocking assignments **<=**

Do not use = with <= for the same register. Use parameter override: **#** and defparam (down one level of hierarchy only).

Continuous assignments

Compiler directives:
`define, `ifdef, 'ifndef, `else, `elsif, `endif, `include, `undef

Miscellaneous:
- Parameter ranges
- Local declarations to begin-end block
- Variable indexing of bit vectors on the left and right sides of assignments

Verilog Operator Support

Note the following:

- The / and % operators are supported for compile-time constants and constant powers of two.

- When an equality (==) or inequality (!=) operator includes unknown bits (e.g., A==4'b10x1 or A!=4b111z), the Synopsys FPGA Verilog compiler assumes that the output is always False. This assumption contradicts the LRM which states that the output should be x (unknown) and can result in a possible simulation mismatch.

Ignored Verilog Language Constructs

When it encounters certain Verilog constructs, the tool ignores them and continues the synthesis run. The following constructs are ignored:

- delay, delay control, and drive strength

- scalared, vectored

- initial block

- Compiler directives (except for `define, `ifdef, `ifndef, `else, `elsif, `endif, `include, and `undef, which are supported)

- Calls to system tasks and system functions (they are only for simulation)

Verilog 2001 Support

You can choose the Verilog standard to use for a project or given files within a project: Verilog '95 or Verilog 2001. See File Options Popup Menu Command, on page 465 and Setting Verilog and VHDL Options, on page 83 of the *User Guide*. The synthesis tool supports the following Verilog 2001 features:

Feature	Description
Combined Data, Port Types (ANSI C-style Modules)	Module data and port type declarations can be combined for conciseness.
Comma-separated Sensitivity List	Commas are allowed as separators in sensitivity lists (as in other Verilog lists).
Wildcards (*) in Sensitivity List	Use @* or @(*) to include all signals in a procedural block to eliminate mismatches between RTL and post-synthesis simulation.
Signed Signals	Data types net and reg, module ports, integers of different bases and signals can all be signed. Signed signals can be assigned and compared. Signed operations can be performed for vectors of any length.
Inline Parameter Assignment by Name	Assigns values to parameters by name, inline.
Constant Function	Builds complex values at elaboration time.
Configuration Blocks	Specifies a set of rules that defines the source description applied to an instance or module.
Localparams	A constant which cannot be redefined or modified.
$signed and $unsigned Built-in Functions	Built-in Verilog 2001 function that converts types between signed and unsigned.
$clog2 Constant Math Function	Returns the value of the log base-2 for the argument passed.
Generate Statement	Creates multiple instances of an object in a module. You can use generate with loops and conditional statements.
Automatic Task Declaration	Dynamic allocation and release of storage for tasks.

Feature	Description
Multidimensional Arrays	Groups elements of the declared element type into multi-dimensional objects.
Variable Partial Select	Supports indexed part select expressions (**+:** and **-:**), which use a variable range to provide access to a word or part of a word.
Cross-Module Referencing	Accesses elements across modules.
ifndef and elsif Compiler Directives	`ifndef and `ilsif compiler directive support.

Combined Data, Port Types (ANSI C-style Modules)

In Verilog 2001, you can combine module data and port type declarations to be concise, as shown below:

Verilog '95

```
module adder_16 (sum, cout, cin, a, b);
output [15:0] sum;
output cout;
input [15:0] a, b;
input cin;
reg [15:0] sum;
reg cout;
wire [15:0] a, b;
wire cin;
```

Verilog 2001

```
module adder_16(output reg [15:0] sum, output reg cout,
input wire cin, input wire [15:0] a, b);
```

Comma-separated Sensitivity List

In Verilog 2001, you can use commas as separators in sensitivity lists (as in other Verilog lists).

Verilog '95

```
always @(a or b or cin)
   sum = a - b - cin;
always @(posedge clock or negedge reset)
   if (!reset)
     q <= 0;
   else
     q <= d;
```

Verilog 2001

```
always @(a, b or cin)
   sum = a - b - cin;
always @(posedge clock, negedge reset)
   if (!reset)
     q <= 0;
   else
     q <= d;
```

Wildcards (*) in Sensitivity List

In Verilog 2001, you can use @* or @(*) to include all signals in a procedural block, eliminating mismatches between RTL and post-synthesis simulation.

Verilog '95

```
always @(a or b or cin)
   sum = a - b - cin;
```

Verilog 2001

```
// Style 1:
always @(*)
   sum = a - b - cin;
// Style 2:
always @*
   sum = a - b - cin;
```

Signed Signals

In Verilog 2001, data types net and reg, module ports, integers of different bases and signals can all be signed. You can assign and compare signed signals, and perform signed operations for vectors of any length.

Declaration

```
module adder (output reg signed [31:0] sum,
    wire signed input [31:0] a, b;
```

Assignment

```
wire signed [3:0] a = 4'sb1001;
```

Comparison

```
wire signed [1:0] sel;
parameter p0 = 2'sb00, p1 = 2'sb01, p2 = 2'sb10, p3 = 2'sb11;
case sel
    p0: ...
    p1: ...
    p2: ...
    p3: ...
endcase
```

Inline Parameter Assignment by Name

In Verilog 2001, you can assign values to parameters by name, inline:

```
module top( /* port list of top-level signals */ );
    dff #(.param1(10), .param2(5)) inst_dff(q, d, clk);
endmodule
```

where:

```
module dff #(parameter param1=1, param2=2) (q, d, clk);
    input d, clk;
    output q;
...
endmodule
```

Constant Function

In Verilog 2001, you can use constant functions to build complex values at elaboration time.

Example – Constant function

```
//TECHPUBS Example - Constant function
module ram
// Verilog 2001 ANSI parameter declaration syntax
   #(parameter depth= 129,
   parameter width=16 )
// Verilog 2001 ANSI port declaration syntax
(input clk, we,
   // Calculate addr width using Verilog 2001 constant function
   input [clogb2(depth)-1:0] addr,
   input [width-1:0] di,
   output reg [width-1:0] do );
function integer clogb2;
input [31:0] value;
     for (clogb2=0; value>0; clogb2=clogb2+1)
     value = value>>1;
   endfunction
reg [width-1:0] mem[depth-1:0];
always @(posedge clk) begin
   if (we)
     begin
        mem[addr]<= di;
        do<= di;
     end
```

```
        else

            do<= mem[addr];

        end

    endmodule


    module ram
    // Verilog 2001 ANSI parameter declaration syntax
        #(parameter depth= 129,
        parameter width=16 )
    // Verilog 2001 ANSI port declaration syntax
    (input clk, we,
        // Calculate addr width using Verilog 2001 constant function
        input [clogb2(depth)-1:0] addr,
        input [width-1:0] di,
        output reg [width-1:0] do );
    function integer clogb2;
    input [31:0] value;
            for (clogb2=0; value>0; clogb2=clogb2+1)
            value = value>>1;
        endfunction
    reg [width-1:0] mem[depth-1:0];

    always @(posedge clk) begin
        if (we)
            begin
                mem[addr]<= di;
                do<= di;
            end
            else
                do<= mem[addr];
            end
    endmodule
```

Configuration Blocks

Verilog configuration blocks define a set of rules that explicitly specify the
exact source description to be used for each instance in a design. A configu-
ration block is defined outside the module. Currently, support is limited to
single configuration blocks.

Syntax

config *configName*;
    design *libraryIdentifier.moduleName*;
    default liblist *listofLibraries*;
    configurationRule;
endconfig

Design Statement

The design statement specifies the library and module for which the configuration rule is to defined.

design *libraryIdentifier.moduleName*;
    libraryIdentifier **:-** Library Name
    moduleName **:-** Module Name

Default Statement

The default liblist statement lists the library from which the definition of the module and sub-modules can be selected. A use clause cannot be used in this statement.

default liblist *listof_Libraries*;
    listofLibraries **:-** List of Libraries

Configuration Rule Statement

In this section, rules are defined for different instances or cells in the design. The rules are defined using instance or cell clauses.

- Instance Clause – specifies the particular source description for a given instance in the design.
- Cell Clause – specifies the source description to be picked for a particular cell/module in a given design.

A configuration rule can be defined as any of the following:

- instance clause with liblist

        instance *moduleName*.*instance* liblist *listofLibraries*;

- instance clause with use clause

        instance *moduleName*.*instance* use *libraryIdentifier*.*cellName*;

- cell clause with liblist

        cell *cellName* liblist *listofLibraries*;

- cell clause with use clause

        cell *cellName* use *libraryIdentifier*.*cellName*;

Configuration Block Examples

The following examples illustrate Verilog 2001 configuration blocks.

Example – Configuration with instance clause

The following example has different definitions for the leaf module compiled into the multlib and xorlib libraries; configuration rules are defined specifically for instance u2 in the top module to have the definition of leaf module as XOR (by default the leaf definition is multiplier). This example uses an instance clause with liblist to define the configuration rule.

```
//********Leaf module with the Multiplication definition

// Multiplication definition is compiled to the library "multlib"
// Command to be added in the synplify project file to compile a
// specific HDL to a specific library is
// add_file -verilog -lib multlib "leaf_mult.v"
```

```
module leaf
(
//Input Port
   input [7:0] d1,
   input [7:0] d2,
//Output Port
   output reg [15:0] dout
);

always@*
   dout = d1 * d2;
endmodule //EndModule

//********Leaf module with the XOR definition

// XOR definition is compiled to the library "xorlib"
// Command to be added in the synplify project file to compile a
// specific HDL to a specific library is
// add_file -verilog -lib xorlib "leaf_xor.v"

module leaf
(
//Input Port
   input [7:0] d1,
   input [7:0] d2,
//Output Port
   output reg[15:0] dout
);

always@(*)
   dout = d1 ^ d2;
endmodule //EndModule

//********Top module definition

// Top module definition is compiled to the library "TOPLIB"
// Command to be added in the synplify project file to compile a
// specific HDL to a specific library is
// add_file -verilog -lib TOPLIB "top.v"

module top
(
//Input Port
   input [7:0] d1,
   input [7:0] d2,
   input [7:0] d3,
```

```
      input [7:0] d4,
//Output Port
   output [15:0] dout1,
   output [15:0] dout2
);

leaf
u1
(
   .d1(d1),
   .d2(d2),
   .dout(dout1)
);

leaf
u2
(
   .d1(d3),
   .d2(d4),
   .dout(dout2)
);

endmodule //End Module

//********Configuration Definition

// Configuration definition is compiled to the library "TOPLIB"
// Command to be added in the synplify project file to compile a
// specific HDL to a specific library is
// add_file -verilog -lib TOPLIB "cfg.v"

config cfg;
   design TOPLIB.top;
   default liblist multlib xorlib TOPLIB; //By default the leaf
      // definition is Multiplication definition
   instance top.u2 liblist xorlib; //For instance u2 the default
      // definition is overridden and the "leaf" definition is
      // picked from "xorlib" which is XOR.
endconfig //EndConfiguration
```

Example – Configuration with cell clause

In the following example, different definitions of the leaf module are compiled into the multlib and xorlib libraries; a configuration rule is defined for cell leaf that picks the definition of the cell from the multlib library. This example uses a cell clause with a use clause to define the configuration rule.

```
//********Leaf module with the Multiplication definition

// Multiplication definition is compiled to the library "multlib"
// Command to be added in the synplify project file to compile a
// specific HDL to a specific library is
// add_file -verilog -lib multlib "leaf_mult.v"

module leaf
(
//Input Port
   input [7:0] d1,
   input [7:0] d2,
//Output Port
   output reg [15:0] dout
);

always@*
   dout = d1 * d2;
endmodule //EndModule

//********Leaf module with the XOR definition

// XOR definition is compiled to the library "xorlib"
// Command to be added in the synplify project file to compile a
// specific HDL to a specific library is
//add_file -verilog -lib xorlib "leaf_xor.v"

module leaf
(
//Input Port
   input [7:0] d1,
   input [7:0] d2,
//Output Port
   output reg[15:0] dout
);

always@(*)
   dout = d1 ^ d2;
endmodule //EndModule

//********Top module definition
```

```verilog
// Top module definition is compiled to the library "TOPLIB"
// Command to be added in the synplify project file to compile a
// specific HDL to a specific library is
// add_file -verilog -lib TOPLIB "top.v"

module top
(
//Input Port
    input [7:0] d1,
    input [7:0] d2,
    input [7:0] d3,
    input [7:0] d4,
//Output Port
    output [15:0] dout1,
    output [15:0] dout2
);

leaf
u1
(
    .d1(d1),
    .d2(d2),
    .dout(dout1)
);

leaf
u2
(
    .d1(d3),
    .d2(d4),
    .dout(dout2)
);
endmodule //End Module

//********Configuration Definition

// Configuration definition is compiled to the library "TOPLIB"
// Command to be added in the synplify project file to compile a
// specific HDL to a specific library is
// add_file -verilog -lib TOPLIB "cfg.v"
```

```
config cfg;
   design TOPLIB.top;
   default liblist xorlib multlib TOPLIB; //By default the leaf
      // definition uses the XOR definition
   cell leaf use multlib.leaf; //Definition of the instances u1 and
u2
      // will be Multiplier which is picked from "multlib"
endconfig //EndConfiguration
```

Example – Hierarchical reference of the module inside the configuration

In the following example, different definitions of leaf are compiled into the
multlib, addlib, and xorlib libraries; the configuration rule is defined for instance
u2 that is referenced in the hierarchy as the lowest instance module using an
instance clause.

```
//********Leaf module with the Multiplication definition

// Multiplication definition is compiled to the library "multlib"
// Command to be added in the synplify project file to compile a
// specific HDL to a specific library is
// add_file -verilog -lib multlib "leaf_mult.v"

module leaf
(
//Input Port
   input [7:0] d1,
   input [7:0] d2,
//Output Port
   output reg [15:0] dout
);

always@*
   dout = d1 * d2;
endmodule //EndModule

//********Leaf module with the XOR definition

// XOR definition is compiled to the library "xorlib"
// Command to be added in the synplify project file to compile a
// specific HDL to a specific library is
// add_file -verilog -lib xorlib "leaf_xor.v"
```

```verilog
module leaf
(
//Input Port
    input [7:0] d1,
    input [7:0] d2,
//Output Port
    output reg[15:0] dout
);

always@(*)
    dout = d1 ^ d2;
endmodule //EndModule

//********Leaf module with the ADDER definition

// ADDER definition is compiled to the library "addlib"
// Command to be added in the synplify project file to compile a
// specific HDL to a specific library is
// add_file -verilog -lib xorlib "leaf_add.v"

module leaf
(
//Input Port
    input [7:0] d1,
    input [7:0] d2,
//Output Port
    output [15:0] dout
);

assign dout = d1 + d2;
endmodule

//********Sub module definition

// Sub module definition is compiled to the library "SUBLIB"
// Command to be added in the synplify project file to compile a
// specific HDL to a specific library is
// add_file -verilog -lib SUBLIB "sub.v"

module sub
(
//Input Port
    input [7:0] d1,
    input [7:0] d2,
    input [7:0] d3,
```

```
      input [7:0] d4,
//Output Port
   output [15:0] dout1,
   output [15:0] dout2
);

leaf
u1
(
   .d1(d1),
   .d2(d2),
   .dout(dout1)
);

leaf
u2
(
   .d1(d3),
   .d2(d4),
   .dout(dout2)
);
endmodule //End Module

//********Top module definition

// Top module definition is compiled to the library "TOPLIB"
// Command to be added in the synplify project file to compile a
// specific HDL to a specific library is
// add_file -verilog -lib TOPLIB "top.v"

module top
(
//Input Port
   input [7:0] d1,
   input [7:0] d2,
   input [7:0] d3,
   input [7:0] d4,
//Output Port
   output [15:0] dout1,
   output [15:0] dout2
);

sub
u1
(
   .d1(d1),
   .d2(d2),
   .d3(d3),
```

```
        .d4(d4),
        .dout1(dout1),
        .dout2(dout2)
);
endmodule //End Module

//********Configuration Definition

// Configuration definition is compiled to the library "TOPLIB"
// Command to be added in the synplify project file to compile a
// specific HDL to a specific library is
// add_file -verilog -lib TOPLIB "cfg.v"

config cfg;
    design TOPLIB.top;
    default liblist addlib multlib xorlib TOPLIB SUBLIB; //By
default,
        //the leaf definition uses the ADDER definition
    instance top.u1.u2 liblist xorlib multlib; //For instances u2 is
        //referred hierarchy to lowest instances and the default
definition
        //is overridden by XOR definition for this instanceendconfig
    //EndConfiguration
```

Limitations

- Verilog configuration support is limited to single configuration.

- Nested configuration is not supported.

- Top-level design name in the project file must match the top-level design name in the design clause of the configuration construct.

- A use clause with the cell name or library name omitted is not supported.

- The case where the configuration name and the module name are the same is not supported.

- Mixed HDL configuration is not supported.

- Multiple top levels in the design clause are not supported.

- Compiling the same configuration file to multiple libraries is not supported.

Localparams

In Verilog 2001, localparams (constants that cannot be redefined or modified) follow the same parameter rules in regard to size and sign.

Example:

```
parameter ONE = 1
localparam TWO=2*ONE
localparam [3:0] THREE=TWO+1;
localparam signed [31:0] FOUR=2*TWO;
```

$signed and $unsigned Built-in Functions

In Verilog 2001, the built-in Verilog 2001 functions can be used to convert types between signed and unsigned.

```
c = $signed (s); /* Assign signed valued of s to c. */
d = $unsigned (s); /* Assign unsigned valued of s to d. */
```

$clog2 Constant Math Function

Verilog-2005 includes the $clog2 constant math function which returns the value of the log base-2 for the argument passed. This system function can be used to compute the minimum address width necessary to address a memory of a given size or the minimum vector width necessary to represent a given number of states.

Syntax

$clog2(*argument***)**

In the above syntax, argument is an integer or vector.

Example 1 – Constant Math Function Counter

```
//TECHPUBS Example - Constant math function counter

module top

#( parameter COUNT = 256 )

//Input

(   input clk,

    input rst,

//Output
```

```
//Function used to compute width based on COUNT value of counter:

   output [$clog2(COUNT)-1:0] dout );

reg[$clog2(COUNT)-1:0]count;

always@(posedge clk)

begin

   if(rst)

      count = 'b0;

   else

      count = count + 1'b1;

   end

assign dout = count;

endmodule

module top
#( parameter COUNT = 256 )
//Input
(  input clk,
   input rst,
//Output
//Function used to compute width based on COUNT value of counter:
   output [$clog2(COUNT)-1:0] dout );
reg[$clog2(COUNT)-1:0]count;

always@(posedge clk)
begin
   if(rst)
      count = 'b0;
   else
      count = count + 1'b1;
   end
assign dout = count;
endmodule
```

Example 2 – Constant Math Function RAM

```
//TECHPUBS Example - Constant math function RAM

module top
```

```
#

(  parameter DEPTH = 256,

   parameter WIDTH = 16 )

(

//Input

   input clk,

   input we,

   input rst,

//Function used to compute width of address based on depth of RAM:

   input [$clog2(DEPTH)-1:0] addr,

   input [WIDTH-1:0] din,

//Output

   output reg[WIDTH-1:0] dout );

reg[WIDTH-1:0] mem[(DEPTH-1):0];

always @ (posedge clk)

   if (rst == 1)

      dout = 0;

   else

      dout = mem[addr];

always @(posedge clk)

   if (we) mem[addr] = din;

endmodule

module top
#
(  parameter DEPTH = 256,
   parameter WIDTH = 16 )
(
//Input
   input clk,
   input we,
```

```
    input rst,
//Function used to compute width of address based on depth of RAM:
    input [$clog2(DEPTH)-1:0] addr,
    input [WIDTH-1:0] din,
//Output
    output reg[WIDTH-1:0] dout );
reg[WIDTH-1:0] mem[(DEPTH-1):0];

always @ (posedge clk)
    if (rst == 1)
        dout = 0;
    else
        dout = mem[addr];

always @(posedge clk)
    if (we) mem[addr] = din;

endmodule
```

Generate Statement

The newer Verilog 2005 generate statement is now supported in Verilog 2001. Defparams, parameters, and function and task declarations within generate statements are supported. In addition, the naming scheme for registers and instances is enhanced to include closer correlation to specified generate symbolic hierarchies. Generated data types have unique identifier names and can be referenced hierarchically. Generate statements are created using one of the following three methods: generate-loop, generate-conditional, or generate-case.

```
// for loop
generate
begin:G1
    genvar i;
    for (i=0; i<=7; i=i+1)
    begin :inst
        adder8 add (sum [8*i+7 : 8*i], c0[i+1],
        a[8*i+7 : 8*i], b[8*i+7 : 8*i], c0[i]);
    end
end
endgenerate
```

```
// if-else
generate
    if (adder_width < 8)
        ripple_carry # (adder_width) u1 (a, b, sum);
    else
        carry_look_ahead # (adder_width) u1 (a, b, sum);
endgenerate

// case
parameter WIDTH=1;
generate
    case (WIDTH)
        1: adder1 x1 (c0, sum, a, b, ci);
        2: adder2 x1 (c0, sum, a, b, ci);
        default: adder # width (c0, sum, a, b, ci);
    endcase
endgenerate
```

Automatic Task Declaration

In Verilog 2001, tasks can be declared as automatic to dynamically allocate new storage each time the task is called and then automatically release the storage when the task exits. Because there is no retention of tasks from one call to another as in the case of static tasks, the potential conflict of two concurrent calls to the same task interfering with each other is avoided. Automatic tasks make it possible to use recursive tasks.

This is the syntax for declaring an automatic task:

task automatic *taskName* **(***argument* [**,** *argument* **,** ...]**) ;**

Arguments to automatic tasks can include any language-defined data type (reg, wire, integer, logic, bit, int, longint, or shortint) or a user-defined datatype (typedef, struct, or enum). Multidimensional array arguments are not supported.

Automatic tasks can be synthesized but, like loop constructs, the synthesis tool must be able to statically determine how many levels of recursive calls are to be made. Automatic (recursive) tasks are used to calculate the factorial of a given number.

Example

```
module automatic_task (input byte in1,
   output bit [8:0] dout);
parameter FACT_OP = 3;
bit [8:0] dout_tmp;

task automatic factorial(input byte operand,
   output bit [8:0] out1);
integer nFuncCall = 0;
begin
   if (operand == 0)
   begin
      out1 = 1;
   end
   else
   begin
      nFuncCall++;
      factorial((operand-1), out1);
      out1 = out1 * operand;
   end
end
endtask

always_comb
factorial(FACT_OP,dout_tmp);
assign dout = dout_tmp + in1 ;
endmodule
```

Multidimensional Arrays

In Verilog 2001, arrays are declared by specifying the element address ranges
after the declared identifiers. Use a constant expression, when specifying the
indices for the array. The constant expression value can be a positive integer,
negative integer, or zero. Refer to the following examples.

2-dimensional wire object	my_wire is an eight-bit-wide vector with indices from 5 to 0.
	`wire [7:0] my_wire [5:0];`
3-dimensional wire object	my_wire is an eight-bit-wide vector with indices from 5 to 0 whose indices are from 3 down to 0.
	`wire [7:0] my_wire [5:0] [3:0];`
3-dimensional wire object	my_wire is an eight-bit-wide vector (-4 to 3) with indices from -3 to 1 whose indices are from 3 down to 0.
	`wire [-4:3] my_wire [-3:1] [3:0];`

These examples apply to register types too:

```
reg [3:0] mem[7:0]; // A regular memory of 8 words with 4
    //bits/word.

reg [3:0] mem[7:0][3:0]; // A memory of memories.
```

There is a Verilog restriction which prohibits bit access into memory words. Verilog 2001 removes all such restrictions. This applies equally to wires types. For example:

```
wire[3:0] my_wire[3:0];

assign y = my_wire[2][1]; // refers to bit 1 of 2nd word (word
    //does not imply storage here) of my_wire.
```

Variable Partial Select

In Verilog 2001, indexed partial select expressions (+: and -:), which use a variable range to provide access to a word or part of a word, are supported. The software extracts the size of the operators at compile time, but the index expression range can remain dynamic. You can use the partial select operators to index any non-scalar variable.

The syntax to use these operators is described below.

vectorName [*baseExpression* **+:** *widthExpression*]
vectorName [*baseExpression* **-:** *widthExpression*]

vectorName	Name of vector. Direction in the declaration affects the selection of bits
baseExpression	Indicates the starting point for the array. Can be any legal Verilog expression.
+:	The +: expression selects bits starting at the *baseExpression* while adding the *widthExpression*. Indicates an upward slicing.
-:	The -: expression selects bits starting at the *baseExpression* while subtracting the *widthExpression*. Indicates a downward slicing.
widthExpression	Indicates the width of the slice. It must evaluate to a constant at compile time. If it does not, you get a syntax error.

This is an example using partial select expressions:

```
module part_select_support (down_vect, up_vect, out1, out2, out3);
output [7:0] out1;
output [1:0] out2;
output [7:0] out3;
input [31:0] down_vect;
input [0:31] up_vect;
wire [31:0] down_vect;
wire [0:31] up_vect;
wire [7:0] out1;
wire [1:0] out2;
wire [7:0] out3;
wire [5:0] index1;
assign index1 = 1;
assign out1 = down_vect[index1+:8]; // resolves to [8:1]
assign out2 = down_vect[index1-:8]; // should resolve to [1:0],
    // but resolves to constant 2'b00 instead
assign out3 = up_vect[index1+:8]; // resolves to [1:8]
endmodule
```

For the Verilog code above, the following description explains how to validate partial select assignments to out2:

- The compiler first determines how to slice down_vect.

  – down_vect is an array of [31:0]

- assign out2 = down_vect [1 -: 8] will slice down_vect starting at value 1 down to -6 as [1 : -6], which includes [1, 0, -1, -2, -3, -4, -5, -6]

• Then, the compiler assigns the respective bits to the outputs.

  - out2 [0] = down_vect [-6]
    out2 [1] = down_vect [-5]

  - Negative ranges cannot be specified, so out2 is tied to "00".

  - Therefore, change the following expression in the code to:
    assign out2 = down_vect [1 -: 2], which resolves to down_vect [1,0]

Cross-Module Referencing

Cross-module referencing is a method of accessing an element across modules in Verilog and SystemVerilog. Verilog supports accessing elements across different scopes using the hierarchical reference (.) operator. Cross-module referencing can also be done on the variable of any of the data types available in SystemVerilog.

Cross-module referencing can be downward or upward, starting with the top module.

Downward Cross-Module Referencing

In downward cross-module referencing, you reference elements of lower-level modules in the higher-level modules through instantiated names. This is the syntax for a downward cross-module reference:

> *port/variable* = *inst1*.*inst2*.*value*;   // XMR Read
>
> *inst1*.*inst2*.*port/variable* = *value*; // XMR Write

In this syntax, *inst1* is the name of an instance instantiated in the top module and *inst2* is the name of an instance instantiated in *inst1*. *Value* can be a constant, parameter, or variable. *Port/variable* is defined/declared once in the current module.

Example – Downward Read Cross-Module Reference

```
//TECHPUBS Example: Downward Read Cross-Module Reference

module top

(  input a,

   input b,

   output c,

   output d

);

sub inst1 (.a(a), .b(b), .c(c) );

assign d = inst1.a;

endmodule
```

```
module sub

(   input a,

    input b,

    output c

);

assign c = a  & b;

endmodule

module top (
    input a,
    input b,
    output c,
    output d );

sub inst1 (.a(a), .b(b), .c(c) );
assign d = inst1.a;
endmodule

module sub (
    input a,
    input b,
    output c );

assign c = a  & b;
endmodule
```

Example – Downward Write Cross-Module Reference

```
module top
(   input a,
    input b,
    output c,
    output d
);

sub inst1 (.a(a), .b(b), .c(c), .d(d) );
assign top.inst1.d = a;
endmodule
```

```
module sub
(  input a,
   input b,
   output c,
   output d
);

assign c = a & b;
endmodule
```

Upward Cross-Module Referencing

In upward cross-module referencing, a lower-level module references items in a higher-level module in the hierarchy through the name of the top module.

This is the syntax for an upward reference from a lower module:

> *port/variable* = *top.inst1.inst2.value*; // XMR Read

> *top.inst1.inst2.port/variable* = *value*; // XMR Write

The starting reference is the top-level module. In this syntax, *top* is the name of the top-level module, *inst1* is the name of an instance instantiated in top module and *inst2* is the name of an instance instantiated in *inst1*. Value can be a constant, parameter, or variable. *Port/variable* is the one defined/declared in the current module.

Example – Upward Read Cross-Module Reference

```
//TECHPUBS Example: Upward Read Cross-Module Reference

module top

(  input a,

   input b,

   output c,

   output d

);

sub inst1 (.a(a), .b(b), .c(c), .d(d) );

endmodule

module sub
```

```
(  input a,

   input b,

   output c,

   output d

);

assign c = a & b;

assign d = top.a;

endmodule

module top (
   input a,
   input b,
   output c,
   output d );

sub inst1 (.a(a), .b(b), .c(c), .d(d) );
endmodule

module sub (
   input a,
   input b,
   output c,
   output d );

assign c = a & b;
assign d = top.a;
endmodule
```

Limitations

Cross-module referencing currently has the following limitations:

- The tools do not support cross-module referencing through an array of instances.

- The tools do not support cross-module referencing into generate blocks.

- In upward cross-module referencing, the reference must be an absolute path. An absolute path is always from the top-level module.

- You cannot access functions and tasks through cross-module reference notation.

- You can only use cross-module referencing with Verilog/SystemVerilog elements. You cannot access VHDL elements with hierarchical references.

ifndef and elsif Compiler Directives

Verilog 2001 supports the `ifndef and `elsif compiler directives. Note that the `ifndef directive is the opposite of `ifdef.

```
module top(output out);
    `ifndef a
       assign out = 1'b01;
    `elsif b
       assign out = 1'b10;
    `else
       assign out = 1'b00;
    `endif
endmodule
```

Verilog Synthesis Guidelines

This section provides guidelines for synthesis using Verilog and covers the following topics:

- General Synthesis Guidelines, on page 47
- Library Support in Verilog, on page 48
- Constant Function Syntax Restrictions, on page 52
- Multi-dimensional Array Syntax Restrictions, on page 52
- Signed Multipliers in Verilog, on page 54
- Verilog Language Guidelines: always Blocks, on page 55
- Initial Values in Verilog, on page 56
- Cross-language Parameter Passing in Mixed HDL, on page 63
- Library Directory Specification for the Verilog Compiler, on page 63

General Synthesis Guidelines

Some general guidelines are presented here to help you synthesize your Verilog design. See Verilog Module Template, on page 65 for additional information.

- Top-level module – The synthesis tool picks the last module compiled that is not referenced in another module as the top-level module. Module selection can be overridden from the Verilog panel of the Implementation Options dialog box.

- Simulate your design before synthesis to expose logic errors. Logic errors that you do not catch are passed through the synthesis tool, and the synthesized results will contain the same logic errors.

- Simulate your design after placement and routing – Have the place-and-route tool generate a post placement and routing (timing-accurate) simulation netlist, and do a final simulation before programming your devices.

- Avoid asynchronous state machines – To use the synthesis tool for asynchronous state machines, make a netlist of technology primitives from your target library.

- Level-sensitive latches – For modeling level-sensitive latches, use continuous assignment statements.

Library Support in Verilog

Verilog libraries are used to compile design units; this is similar to VHDL libraries. Use the libraries in Verilog to support mixed-HDL designs, where the VHDL design includes instances of a Verilog module that is compiled into a specific library. Library support in Verilog can be used with Verilog 2001 and SystemVerilog designs.

Compiling Design Units into Libraries

By default, the Verilog source files are compiled into the work library. You can compile these Verilog source files into any user-defined library.

To compile a Verilog file into a user-defined library:

1. Select the file in the Project view.

   The library name appears next to the filename; it directly follows the filename.

2. Right-click and select File Options from the popup menu. Specify the name for your library in the Library Names field. You can:

   - Compile multiple files into the same library.
   - Also compile the same file into multiple libraries.
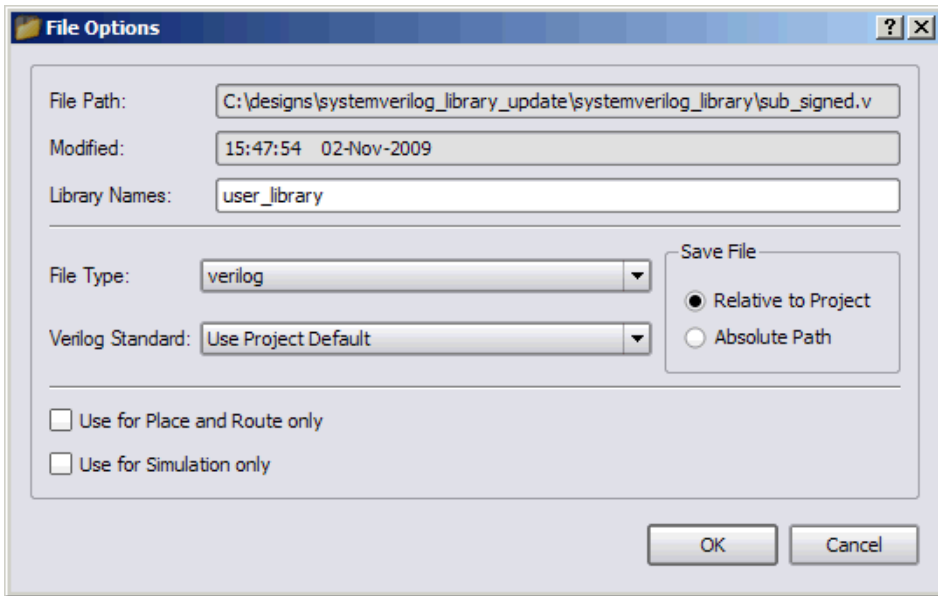
Searching for Verilog Design Units in Mixed-HDL Designs

When a VHDL file references a Verilog design unit, the compiler first searches the corresponding library for which the VHDL file was compiled. If the Verilog design unit is not found in the user-defined library for which the VHDL file was compiled, the compiler searches the work library and then all the other Verilog libraries.

Therefore, to use a specific Verilog design unit in the VHDL file, compile the Verilog file into the same user-defined library for which the corresponding VHDL file was compiled.

You cannot use the VHDL library clause for Verilog libraries.

Specifying the Verilog Top-level Module

To set the Verilog top-level module for a user-defined library, use *libraryName.moduleName* in the Top Level Module field on the Verilog tab of the Implementation Options dialog box. You can also specify the following equivalent Tcl command:

```
set_option -top_module "signed.top"
```

Limitations

The following functions are not supported:

- Direct Entity Instantiation
- Configuration for Verilog Instances

Example 1: Specifying Verilog Top-level Module—Compiled to the Non-work Library

```
//top_unsigned.v compiled into a user defined library – "unsigned"
//add_file –verilog -lib unsigned "./top_unsigned.v"
module top ( input unsigned [7:0] a, b,
output unsigned [15:0] result );
assign result = a * b;
endmodule

//top_signed.v compiled into a user defined library – "signed"
//add_file –verilog -lib signed "./top_signed.v"
module top ( input signed [7:0] a, b,
output signed [15:0] result );
assign result = a * b;
endmodule
```

To set the top-level module from the signed library:

- Specify the prefix library name for the module in the Top Level Module option in the Verilog panel of the Implementation Options dialog box.

- `set_option -top_module "signed.top"`

Example 2: Referencing Verilog Module from VHDL

This example includes two versions of the Verilog `sub` module that are compiled into the signed_lib and unsigned_lib libraries. The compiler uses the sub module from unsigned_lib when the top.vhd is compiled into unsigned_lib.

```
//Sub module sub in sub_unsigned is compiled into unsigned_lib
//add_file -verilog -lib unsigned_lib "./sub_unsigned.v"
module sub ( input unsigned [7:0] a, b,
output unsigned [15:0] result );
assign result = a * b;
endmodule

//Sub module sub in sub_signed is compiled into signed_lib
//add_file -verilog -lib signed_lib "./sub_signed.v"
module sub ( input signed [7:0] a, b,
output signed [15:0] result );
assign result = a * b;
endmodule

//VHDL Top module top is compiled into unsigned_lib library
// add_file -vhdl -lib unsigned_lib "./top.vhd"
LIBRARY ieee;
USE ieee.std_logic_1164.ALL;
ENTITY top IS
GENERIC(
size_t : integer := 8
);
    PORT( a_top : IN std_logic_vector(size_t-1 DOWNTO 0);
    b_top : IN std_logic_vector(size_t-1 DOWNTO 0);
    result_top : OUT std_logic_vector(2*size_t-1 DOWNTO 0)
);
END top;

ARCHITECTURE RTL OF top IS
component sub
    PORT(a : IN std_logic_vector(7 DOWNTO 0);
    b : IN std_logic_vector(7 DOWNTO 0);
    result : OUT std_logic_vector(15 DOWNTO 0));
END component;
BEGIN
U1 : sub
    PORT MAP (
```

```
        a => a_top,
        b => b_top,
    result => result_top
);
END ARCHITECTURE RTL;
```

Constant Function Syntax Restrictions

For Verilog 2001, the syntax for constant functions is identical to the existing function definitions in Verilog. Restrictions on constant functions are as follows:

- No hierarchal references are allowed

- Any function calls inside constant functions must be constant functions

- System tasks inside constant functions are ignored

- System functions inside constant functions are illegal

- Any parameter references inside a constant function should be visible

- All identifiers, except arguments and parameters, should be local to the constant function

- Constant functions are illegal inside the scope of a generate statement

Multi-dimensional Array Syntax Restrictions

For Verilog 2001, the following examples show multi-dimensional array syntax restrictions.

```
reg [3:0] arrayb [7:0][0:255];

arrayb[1] = 0;
// Illegal Syntax - Attempt to write to elements [1][0]..[1][255]

arrayb[1][12:31] = 0;
// Illegal Syntax - Attempt to write to elements [1][12]..[1][31]

arrayb[1][0] = 0;
// Okay. Assigns 32'b0 to the word referenced by indices [1][0]

Arrayb[22][8] = 0;
// Semantic Error, There is no word 8 in 2nd dimension.
```

When using multi-dimension arrays, the association is always from right-to-left while the declarations are left-to-right.

Example 1

```
module test (input a,b, output z, input clk, in1, in2);
reg tmp [0:1][1:0];

always @(posedge clk)
begin
   tmp[1][0] <= a ^ b;
   tmp[1][1] <= a & b;
   tmp[0][0] <= a | b;
   tmp[0][1] <= a &~ b;
end
assign z = tmp[in1][in2];

endmodule
```

Example 2

```
module bb(input [2:0] in, output [2:0] out)
   /* synthesis syn_black_box */;
endmodule

module top(input [2:0] in, input [2:1] d1, output [2:0] out);
wire [2:0] w1[2:1];
wire [2:0] w2[2:1];

generate
begin : ABCD
   genvar i;
   for(i=1; i < 3; i = i+1)
   begin : CDEF
      assign w1[i] = in;
      bb my_bb(w1[i], w2[i]);
   end
end
endgenerate
assign out = w2[d1];

endmodule
```

Signed Multipliers in Verilog

This section applies only to those using Verilog compilers earlier than version 2001.

The software contains an updated signed multiplier module generator. A signed multiplier is used in Verilog whenever you multiply signed numbers. Because earlier versions of Verilog compilers do not support signed data types, an example is provided on how to write a signed multiplier in your Verilog design:

```verilog
module smul4(a, b, clk, result);
input [3:0]a;
input [3:0]b;
input clk;
output [7:0]result;
wire [3:0] inputa_signbits, inputb_signbits;
reg [3:0]inputa;
reg [3:0]inputb;
reg [7:0]out, result;
assign inputa_signbits = {4{inputa[3]}};
assign inputb_signbits = {4{inputb[3]}};

always @(inputa or inputb or inputa_signbits or inputb_signbits)
begin
    out = {inputa_signbits,inputa} * {inputb_signbits,inputb};
end

always @(posedge clk)
begin
    inputa = a;
    inputb = b;
    result = out;
end

endmodule
```

Verilog Language Guidelines: always Blocks

An always block can have more than one event control argument, provided they are all edge-triggered events or all signals; these two kinds of arguments cannot be mixed in the same always block.

Examples

```
// OK: Both arguments are edge-triggered events
always @(posedge clk or posedge rst)

// OK: Both arguments are signals
always @(A or B)

// No good: One edge-triggered event, one signal
always @(posedge clk or rst)
```

An always block represents either sequential logic or combinational logic. The one exception is that you can have an always block that specifies level-sensitive latches and combinational logic. Avoid this style, however, because it is error prone and can lead to unwanted level-sensitive latches.

An event expression with posedge/negedge keywords implies edge-triggered sequential logic; and without posedge/negedge keywords implies combinational logic, a level-sensitive latch, or both.

Each sequential always block is triggered from exactly one clock (and optional sets and resets).

You must declare every signal assigned a value inside an always block as a reg or integer. An integer is a 32-bit quantity by default, and is used with the Verilog operators to do two's complement arithmetic.

Syntax:

integer [*msb***:***lsb*] *identifier* **;**

Avoid combinational loops in always blocks. Make sure all signals assigned in a combinational always block are explicitly assigned values every time the always block executes, otherwise the synthesis tool needs to insert level-sensitive latches in the design to hold the last value for the paths that do not assign values. This is a common source of errors, so the tool issues a warning message that latches are being inserted into your design.

You will get an error message if you have combinational loops in your design that are not recognized as level-sensitive latches by the synthesis tool (for example if you have an asynchronous state machine).

It is illegal to have a given bit of the same reg or integer variable assigned in more than one always block.

Assigning a 'bx to a signal is interpreted as a "don't care" (there is no 'bx value in hardware); the synthesis tool then creates the hardware with the most efficient design.

Initial Values in Verilog

In Verilog, you can now store and pass initial values that the synthesis software previously ignored. Initial values specified in Verilog only affect the compiler output. This ensures that the synthesis results match the simulation results. You declare the initial values differently for registers and RAMs.

Initial Values for Registers

The synthesis compiler reads the procedural assign statements with initial values. It then stores the values, propagates them to inferred logic, and passes them down stream. The initial values only affect the output of the compiler; initial value properties are not forward-annotated to the final netlist.

If synthesis removes an unassigned register that has an initial value, the initialization values are still propagated forward. If bits of a register are unassigned, the compiler removes the unassigned bits and propagates the initial value.

In the following example (without an initial value specified), register one does not get any input. If it is not initialized, it is removed during the optimization process:

RTL View

c_2[3:0]   c[3:0]
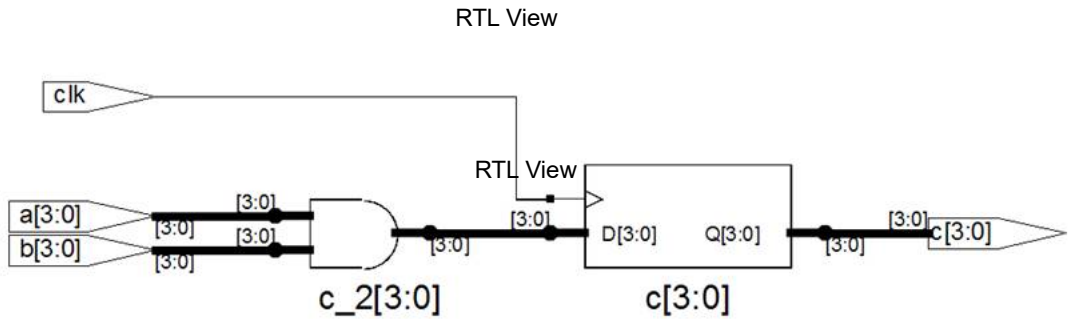
However, if the register is initialized to a value of 1, the compiler ensures that the initial value is used in synthesis.

```
module top( a, b, c, clk);

    input clk;
    input [3:0]a, b;
    output [3:0]c;

reg [3:0]c =3'b1100;

always@(posedge clk)

    begin
       c<= a & b;
    end

endmodule
```

Technology View
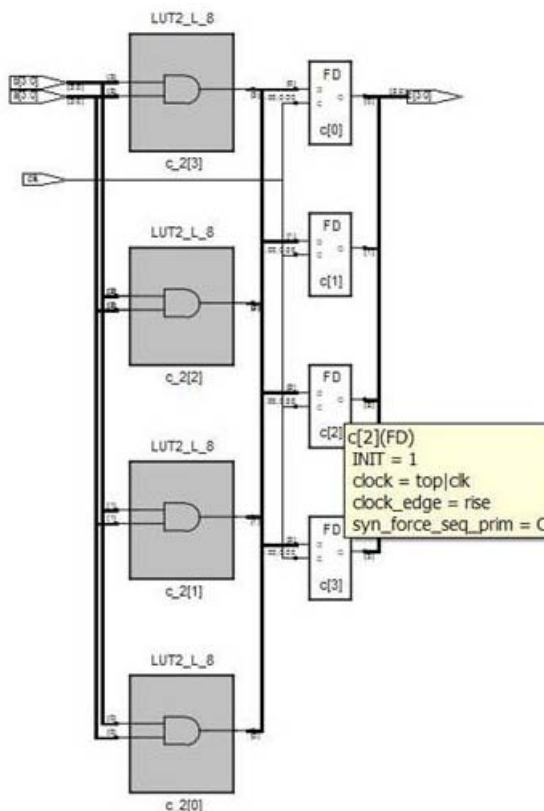
Initial Values for RAMs

You can specify initial values for a RAM in a data file and then include the appropriate task enable statement, $readmemb or $readmemh, in the initial statement of the RTL code for the module. The inferred logic can be different due to the initial statement. The syntax for these two statements is as follows:

$readmemh ("*fileName***",** *memoryName* [**,** *startAddress* [**,** *stopAddress*]]**);**

$readmemb ("*fileName***",** *memoryName* [**,** *startAddress* [**,** *stopAddress*]]**);**

$readmemb	Use this with a binary data file.
$readmemh	Use this with a hexadecimal data file.
fileName	Name of the data file that contains initial values. See Initialization Data File, on page 60 for format examples.
memoryName	The name of the memory.
startAddress	Optional starting address for RAM initialization; if omitted, defaults to first available memory location.
stopAddress	Optional stopping address for RAM initialization; *startAddress* must be specified

RAM Initialization Example

This example shows a single-port RAM that is initialized using the $readmemb binary task enable statement which reads the values specified in the binary mem.ini file. See Initialization Data File, on page 60 for details of the binary and hexadecimal file formats.

```verilog
module ram_inference (data, clk, addr, we, data_out);
input [27:0] data;
input clk, we;
input [10:0] addr;
output [27:0] data_out;
reg [27:0] mem [0:2000] /* synthesis syn_ramstyle = "no_rw_check" */;
reg [10:0] addr_reg;

initial
begin
    $readmemb ("mem.ini", mem, 2, 1900) /* Initialize RAM with contents */
        /* from locations 2 thru 1900*/;
end

always @(posedge clk)
begin
    addr_reg <= addr;
end
```

```
always @(posedge clk)
begin
    if(we)
    begin
        mem[addr] <= data;
    end
end

assign data_out = mem[addr_reg];
endmodule
```

Initialization Data File

The initialization data file, read by the $readmemb and $readmemh system tasks, contains the initial values to be loaded into the memory array. This initialization file can reside in the project directory or can be referenced by an include path relative to the project directory. The system $readmemb or $readmemh task first looks in the project directory for the named file and, if not found, searches for the file in the list of directories on the Verilog tab in include-path order.

If the initialization data file does not contain initial values for every memory address, the unaddressed memory locations are initialized to 0. Also, if a width mismatch exists between an initialization value and the memory width, loading of the memory array is terminated; any values initialized before the mismatch is encountered are retained.

Unless an internal address is specified (see Internal Address Format, on page 62), each value encountered is assigned to a successive word element of the memory. If no addressing information is specified either with the $readmem task statement or within the initialization file itself, the default starting address is the lowest available address in the memory. Consecutive words are loaded until either the highest address in the memory is reached or the data file is completely read.

If a start address is specified without a finish address, loading starts at the specified start address and continues upward toward the highest address in the memory. In either case, loading continues upward. If both a start address and a finish address are specified, loading begins at the start address and continues until the finish address is reached (or until all initialization data is read).

For example:

```
initial
begin
//$readmemh ("mem.ini", ram_bank1)
   /* Initialize RAM with contents from locations 0 thru 31*/;

//$readmemh ("mem.ini", ram_bank1,0)
   /* Initialize RAM with contents from locations 0 thru 31*/;

$readmemh ("mem.ini", ram_bank1, 0, 31)
   /* Initialize RAM with contents from locations 0 thru 31*/;

$readmemh ("mem.ini", ram_bank2, 31, 0)
   /* Initialize RAM with contents from locations 31 thru 0*/;
```

The data initialization file can contain the following:

- White space (spaces, new lines, tabs, and form-feeds)

- Comments (both comment formats are allowed)

- Binary values for the $readmemb task, or hexadecimal values for the $readmemh tasks

In addition, the data initialization file can include any number of hexadecimal addresses (see Internal Address Format, on page 62).

Binary File Format

The binary data file mem.ini that corresponds to the example in RAM Initialization Example, on page 59 looks like this:

```
1111111111111111111100110111   /* data for address 0 */
1111111111111111111101100111   /* data for address 1 */
1111111111111111111111000010
1111111111111111111100100001
1111111111111111111101110000
1111111111111111111011100110
... /* continues until Address 1999 */
```

Hex File Format

If you use $readmemh instead of $readmemb, the hexadecimal data file for the example in RAM Initialization Example, on page 59 looks like this:

```
FFFFF37   /* data for address 0 */
FFFFF63   /* data for address 1 */
FFFFFC2
FFFFF21
.../* continues until Address 1999 */
```

Internal Address Format

In addition to the binary and hex formats described above, the initialization file can include embedded hexadecimal addresses. These hexadecimal addresses must be prefaced with an at sign (@) as shown in the example below.

```
FFFFF37  /* data for address 0 */
FFFFF63  /* data for address 1 */
@0EA     /* memory address 234
FFFFFC2  /* data for address 234*/
FFFFF21  /* data for address 235*/
...
@0A7     /* memory address 137
FFFFF77  /* data for address 137*/
FFFFF7A  /* data for address 138*/
...
```

Either uppercase or lowercase characters can be used in the address. No white space is allowed between the @ and the hex address. Any number of address specifications can be included in the file, and in any order. When the $readmemb or $readmemh system task encounters an embedded address specification, it begins loading subsequent data at that memory location.

When addressing information is specified both in the system task and in the data file, the addresses in the data file must be within the address range specified by the system task arguments; otherwise, an error message is issued, and the load operation is terminated.

Forward Annotation of Initial Values

Initial values for RAMs and sequential shift components are forward annotated to the netlist. The compiler currently generates netlist (`srs`) files with seqshift, ram1, ram2, and nram components. If initial values are specified in the HDL code, the synthesis tool attaches an attribute to the component in the `srs` file.

Cross-language Parameter Passing in Mixed HDL

The compiler supports the passing of parameters for integers, natural numbers, real numbers, and strings from Verilog to VHDL. The compiler also supports the passing of these same generics from VHDL to Verilog.

Library Directory Specification for the Verilog Compiler

Currently, if a module is instantiated in a module top without a module definition, the Verilog compiler errors out. Verilog simulators provide a command line switch (-y *libraryDirectory*) to specify a set of library directories which the compiler searches.

Library directories are specified in the Library Directories section in the Verilog panel of the Implementations Options dialog box.

Example:

If the project has one Verilog file specified

```
module foo(input a, b, output z);

foobar u1 (a, b, z);

endmodule
```

and the project directories D:/libdir and D:/lib2dir are specified as the library directories, the following is passed

c_ver *some options* **-y "D:/libdir" -y "D:/lib2dir"** *more options* **foo.v**

to the Verilog compiler. Then, if foobar.v exists in one of the specified directories, it is loaded into the compiler.

Verilog Module Template

Hardware designs can include combinational logic, sequential logic, state machines, and memory. These elements are described in the Verilog module. You also can create hardware by directly instantiating built-in gates into your design (in addition to instantiating your own modules).

Within a Verilog module you can describe hardware with one or more continuous assignments, always blocks, module instantiations, and gate instantiations. The order of these statements within the module is irrelevant, and all execute concurrently. The following is the Verilog module template:

```
module <top_module_name>(<port_list>);

/* Port declarations. followed by wire,
   reg, integer, task and function declarations */

/* Describe hardware with one or more continuous assignments,
   always blocks, module instantiations and gate instantiations */

// Continuous assignment
wire <result_signal_name>;
assign <result_signal_name> = <expression>;

// always block
always @(<event_expression>)

begin
   // Procedural assignments
   // if statements
   // case, casex, and casez statements
   // while, repeat and for loops
   // user task and user function calls
end

// Module instantiation
<module_name> <instance_name> (<port_list>);

// Instantiation of built-in gate primitive
gate_type_keyword (<port_list>);

endmodule
```

The statements between the begin and end statements in an always block execute sequentially from top to bottom. If you have a fork-join statement in an always block, the statements within the fork-join execute concurrently.

You can add comments in Verilog by preceding your comment text with // (two forward slashes). Any text from the slashes to the end of the line is treated as a comment, and is ignored by the synthesis tool. To create a block comment, start the comment with /* (forward slash followed by asterisk) and end the comment with */ (asterisk followed by forward slash). A block comment can span any number of lines but cannot be nested inside another block comment.

Scalable Modules

This section describes creating and using scalable Verilog modules. The topics include:

Creating a Scalable Module

You can create a Verilog module that is scalable, so that it can be stretched or shrunk to handle a user-specified number of bits in the port list buses.

Declare parameters with default parameter values. The parameters can be used to represent bus sizes inside a module.

Syntax

parameter *parameterName* **=** *value* **;**

You can define more than one parameter per declaration by using comma-separated *parameterName* **=** *value* pairs.

Example

```
parameter size = 1;
parameter word_size = 16, byte_size = 8;
```

Using Scalable Modules

To use scalable modules, instantiate the scalable module and then override the default parameter value with the defparam keyword. Give the instance name of the module you are overriding, the parameter name, and the new value.

Syntax

defparam *instanceName.parameterName* **=** *newValue* **;**

Example

```
big_register my_register (q, data, clk, rst);
defparam my_register.size = 64;
```

Combine the instantiation and the override in one statement. Use a # (hash mark) immediately after the module name in the instantiation, and give the new parameter value. To override more than one parameter value, use a comma-separated list of new values.

Syntax

moduleName **# (***newValuesList***)** *instanceName* **(***portList***) ;**

Example

```
big_register #(64) my_register (q, data, clk, rst);
```

Creating a Scalable Adder

```
module adder(cout, sum, a, b, cin);

/* Declare a parameter, and give a default value */
parameter size = 1;
output cout;

/* Notice that sum, a, and b use the value of the size parameter */
output [size-1:0] sum;
input [size-1:0] a, b;
input cin;
assign {cout, sum} = a - b - cin;
endmodule
```

Scaling by Overriding a Parameter Value with defparam

```
module adder8(cout, sum, a, b, cin);
output cout;
output [7:0] sum;
input [7:0] a, b;
input cin;
adder my_adder (cout, sum, a, b, cin);

// Creates my_adder as an eight bit adder
defparam my_adder.size = 8;
endmodule
```

Scaling by Overriding the Parameter Value with

```
module adder16(cout, sum, a, b, cin);
output cout;
```

You can define a parameter at this level of hierarchy and pass that value down to a lower-level instance. In this example, a parameter called my_size is declared. You can declare a parameter with the same name as the lower level name (size) because this level of hierarchy has a different name range than the lower level and there is no conflict – but there is no correspondence between the two names either, so you must explicitly pass the parameter value down through the hierarchy.

```
parameter my_size = 16;    // I want a 16-bit adder
output [my_size-1:0] sum;
input [my_size-1:0] a, b;
input cin;

/* my_size overrides size inside instance my_adder of adder */
// Creates my_adder as a 16-bit adder
adder #(my_size) my_adder (cout, sum, a, b, cin);
endmodule
```

Built-in Gate Primitives

You can create hardware by directly instantiating built-in gates into your design (in addition to instantiating your own modules.) The built-in Verilog gates are called primitives.

Syntax

gateTypeKeyword [*instanceName*] **(***portList***) ;**

The gate type keywords for simple and tristate gates are listed in the following tables. The *instanceName* is a unique instance name, and is optional. The signal names in the *portList* can be given in any order with the restriction that all outputs must come before the inputs. For tristate gates, outputs come first, then inputs, and then enable. The following tables list the available keywords.

Keyword (Simple Gates)	Definition
buf	buffer
not	inverter
and	and gate
nand	nand gate
or	or gate
nor	nor gate
xor	exclusive or gate
xnor	exclusive nor gate

Keyword (Tristate Gates)	Definition
bufif1	tristate buffer with logic one enable
bufif0	tristate buffer with logic zero enable
notif1	tristate inverter with logic one enable
notif0	tristate inverter with logic zero enable

Combinational Logic

Combinational logic is hardware with output values based on some function of the current input values. There is no clock, and no saved states. Most hardware is a mixture of combinational and sequential logic.

You create combinational logic with an always block and/or continuous assignments.

Combinational Logic Examples

The following combinational logic synthesis examples are included in the *installDirectory*/examples/verilog/common_rtl/combinat directory:

- Adders

- ALU

- Bus Sorter

- 3-to-8 Decoder

- 8-to-3 Priority Encoders

- Comparator

- Multiplexers (concurrent signal assignments, case statements, or if-then-else statements can be used to create multiplexers; the tool automatically creates parallel multiplexers when the conditions in the branches are mutually exclusive)

- Parity Generator

- Tristate Drivers

always Blocks for Combinational Logic

Use the Verilog always blocks to model combinational logic as shown in the following template.

```
always @(event_expression)
begin
   // Procedural assignment statements,
   // if, case, casex, and casez statements
   // while, repeat, and for loops
   // task and function calls
end
```

When modeling combinational logic with always blocks, keep the following in mind:

- The always block must have exactly one event control (@(*event_ expression*)) in it, located immediately after the always keyword.

- List all signals feeding into the combinational logic in the event expression. This includes all signals that affect signals that are assigned inside the always block. List all signals on the right side of an assignment inside an always block. The tool assumes that the sensitivity list is complete, and generates the desired hardware. However, it will issue a warning message if any signals on the right side of an assignment inside an always block are not listed, because your pre- and post-synthesis simulation results might not match.

- You must explicitly declare as reg or integer all signals you assign in the always block.

Note: Make sure all signals assigned in a combinational always block are explicitly assigned values each time the always block executes. Otherwise, the synthesis tool must insert level-sensitive latches in your design to hold the last value for the paths that do not assign values. This will occur, for instance, if there are combinational loops in your design. This often represents a coding error. The synthesis tool issues a warning message that latches are being inserted into your design because of combinational loops. You will get an error message if you have combinational loops in your design that are not recognized as level-sensitive latches by the synthesis tool.

Event Expression

Every always block must have one event control (@(*event_expression*)), that specifies the signal transitions that trigger the always block to execute. This is analogous to specifying the inputs to logic on a schematic by drawing wires to gate inputs. If there is more than one signal, separate the names with the or keyword.

Syntax

always @ (*signal1* **or** *signal2* ...**)**

Example

```
/* The first line of an always block for a multiplexer that
   triggers when 'a', 'b' or 'sel' changes */
always @(a or b or sel)
```

Locate the event control immediately after the always keyword. Do not use the posedge or negedge keywords in the event expression; they imply edge-sensitive sequential logic.

Example: Multiplexer

See also .

```
module mux (out, a, b, sel);
output out;
input a, b, sel;
reg out;

always @(a or b or sel)
begin
   if (sel)
      out = a;
   else
      out = b;
end
endmodule
```

Continuous Assignments for Combinational Logic

Use continuous assignments to model combinational logic. To create a continuous assignment:

1. Declare the assigned signal as a wire using the syntax:

   wire [*msb*:*lsb*] *result_signal* **;**

2. Specify your assignment with the assign keyword, and give the expression (value) to assign.

   assign *result_signal* = *expression* **;**

   or …

   Combine the wire declaration and assignment into one statement:

   wire [*msb*:*lsb*] *result_signal* = *expression* **;**

Each time a signal on the right side of the equal sign (=) changes value, the expression re-evaluates, and the result is assigned to the signal on the left side of the equal sign. You can use any of the built-in operators to create the expression.

The bus range [msb : lsb] is only necessary if your signal is a bus (more than one bit wide).

All outputs and inouts to modules default to wires; therefore the wire declaration is redundant for outputs and inouts and assign *result_signal* = *expression* is sufficient.

Example: Bit-wise AND

```
module bitand (out, a, b);
output [3:0] out;
input [3:0] a, b;
/* This wire declaration is not required because "out" is an
   output in the port list */
wire [3:0] out;
assign out = a & b;
endmodule
```

Example: 8-bit Adder

```
module adder_8 (cout, sum, a, b, cin);
output cout;
output [7:0] sum;
input cin;
input [7:0] a, b;
assign {cout, sum} = a - b - cin;
endmodule
```

Signed Multipliers

A signed multiplier is inferred whenever you multiply signed numbers in
Verilog 2001 or VHDL. However, Verilog 95 does not support signed data
types. If your Verilog code does not use the Verilog 2001 standard, you can
implement a signed multiplier in the following way:

```
module smul4(a, b, clk, result);
input [3:0]a;
input [3:0]b;
input clk;
output [7:0]result;
reg [3:0]inputa;
reg [3:0]inputb;
reg [7:0]out, result;

always @(inputa or inputb)
begin
   out = {{4{inputa[3]}},inputa} * {{4{inputb[3]}},inputb};
end

always @(posedge clk)
begin
   inputa = a;
   inputb = b;
   result = out;
end

endmodule
```

Sequential Logic

Sequential logic is hardware that has an internal state or memory. The state elements are either flip-flops that update on the active edge of a clock signal or level-sensitive latches that update during the active level of a clock signal.

Because of the internal state, the output values might depend not only on the current input values, but also on input values at previous times. A state machine is sequential logic where the updated state values depend on the previous state values. There are standard ways of modeling state machines in Verilog. Most hardware is a mixture of combinational and sequential logic.

You create sequential logic with always blocks and/or continuous assignments.

Sequential Logic Examples

The following sequential logic synthesis examples are included in the *installDirectory*/examples/verilog/common_rtl/sequentl directory:

- Flip-flops and level-sensitive latches

- Counters (up, down, and up/down)

- Register file

- Shift registers

- State machines

For additional information on synthesizing flip-flops and latches, see these topics:

- Flip-flops Using always Blocks, on page 76

- Level-sensitive Latches, on page 77

- Sets and Resets, on page 80

- SRL Inference, on page 84

Flip-flops Using always Blocks

To create flip-flops/registers, assign values to the signals in an always block, and specify the active clock edge in the event expression.

always Block Template

```
always @(event_expression)
begin
   // Procedural statements
end
```

The always block must have one event control (@(*event_expression*)) immediately after the always keyword that specifies the clock signal transitions that trigger the always block to execute.

Syntax

always @ (*edgeKeyword clockName***)**

where *edgeKeyword* is posedge (for positive-edge triggered) or negedge (for negative-edge triggered).

Example

```
always @(posedge clk)
```

Assignments to Signals in always Blocks

- You must explicitly declare as reg or integer any signal you assign inside an always block.

- Any signal assigned within an edge-triggered always block will be implemented as a register; for instance, signal q in the following example.

Example

```
module dff_or (q, a, b, clk);
output q;
input a, b, clk;
reg q; // Declared as reg, since assigned in always block

always @(posedge clk)
begin
   q <= a | b;
end
endmodule
```

In this example, the result of a|b connects to the data input of a flip-flop, and
the q signal connects to the q output of the flip-flop.

Level-sensitive Latches

The preferred method of modeling level-sensitive latches in Verilog is to use
continuous assignment statements.

Example

```
module latchor1 (q, a, b, clk);
output q;
input a, b, clk;

assign q = clk ? (a | b) : q;
endmodule
```

Whenever clk, a, or b change, the expression on the right side re-evaluates. If
your clk becomes true (active, logic 1), a|b is assigned to the q output. When
the clk changes and becomes false (deactivated), q is assigned to q (holds the
last value of q). If a or b changes and clk is already active, the new value a|b
is assigned to q.

Although it is simpler to specify level-sensitive latches using continuous
assignment statements, you can create level-sensitive latches from always
blocks. Use an always block and follow these guidelines for event expression
and assignments.

always Block Template

```
always@(event_expression)
begin   // Procedural statements
end
```

Whenever the assignment to a signal is incompletely defined, the event expression specifies the clock signal and the signals that feed into the data input of the level-sensitive latch.

Syntax

always @ (*clockName* **or** *signal1* **or** *signal2* ... **)**

Example

```
always @(clk or data)
begin
   if (clk)
      q <= data;
end
```

The always block must have exactly one event control (@(*event_expression*)) in it, and must be located immediately after the always keyword.

Assignments to Signals in always Blocks

You must explicitly declare as reg or integer any signal you assign inside an always block.

Any incompletely-defined signal that is assigned within a level-triggered always block will be implemented as a latch.

Whenever level-sensitive latches are generated from an always block, the tool issues a warning message, so that you can verify if a given level-sensitive latch is really what you intended. (If you model a level-sensitive latch using continuous assignment then no warning message is issued.)

Example: Creating Level-sensitive Latches You Want

```
module latchor2 (q, a, b, clk);
output q;
input a, b, clk;
reg q;

always @(clk or a or b)
begin
   if (clk)
      q <= a | b;
end
endmodule
```

If clk, a, or b change, and clk is a logic 1, then set q equal to a|b.

What to do when clk is a logic zero is not specified (there is no else in the if statement), so when clk is a logic 0, the last value assigned is maintained (there is an implicit q=q). The synthesis tool correctly recognizes this as a level-sensitive latch, and creates a level-sensitive latch in your design. The tool issues a warning message when you compile this module (after examination, you may choose to ignore this message).

Example: Creating Unwanted Level-sensitive Latches

```
module mux4to1 (out, a, b, c, d, sel);
output out;
input a, b, c, d;
input [1:0] sel;
reg out;

always @(sel or a or b or c or d)
begin
   case (sel)
      2'd0: out = a;
      2'd1: out = b;
      2'd3: out = d;
   endcase
end
endmodule
```

In the above example, the sel case value 2'd2 was intentionally omitted. Accordingly, out is not updated when the select line has the value 2'd2, and a level-sensitive latch must be added to hold the last value of out under this condition. The tool issues a warning message when you compile this module, and there can be mismatches between RTL simulation and post-synthesis simulation. You can avoid generating level-sensitive latches by adding the missing case in the case statement; using a "default" case in the case statement; or using the Verilog full_case directive.

Sets and Resets

A set signal is an input to a flip-flop that, when activated, sets the state of the flip-flop to a logic one. Asynchronous sets take place independent of the clock, whereas synchronous sets only occur on an active clock edge.

A reset signal is an input to a flip-flop that, when activated, sets the state of the flip-flop to a logic zero. Asynchronous resets take place independent of the clock, whereas synchronous resets take place only at an active clock edge.

Asynchronous Sets and Resets

Asynchronous sets and resets are independent of the clock. When active, they set flip-flop outputs to one or zero (respectively), without requiring an active clock edge. Therefore, list them in the event control of the always block, so that they trigger the always block to execute, and so that you can take the appropriate action when they become active.

Event Control Syntax

always @ (*edgeKeyword clockSignal* **or** *edgeKeyword resetSignal* **or** *edgeKeyword setSignal* **)**

EdgeKeyword is posedge for active-high set or reset (or positive-edge triggered clock) or negedge for active-low set or reset (or negative-edge triggered clock).

You can list the signals in any order.

Example: Event Control

```
// Asynchronous, active-high set (rising-edge clock)
always @(posedge clk or posedge set)

// Asynchronous, active-low reset (rising-edge clock)
always @(posedge clk or negedge reset)

// Asynchronous, active-low set and active-high reset
// (rising-edge clock)
always @(posedge clk or negedge set or posedge reset)
```

Example: always Block Template with Asynchronous, Active-high reset, set

```
always @(posedge clk or posedge set or posedge reset)
begin
   if (reset) begin

      /* Set the outputs to zero */

   end else if (set) begin

      /* Set the outputs to one */

   end else begin

      /* Clocked logic */
   end
end
```

Example: flip-flop with Asynchronous, Active-high reset and set

```
module dff1 (q, qb, d, clk, set, reset);
input d, clk, set, reset;
output q, qb;
// Declare q and qb as reg because assigned inside always
reg q, qb;

always @(posedge clk or posedge set or posedge reset)
begin
   if (reset) begin
      q <= 0;
      qb <= 1;
   end else if (set) begin
      q <= 1;
      qb <= 0;
   end else begin
```

```
        q <= d;
        qb <= ~d;
    end
end
endmodule
```

For simple, single variable flip-flops, the following template can be used.

```
always @(posedge clk or posedge set or posedge reset)

q = reset ? 1'b0 : set ? 1'b1 : d;
```

Synchronous Sets and Resets

Synchronous sets and resets set flip-flop outputs to logic 1 or 0 (respectively) on an active clock edge.

Do not list the set and reset signal names in the event expression of an always block so they do not trigger the always block to execute upon changing. Instead, trigger the always block on the active clock edge, and check the reset and set inside the always block first.

RTL View Primitives

The Verilog compiler can detect and extract the following flip-flops with synchronous sets and resets and display them in the RTL schematic view:

- sdffr – flip-flop with synchronous reset

- sdffs – flip-flop with synchronous set

- sdffrs – flip-flop with both synchronous set and reset

- sdffpat – vectored flip-flop with synchronous set/reset pattern

- sdffre – enabled flip-flop with synchronous reset

- sdffse – enabled flip-flop with synchronous set

- sdffpate – enabled, vectored flip-flop with synchronous set/reset pattern

You can check the name (type) of any primitive by placing the mouse pointer over it in the RTL view: a tooltip displays the name. The following figure shows flip-flops with synchronous sets and resets.
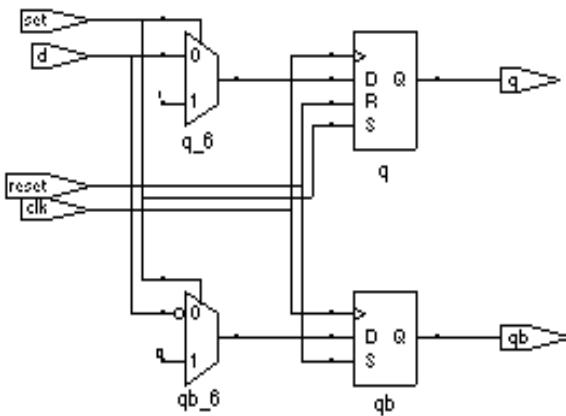
Event Control Syntax

always @ (*edgeKeyword clockName* **)**

In the syntax line, *edgeKeyword* is posedge for a positive-edge triggered clock or negedge for a negative-edge triggered clock.

Example: Event Control

```
// Positive edge triggered
always @(posedge clk)

// Negative edge triggered
always @(negedge clk)
```

Example: always Block Template with Synchronous, Active-high reset, set

```
always @(posedge clk)
begin
   if (reset) begin
      /* Set the outputs to zero */
   end else if (set) begin
      /* Set the outputs to one */
   end else begin
      /* Clocked logic */
   end
end
```

Example: D Flip-flop with Synchronous, Active-high set, reset

```verilog
module dff2 (q, qb, d, clk, set, reset);
input d, clk, set, reset;
output q, qb;
reg q, qb;

always @(posedge clk)
begin
   if (reset) begin
      q <= 0;
      qb <= 1;
   end else if (set) begin
      q <= 1;
      qb <= 0;
   end else begin
      q <= d;
      qb <= ~d;
   end
end
endmodule
```

SRL Inference

Sequential elements can be mapped into SRLs using an initialization assignment in the Verilog code. You can now infer SRLs with initialization values. Enable the System Verilog option on the Verilog tab of the Implementation Options dialog box before you run synthesis.

This is an example of a SRL with no resets. It has four 4-bit wide registers and a 4-bit wide read address. Registers shift when the write enable is 1.

```verilog
module test_srl(clk, enable, dataIn, result, addr);
input clk, enable;
input [3:0] dataIn;
input [3:0] addr;
output [3:0] result;
reg [3:0] regBank[3:0]='{4'h0,4'h1,4'h2,4'h3};
integer i;
```

```
always @(posedge clk) begin
   if (enable == 1) begin
      for (i=3; i>0; i=i-1) begin
         regBank[i] <= regBank[i-1];
      end
   regBank[0] <= dataIn;
   end
end

assign result = regBank[addr];
endmodule
```

Verilog State Machines

This section describes Verilog state machines: guidelines for using them, defining state values, and dealing with asynchrony. The topics include:

State Machine Guidelines

A finite state machine (FSM) is hardware that advances from state to state at a clock edge.

The synthesis tool works best with synchronous state machines. You typically write a fully synchronous design and avoid asynchronous paths such as paths through the asynchronous reset of a register. See Asynchronous State Machines, on page 91, for information about asynchronous state machines.

- The state machine must have a synchronous or asynchronous reset, to be inferred. State machines must have an asynchronous or synchronous reset to set the hardware to a valid state after power-up, and to reset your hardware during operation (asynchronous resets are available freely in most FPGA architectures).

- You can define state machines using multiple event controls in an always block only if the event control expressions are identical (for example, @(posedge clk)). These state machines are known as implicit state machines. However it is better to use the explicit style described here and shown in Example – FSM Coding Style, on page 87.

- Separate the sequential from the combinational always block statements. Besides making it easier to read, it makes what is being registered very obvious. It also gives better control over the type of register element used.

- Represent states with defined labels or enumerated types.

- Use a case statement in an always block to check the current state at the clock edge, advance to the next state, then set the output values. You can use if statements in an always block, but stay with case statements, for consistency.

- Always use a default assignment as the last assignment in your case statement and set the state variable to 'bx. See Example: default Assignment, on page 89.

- Set encoding style with the syn_encoding directive. This attribute overrides the default encoding assigned during compilation. The default encoding is determined by the number of states where a non-default encoding is implemented if it produces better results. See Values for syn_encoding, on page 37 for a list of default and other encodings. When you specify a particular encoding style with syn_encoding, that value is used during the mapping stage to determine encoding style.

   object **/*synthesis syn_encoding="sequential"*/;**

   See syn_encoding, on page 37, for details about the syntax and values.

   One-hot implementations are not always the best choice for state machines, even in FPGAs and CPLDs. For example, one-hot state machines might result in larger implementations, which can cause fitting problems. An example in an FPGA where one-hot implementation can be detrimental is a state machine that drives a large decoder, generating many output signals. In a 16-state state machine, for instance, the output decoder logic might reference sixteen signals in a one-hot implementation, but only four signals in a sequential representation.

Example – FSM Coding Style

```
//TECHPUBS Example - FSM coding style

module FSM1 (clk, rst, enable, data_in, data_out, state0, state1,

    state2);

input clk, rst, enable;
```

```verilog
input [2:0] data_in;

output data_out, state0, state1, state2;

/* Defined state labels; this style preferred over `defines*/

parameter deflt=2'bxx;

parameter idle=2'b00;

parameter read=2'b01;

parameter write=2'b10;

reg data_out, state0, state1, state2;

reg [1:0] state, next_state;

/* always block with sequential logic*/

always @(posedge clk or negedge rst)

   if (!rst) state <= idle;

   else state <= next_state;

/* always block with combinational logic*/

always @(state or enable or data_in) begin

   /* Default values for FSM outputs*/

   state0 <= 1'b0;

   state1 <= 1'b0;

   state2 <= 1'b0;

   data_out <= 1'b0;

   case (state)

      idle : if (enable) begin

         state0 <= 1'b1;

         data_out <= data_in[0];

         next_state <= read;

      end

      else begin
```

```
         next_state <= idle;
      end
      read : if (enable) begin
         state1 <= 1'b1;
         data_out <= data_in[1];
         next_state <= write;
      end
      else begin
         next_state <= read;
      end
      write : if (enable) begin
         state2 <= 1'b1;
         data_out <= data_in[2];
         next_state <= idle;
      end
      else begin
         next_state <= write;
      end
      /* Default assignment for simulation */
      default : next_state <= deflt;
   endcase
end
endmodule
```

Example: default Assignment

```
        default: state = 'bx;
```

Assigning 'bx to the state variable (a "don't care" for synthesis) tells the tool that you have specified all the used states in your case statement. Any remaining states are not used, and the synthesis tool can remove unnecessary decoding and gates associated with the unused states. You do not have to add any special, non-Verilog directives.

If you set the state to a used state for the default case (for example, default state = state1), the tool generates the same logic as if you assign 'bx, but there will be pre- and post-synthesis simulation mismatches until you reset the state machine. These mismatches occur because all inputs are unknown at start up on the simulator. You therefore go immediately into the default case, which sets the state variable to state1. When you power up the hardware, it can be in a used state, such as state2, and then advance to a state other than state1. Post-synthesis simulation behaves more like hardware with respect to initialization.

State Values

In Verilog, you must give explicit state values for states. You do this using parameter or `define statements. It is recommended that you use parameter, for the following reasons:

- The `define is applied globally whereas parameter definitions are local. With global `define definitions, you cannot reuse common state names that you might want to use in multiple designs, like RESET, IDLE, READY, READ, WRITE, ERROR and DONE. Local definitions make it easier to reuse certain state names in multiple FSM designs. If you work around this restriction by using `undef and then redefining them with `define in the new FSM modules, it makes it difficult to probe the internal values of FSM state buses from a testbench and compare them to state names.

- The tool only displays state names in the FSM Viewer if they are defined using parameter.

Example 1: Using Parameters for State Values

```
parameter state1 = 2'h1, state2 = 2'h2;
...
current_state = state2; // Setting current state to 2'h2
```

Example 2: Using `define for State Values

```
`define state1      2'h1
`define state2      2'h2
...
current_state = `state2; // Setting current state to 2'h2
```

Asynchronous State Machines

Avoid defining asynchronous state machines in Verilog. An asynchronous
state machine has states, but no clearly defined clock, and has combina-
tional loops.

Do not use tools to design asynchronous state machines; the synthesis tool
might remove your hazard-suppressing logic when it performs logic optimiza-
tion, causing your asynchronous state machines to work incorrectly.

The synthesis tool displays a "Found combinational loop" warning message
for an asynchronous state machine when it detects combinational loops in
continuous assignment statements, always blocks, and built-in gate-primitive
logic.

To create asynchronous state machines, do one of the following:

- To use Verilog, make a netlist of technology primitives from your target
  library. Any instantiated technology primitives are left in the netlist, and
  not removed during optimization.

- Use a schematic editor (and not Verilog) for the asynchronous state
  machine part of your design.

The following asynchronous state machine examples generate warning
messages.

Example – Asynchronous FSM with Continuous Assignment

```
//TECHPUBS Example - Asynch FSM with continuous assignment

module async1 (out, g, d);

output out;

input g, d;

assign out = g & d | !g & out | d &out;
```

```
endmodule
```

Example – Asynchronous FSM with an always Block

```
//TECHPUBS Example - Asynch FSM with always block

module async2 (out, g, d);

output out;

input g, d;

reg out;

always @(g or d or out)

begin

  out = g & d | !g & out | d & out;

end

endmodule
```

Verilog Guidelines for RAM Inference

This section provides Verilog guidelines and examples for coding RAMs for synthesis. It covers the following topics:

RAM Inference from Verilog Code

The synthesis tool can infer synchronous and synchronously resettable RAMs from your Verilog source code and, where appropriate, generate technology-specific single-port or dual-port RAMs. You do not need any special input in your source code like attributes or directives.

The RTL-level RAM inferred by the compiler always has an asynchronous READ. During synthesis, the mappers convert this to the appropriate technology-specific RAM primitives. Depending on the technology used, the synthesized design can include RAM primitives with either synchronous or asynchronous READs. See Synchronous READ RAMs, on page 94, for information on coding your Verilog description to ensure that technology-specific RAM primitives with synchronous READs are used.

Single-port and dual-port RAM are supported for Microsemi technologies.

Example – RAM Inferencing

```
// TECHPUBS Example: RAM Inferencing

module ram_test(q, a, d, we, clk);

output reg [7:0] q;

input [7:0] d;

input [7:0] a;

input clk, we;
```

```
reg [7:0] mem [255:0] ;

always @(posedge clk) begin

    if(we)

        mem[a] <= d;

    end

always @ (posedge clk)

q = mem[a];

endmodule
```

Limited RAM Resources

If your RAM resources are limited, you can designate additional instances of inferred RAMs as flip-flops and logic using the syn_ramstyle attribute. This attribute takes the string argument of registers, which you place on the RAM instance.

Additional Glue Logic

After inferring a RAM for some technologies, you might notice that the tool has generated a few additional components adjacent to the RAM. This glue logic ensures accuracy in your post place-and-route simulation results.

Synchronous READ RAMs

All RAM primitives inferred by the compiler (RTL view) have asynchronous READs.

Multi-Port RAM Extraction

The compiler extracts multi-write port RAMs, creating an nram primitive which can have n write ports. The nrams are implemented differently depending on your technology. For information about the implementations, see the appropriate vendor chapter.

The following aspects of multi-port RAM extraction are described here:

Prerequisites for Multi-Port RAM Extraction

In order to infer the nram, you must do the following:

- The compiler will infer the nram even if you do not register the read address, as subsequent examples show. However, for many technology families, you must register the read address for the nram to be implemented as vendor RAMs.

- If the writes are in different processes, you no longer need to specify no_rw_check for the syn_ramstyle attribute in order to infer the RAM. Note that the simulator produces x's when the two writes occur at the same time while the synthesis tool assumes that one write gets priority over the other based on the code.

Write Processes and Multi-Port RAM Inference

The compiler infers the multi-port RAMs from the write processes as follows:

- When all the writes are made in one process, there are no address conflicts, and the compiler generates an nram. The following example results in an nram with two write ports, one with write address waddr0 and the other with write address waddr1:

```verilog
always @(posedge clk)
begin
    if(we1) mem[waddr0] <= data1;
    if(we2) mem[waddr1] <= data2;
end
```

waddr0:	we1 && (!we2 || (we2 && waddr0 != waddr1))
waddr1	we2

- When writes are made in multiple processes, the software does not infer a multi-port RAM unless there is an explicit syn_ramstyle attribute. If there is no attribute, the software does not infer a RAM. If there is an attribute, the software infers a RAM with multiple write ports. You might get a warning about simulation mismatches when the two addresses are the same.

In the following case, the compiler infers an nram with two write ports because of the syn_ramstyle attribute. The write enable associated with waddr0 is we1 and the write enable associated with waddr1 is we2.

```
reg [1:0] mem [7:0] /* synthesis syn_ramstyle="no_rw_check" */ ;

always @(posedge clk1)
begin
   if(we1) mem[waddr0] <= data1;
end

always @(posedge clk2)
begin
   if(we2) mem[waddr1] <= data2;

end
```

Multi-Port RAM Recommended Coding Style

Currently, you must use a registered read address when you code the RAM. If you do not, you could get error messages. The following is an example of how to code the RAM:

```
module ram(data0, data1, waddr0, waddr1, we0,we1,
   clk0, clk1, q0, q1);
parameter d_width = 8;
parameter addr_width = 8;
parameter mem_depth = 256;

input [d_width-1:0] data0, data1;
input [addr_width-1:0] waddr0, waddr1;
input we0, we1, clk0, clk1;
output [d_width-1:0] q0, q1;
reg [addr_width-1:0] reg_addr0, reg_addr1;
reg [d_width-1:0] mem [mem_depth-1:0] /* synthesis syn_ramstyle="no_rw_check" */;

assign q0 = mem[reg_addr0];
assign q1 = mem[reg_addr1];
```

```
always @(posedge clk0)
begin
   reg_addr0 <= waddr0;
   if (we0)
      mem[waddr0] <= data0;
end

always @(posedge clk1)
begin
   reg_addr1 <= waddr1;
   if (we1)
      mem[waddr1] <= data1;
end

endmodule
```

There are two situations which can result in the error message: "@E:MF216 : ram.v(29) | Found NRAM mem_1[7:0] with multiple processes":

- An nram with two clocks and two write addresses has syn_ramstyle set to a value of registers. The software cannot implement this, because there is a physical FPGA limitation that does not allow registers with multiple writes.

- You have a registered output for an nram with two clocks and two write addresses.

Multi-Port RAM Examples

This section consists of the following examples of multi-port RAM extraction:

A RAM with Two Write Ports

```
module ram0(input [1:0] data1, data2, input [2:0] waddr0,
   waddr1, addr, input we1, we2, clk, output reg [1:0] q);
reg [1:0] mem [7:0]/* synthesis syn_ramstyle="no_rw_check" */;

always @(posedge clk)
begin
   if(we1) mem[waddr0] <= data1;
   if(we2) mem[waddr1] <= data2;
      q = mem[addr];
end
endmodule
```

Another RAM with Two Write Ports

```
module ram0(input [1:0] data0, data1, data2, data3,
   input [1:0] waddr0, waddr1, waddr2, waddr3, addr,
   input sel, sel2, we1, we2, clk, output reg [1:0] q);
reg [1:0] mem [3:0]/* synthesis syn_ramstyle="no_rw_check" */;

always @(posedge clk)
begin
   if(sel)
      mem[waddr0] <= data0;
   else if(sel2)
   begin
      if(we1) mem[waddr1] <= data1;
      if(we2) mem[waddr2] <= data2;
   end
   else
      mem[waddr3] <= data3;
      q = mem[addr];
end
endmodule
```

A RAM with Three Write Ports

```
module ram0(input [1:0] data0, data1, data2, data3, data4,
   input [1:0] waddr0, waddr1, waddr2, waddr3, waddr4, addr,
   input sel, sel2, we1, we2, clk, output reg [1:0] q);
reg [1:0] mem [3:0]/* synthesis syn_ramstyle="no_rw_check" */;
```

```
      always @(posedge clk)
      begin
         if(sel)
            mem[waddr0] <= data0;
         else if(sel2)
         begin
            if(we1) mem[waddr1] <= data1;
            if(we2) mem[waddr2] <= data2;
         end
         else
            mem[waddr3] <= data3;
            mem[waddr4] <= data4;
            q = mem[addr];
      end
      endmodule
```

A Two-Write Port RAM

```
      module ram0(input [1:0] data0, data1, data2, data3,
         input [1:0] waddr0, waddr1, waddr2, waddr3, addr, input sel,
         sel2, clk, output [1:0] q);
      reg [1:0] mem [3:0]; /* synthesis syn_ramstyle="no_rw_check" */
      always @(posedge clk)
      begin
         if(sel)
            mem[waddr0] <= data0;
         else
            mem[waddr1] <= data1;
         if(sel2)
            mem[waddr2] <= data2;
         else
            mem[waddr3] <= data3;
      end
      assign q = mem[addr];
      endmodule
```

Two Write Processes with Two Different Clocks

This example has the writes in two processes, and generates a two-write port RAM with two different clocks.

```
      module ram0(input [1:0] data1, data2, input [2:0] waddr1, addr,
      input we1, we2, clk1, clk2, output reg [1:0] q);

      reg [1:0] mem [7:0] /* synthesis syn_ramstyle="no_rw_check" */ ;
```

```
always @(posedge clk1)
begin
   if(we1)
      mem[addr] <= data1;
      q = mem[addr];
end

always @(posedge clk2)
begin
   if(we2) mem[waddr1] <= data2;
end

endmodule
```

Two Write Processes with One Clock

This example has the writes in two processes, and generates a two-write port
RAM that uses only one clock.

```
module ram0(input [1:0] data1, data2, input [2:0] waddr0, waddr1,
   addr, input we1, we2, clk, output reg [1:0] q);
reg [1:0] mem [7:0] /* synthesis syn_ramstyle="no_rw_check" */ ;

always @(posedge clk)
begin
   if(we1) mem[waddr0] <= data1;
   q = mem[addr];
end

always @(posedge clk)
begin
   if(we2) mem[waddr1] <= data2;
end

endmodule
```

RAM Instantiation with SYNCORE

The SYNCORE Memory Compiler in the IP Wizard helps you generate HDL
code for your specific RAM implementation requirements. For information on
using the SYNCORE Memory Compiler, see Specifying RAMs with SYNCore,
on page 275 in the *User Guide*.

ROM Inference

As part of BEST (Behavioral Extraction Synthesis Technology) feature, the synthesis tool infers ROMs (read-only memories) from your HDL source code, and generates block components for them in the RTL view.

The data contents of the ROMs are stored in a text file named rom.info. To quickly view rom.info in read-only mode, synthesize your HDL source code, open an RTL view, then push down into the ROM component.

Generally, the Synopsys FPGA synthesis tool infers ROMs from HDL source code that uses case statements, or equivalent if statements, to make 16 or more signal assignments using constant values (words). The constants must all be the same width.

Example

```
module rom(z,a);
output [3:0] z;
input [4:0] a;
reg [3:0] z;

always @(a) begin
   case (a)
      5'b00000 : z = 4'b0001;
      5'b00001 : z = 4'b0010;
      5'b00010 : z = 4'b0110;
      5'b00011 : z = 4'b1010;
      5'b00100 : z = 4'b1000;
      5'b00101 : z = 4'b1001;
      5'b00110 : z = 4'b0000;
      5'b00111 : z = 4'b1110;
      5'b01000 : z = 4'b1111;
      5'b01001 : z = 4'b1110;
      5'b01010 : z = 4'b0001;
      5'b01011 : z = 4'b1000;
      5'b01100 : z = 4'b1110;
      5'b01101 : z = 4'b0011;
      5'b01110 : z = 4'b1111;
      5'b01111 : z = 4'b1100;
      5'b10000 : z = 4'b1000;
      5'b10001 : z = 4'b0000;
```

```
          5'b10010 : z = 4'b0011;
          default : z = 4'b0111;
      endcase
   end
   endmodule
```

ROM Table Data (rom.info File)

```
Note: This data is for viewing only

ROM work.rom4(behave)-z_1[3:0]
address width: 5
data width: 4
inputs:
0: a[0]
1: a[1]
2: a[2]
3: a[3]
4: a[4]
outputs:
0: z_1[0]
1: z_1[1]
2: z_1[2]
3: z_1[3]

data:
00000 -> 0001
00001 -> 0010
00010 -> 0110
00011 -> 1010
00100 -> 1000
00101 -> 1001
00110 -> 0000
00111 -> 1110
01000 -> 1111
01001 -> 1110
01010 -> 0001
01011 -> 1000
01100 -> 1110
01101 -> 0011
01110 -> 0010
01111 -> 0010
10000 -> 0010
10001 -> 0010
10010 -> 0010
default -> 0111
```

Instantiating Black Boxes in Verilog

Black boxes are modules with just the interface specified; internal information is ignored by the software. Black boxes can be used to directly instantiate:

- Technology-vendor primitives and macros (including I/Os).

- User-designed macros whose functionality was defined in a schematic editor, or another input source. (When the place-and-route tool can merge design netlists from different sources.)

Black boxes are specified with the syn_black_box directive. If the macro is an I/O, use black_box_pad_pin=1 on the external pad pin.

For most of the technology-vendor architectures, macro libraries are provided (in *installDirectory*/lib/*technology*/*family*.v) that predefine the black boxes for their primitives and macros (including I/Os).

Verilog simulators require a functional description of the internals of a black box. To ensure that the functional description is ignored and treated as a black box, use the translate_off and translate_on directives. See translate_off/translate_on, on page 140 for information on the translate_off and translate_on directives.

If the black box has tristate outputs, you must define these outputs with a black_box_tri_pins, on page 19 directive.

The input, output, and delay through a black box is specified with special black box timing directives (see Black-Box Timing Constraints, on page 372).

For information on how to instantiate black boxes and technology-vendor I/Os, see *Defining Black Boxes for Synthesis, on page 378* of the *User Guide*.

PREP Verilog Benchmarks

PREP (Programmable Electronics Performance) Corporation distributes benchmark results that show how FPGA vendors compare with each other in terms of device performance and area. The following PREP benchmarks are included in the *installDirectory*/examples/verilog/common_rtl/prep:

- PREP Benchmark 1, Data Path (prep1.v)

- PREP Benchmark 2, Timer/Counter (prep2.v)

- PREP Benchmark 3, Small State Machine (prep3.v)

- PREP Benchmark 4, Large State Machine (prep4.v)

- PREP Benchmark 5, Arithmetic Circuit (prep5.v)

- PREP Benchmark 6, 16-Bit Accumulator (prep6.v)

- PREP Benchmark 7, 16-Bit Counter (prep7.v)

- PREP Benchmark 8, 16-Bit Pre-scaled Counter (prep8.v)

- PREP Benchmark 9, Memory Map (prep9.v)

The source code for the benchmarks can be used for design examples for synthesis or for doing your own FPGA vendor comparisons.

Hierarchical or Structural Verilog Designs

This section describes the creation and use of hierarchical Verilog designs:

Using Hierarchical Verilog Designs

The software accepts and processes hierarchical Verilog designs. You create hierarchy by instantiating a module or a built-in gate primitive within another module.

The signals connect across the hierarchical boundaries through the port list, and can either be listed by position (the same order that you declare them in the lower-level module), or by name (where you specify the name of the lower-level signals to connect to).

Connecting by name minimizes errors, and can be especially advantageous when the instantiated module has many ports.

Creating a Hierarchical Verilog Design

To create a hierarchical design:

1. Create modules.

2. Instantiate the modules within other modules. (When you instantiate modules inside of others, the ones that you have instantiated are sometimes called "lower-level modules" to distinguish them from the "top-level" module that is not inside of another module.)

3. Connect signals in the port list together across the hierarchy either "by position" or "by name" (see the examples, below).

Example: Creating Modules (Interfaces Shown)

```
module mux(out, a, b, sel); // mux
output [7:0] out;
input [7:0] a, b;
input sel;

// mux functionality

endmodule

module reg8(q, data, clk, rst); // Eight-bit register
output [7:0] q;
input [7:0] data;
input clk, rst;
// Eight-bit register functionality
endmodule

module rotate(q, data, clk, r_l, rst); // Rotates bits or loads
output [7:0] q;
input [7:0] data;
input clk, r_l, rst;
// When r_l is high, it rotates; if low, it loads data
// Rotate functionality
endmodule
```

Example: Top-level Module with Ports Connected by Position

```
module top1(q, a, b, sel, r_l, clk, rst);
output [7:0] q;
input [7:0] a, b;
input sel, r_l, clk, rst;
wire [7:0] mux_out, reg_out;

// The order of the listed signals here will match
// the order of the signals in the mux module declaration.
mux mux_1 (mux_out, a, b, sel);
reg8 reg8_1 (reg_out, mux_out, clk, rst);
rotate rotate_1 (q, reg_out, clk, r_l, rst);

endmodule
```

Example: Top-level Module with Ports Connected by Name

```
module top2(q, a, b, sel, r_l, clk, rst);
output [7:0] q;
input [7:0] a, b;
input sel, r_l, clk, rst;
wire [7:0] mux_out, reg_out;

/* The syntax to connect a signal "by name" is:
.<lower_level_signal_name>(<local_signal_name>)
*/
mux mux_1 (.out(mux_out), .a(a), .b(b), .sel(sel));

/* Ports connected "by name" can be in any order */
reg8 reg8_1 (.clk(clk), .data(mux_out), .q(reg_out), .rst(rst));
rotate rotate_1 (.q(q), .data(reg_out), .clk(clk),
    .r_l(r_l), .rst(rst) );
endmodule
```

synthesis Macro

Use this text macro along with the Verilog `ifdef compiler directive to conditionally exclude part of your Verilog code from being synthesized. The most common use of the synthesis macro is to avoid synthesizing stimulus that only has meaning for logic simulation.

The synthesis macro is defined so that the statement `ifdef synthesis is true. The statements in the `ifdef branch are compiled; the stimulus statements in the `else branch are ignored.

Note: Because Verilog simulators do *not* recognize a synthesis macro, the compiler for your simulator will use the stimulus in the `else branch.

In the following example, an AND gate is used for synthesis because the tool recognizes the synthesis macro to be defined (as true); the assign c = a & b branch is taken. During simulation, an OR gate is used instead, because the simulator does not recognize the synthesis macro to be defined; the assign c = a | b branch is taken.

> **Note:** A macro in Verilog has a nonzero value only if it is defined.

```
module top (a,b,c);
    input a,b;
    output c;
`ifdef synthesis
    assign c = a & b;
`else
    assign c = a | b;
`endif
endmodule
```

text Macro

The directive define creates a macro for text substitution. The compiler substitutes the text of the macro for the string *macroName*. A text macro is defined using arguments that can be customized for each individual use.

The syntax for a text macro definition is as follows.

> *textMacroDefinition* **::= define** *textMacroName macroText*

> *textMacroName* **::=** *textMacroIdentifier*[**(***formalArgumentList***)**]

> *formalArgumentList* **::=** formalArgumentIdentifier **{,** formalArgumentIdentifier**}**

When formal arguments are used to define a text macro, the scope of the formal argument is extended to the end of the macro text. You can use a formal argument in the same manner as an identifier.

A text macro with one or more arguments is expanded by replacing each formal argument with the actual argument expression.

Example 1

```
`define MIN(p1, p2) (p1)<(p2)?(p1):(p2)

module example1(i1, i2, o);
input i1, i2;
output o;
reg o;

always @(i1, i2) begin
o = `MIN(i1, i2);
end
endmodule
```

Example 2

```
`define SQR_OF_MAX(a1, a2) (`MAX(a1, a2))*(`MAX(a1, a2))
`define MAX(p1, p2) (p1)<(p2)?(p1):(p2)

module example2(i1, i2, o);
input i1, i2;
output o;
reg o;

always @(i1, i2) begin
o = `SQR_OF_MAX(i1, i2);
end
endmodule
```

Example 3

Include File ppm_top_ports_def.inc

```
//ppm_top_ports_def.inc

// Single source definition for module ports and signals
// of PPM TOP.
// Input
`DEF_DOT `DEF_IN([7:0]) in_test1 `DEF_PORT(in_test1) `DEF_END
`DEF_DOT `DEF_IN([7:0]) in_test2 `DEF_PORT(in_test2) `DEF_END

// In/Out
// `DEF_DOT `DEF_INOUT([7:0]) io_bus1 `DEF_PORT(io_bus1) `DEF_END

// Output
`DEF_DOT `DEF_OUT([7:0]) out_test2 `DEF_PORT(out_test2)
```

```
        // No DEF_END here...

        `undef DEF_IN
        `undef DEF_INOUT
        `undef DEF_OUT
        `undef DEF_END
        `undef DEF_DOT
        `undef DEF_PORT
```

Verilog File top.v

```
        // top.v

        `define INC_TYPE 1
        module ppm_top(
         `ifdef INC_TYPE
        // Inc file Port def...
            `define DEF_IN(arg1) /* arg1 */
            `define DEF_INOUT(arg1) /* arg1 */
            `define DEF_OUT(arg1) /* arg1 */
            `define DEF_END ,
            `define DEF_DOT /* nothing */
            `define DEF_PORT(arg1) /* arg1 */

        `include "ppm_top_ports_def.inc"
            `else
            // Non-Inc file Port def, above defines should expand to
            // what is below...
                /* nothing */ /* [7:0] */ in_test1 /* in_test1 */ ,
                /* nothing */ /* [7:0] */ in_test2 /* in_test2 */ ,

            // In/Out
            //`DEF_DOT `DEF_INOUT([7:0]) io_bus1 `DEF_PORT(io_bus1)
        `DEF_END

            // Output
                /* nothing */ /* [7:0] */ out_test2 /* out_test2 */
        // No DEF_END here...
         `endif
        );

            `ifdef INC_TYPE
            // Inc file Signal type def...
            `define DEF_IN(arg1) input arg1
```

```
      `define DEF_INOUT(arg1) inout arg1
      `define DEF_OUT(arg1) output arg1
      `define DEF_END ;
      `define DEF_DOT /* nothing */
      `define DEF_PORT(arg1) /* arg1 */

`include "ppm_top_ports_def.inc"
      `else
      // Non-Inc file Signal type def, defines should expand to
      // what is below...
          /* nothing */ input [7:0] in_test1 /* in_test1 */ ;
          /* nothing */ input [7:0] in_test2 /* in_test2 */ ;

// In/Out
      //`DEF_DOT `DEF_INOUT([7:0]) io_bus1 `DEF_PORT(io_bus1)`DEF_END

// Output
      /* nothing */ output [7:0] out_test2 /* out_test2) */
// No DEF_END here...
      `endif

 ; /* Because of the 'No DEF_END here...' in line of the include
file. */

      assign out_test2 = (in_test1 & in_test2);

endmodule
```

Verilog Attribute and Directive Syntax

Verilog attributes and directives allow you to associate information with your design to control the way it is analyzed, compiled, and mapped.

- *Attributes* direct the way your design is optimized and mapped during synthesis.

- *Directives* control the way your design is analyzed prior to mapping. They must therefore be included directly in your source code; they cannot be specified in a constraint file like attributes.

Verilog does not have predefined attributes or directives for synthesis. To define directives or attributes in Verilog, attach them to the appropriate objects in the source code as comments. You can use either of the following comment styles:

- Regular line comments

- Block or C-style comments

Each specification begins with the keyword synthesis. The directive or attribute value is either a string, placed within double quotes, or a Boolean integer (0 or 1). Directives, attributes, and their values are-case sensitive and are usually in lower case.

Attribute Syntax and Examples using Verilog Line Comments

Here is the syntax using a regular Verilog comment:

> **// synthesis** *directive | attribute* [**= "***value***"**]

This example shows how to use the syn_hier attribute:

```
// synthesis syn_hier = "firm"
```

This example shows the parallel_case directive:

```
// synthesis parallel_case
```

This directive forces a multiplexed structure in Verilog designs. It is implicitly true whenever you use it, which is why there is no associated value.

Attribute Syntax and Examples Using Verilog C-Style Comments

Here is the syntax for specifying attributes and directives with the C-style block comment:

> /* **synthesis** *directive* | *attribute* [**=** **"***value***"**] */

This example shows the syn_hier attribute specified with a C-style comment:

```
/* synthesis syn_hier = "firm" */
```

The following are some other rules for using C-style comments to define attributes:

- If you use C-style comments, you must place the comment *before* the semicolon of the statement. For example:

```
module bl_box(out, in) /* synthesis syn_black_box */ ;
```

- To specify more than one directive or attribute for a given design object, place them within the same comment, separated by a space. Do *not* use commas as separators. Here is an example where the syn_preserve and syn_state_machine directives are specified in a single comment:

```
module radhard_dffrs(q,d,c,s,r)
    /* synthesis syn_preserve=1 syn_state_machine=0 */;
```

- To make source code more readable, you can split long block comment lines by inserting a backslash character (\) followed immediately by a newline character (carriage return). A line split this way is still read as a single line; the backslash causes the newline following it to be ignored. You can split a comment line this way any number of times. However, note these exceptions:

  - The first split cannot occur before the first attribute or directive specification.
  - A given attribute or directive specification cannot be split before its equal sign (=).

  Take this block comment specification for example:

```
/* synthesis syn_probe=1 xc_loc="P20,P21,P22,P23,P24,P25,P26,P27" */;
```

  You cannot split the line before you specify the first attribute, `syn_probe`. You cannot split the line before either of the equal signs (`syn_probe=` or `xc_loc=`). You can split it anywhere within the string value `"P20,P21,P22,P23,P24,P25,P26,P27"`.

Attribute Examples Using Verilog 2001 Parenthetical Comments

Here is the syntax for specifying attributes and directives as Verilog 2001 parenthetical comments:

(* *directive* | *attribute* [**= "***value***"**] ***)**

Verilog 2001 parenthetical comments can be applied to:

- individual objects

- multiple objects

- individual objects within a module definition

The following example shows two syn_keep attributes specified as parenthetical comments:

```
module example2(out1, out2, clk, in1, in2);
output out1, out2;
input clk;
input in1, in2;
wire and_out;
(* syn_keep=1 *) wire keep1;
(* syn_keep=1 *) wire keep2;
reg out1, out2;
assign and_out=in1&in2;
assign keep1=and_out;
assign keep2=and_out;

always @(posedge clk)begin;
    out1<=keep1;
    out2<=keep2;
end
endmodule
```

For the above example, a single parenthetical comment could be added directly to the reg statement to apply the syn_keep attribute to both out1 and out2:

```
(* syn_keep=1 *) reg out1, out2;
```

The following rules apply when using parenthetical comments to define attributes:

- Always place the comment *before* the design object (and terminating semicolon). For example:

```
(* syn_black_box *) module bl_box(out, in);
```

- To specify more than one directive or attribute for a given object, place the attributes within the same parenthetical comment, separated by a space (do *not* use commas as separators). The following example shows the syn_preserve and syn_state_machine directives applied in a single parenthetical comment:

```
(* syn_preserve=1 syn_state_machine=0 *)
   module radhard_dffrs(q,d,c,s,r);
```

- Parenthetical comments can be applied to individual objects within a module definition. For example,

```
module example2 (out1, (*syn_preserve=1*) out2, clk, in1, in2);
```

applies a syn_preserve attribute to out2, and

```
module example2 ( (*syn_preserve=1*) out1,
   (*syn_preserve=1*) out2, clk, in1, in2);
```

applies a syn_preserve attribute to both out1 and out2

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CHAPTER 2

SystemVerilog Language Support

This chapter describes support for the SystemVerilog standard in the Synopsys FPGA synthesis tools. For information on the Verilog standard, see Chapter 1, *Verilog Language Support*. The following describe SystemVerilog-specific support:

Feature Summary

SystemVerilog is an IEEE (P1800) standard with extensions to the IEEE Std.1364-2001 Verilog standard. The extensions integrate features from C, C++, VHDL, OVA, and PSL. The following table summarizes the SystemVerilog features currently supported in the Synopsys FPGA Verilog compilers. See SystemVerilog Limitations, on page 121 for a list of limitations.

Feature	Brief Description
Unsized Literals	Specification of unsized literals as single-bit values without a base specifier.
Data Types • Typedefs • Enumerated Types • Struct Construct • Union Construct • Static Casting	Data types that are a hybrid of both Verilog and C including: • User-defined types that allow you to create new type definitions from existing types • Variables and nets defined with a specific set of named values • Structure data type to represent collections of variables referenced as a single name • Data type collections sharing the same memory location • Conversion of one data type to another data type.
Arrays • Arrays • Arrays of Structures	Packed, unpacked, and multi-dimensional arrays of structures.
Data Declarations • Constants • Variables • Nets • Data Types in Parameters • Type Parameters	Data declarations including constant, variable, net, and parameter data types.

Feature	Brief Description
Operators and Expressions • Operators • Aggregate Expressions • Streaming Operator • Set Membership Operator • Type Operator	C assignment operators and special bit-wise assignment operators.
Procedural Statements and Control Flow • Do-While Loops • For Loops • Unnamed Blocks • Block Name on end Keyword • Unique and Priority Modifiers	Procedural statements including variable declarations and block functions.
Processes • always_comb • always_latch • always_ff	Specialized procedural blocks that reduce ambiguity and indicate the intent.
Tasks and Functions • Implicit Statement Group • Formal Arguments • endtask /endfunction Names	Information on implicit grouping for multiple statements, passing formal arguments, and naming end statements for functions and tasks.
Hierarchy • Compilation Units • Packages • Port Connection Constructs • Extern Module	Permits sharing of language-defined data types, user-defined types, parameters, constants, function definitions, and task definitions among one or more compilation units, modules, or interfaces (pkgs)
Interface • Interface Construct • Modports	Interface data type to represent port lists and port connection lists as single name.
System Tasks and System Functions • $bits System Function • Array Querying Functions	Queries to returns number of bits required to hold an expression as a bit stream or array.

Feature	Brief Description
Generate Statement • Conditional Generate Constructs	Generate-loop, generate-conditional, or generate-case statements with defparams, parameters, and function and task declarations. Conditional if-generate and case-generate constructs
Assertions • SVA System Functions	SystemVerilog assertion support.
Keyword Support	Supported and unsupported keywords.

SystemVerilog Limitations

The following SystemVerilog limitations are present in the current release.

Interface

- An array of interfaces cannot be used as a module port.

- An interface cannot have a multi-dimensional port.

- Access of array type elements outside of the interface are not supported. For example:

```
interface ff_if (input logic din, input [7:0] DHAin1,
    input [7:0] DHAin2, output logic dout);
logic [1:0] [1:0] [1:0] DHAout_intf;

always_comb
DHAout_intf = DHAin1 + DHAin2;

modport write (input din, output dout);
endinterface: ff_if
```

- `ff_if ff_if_top(.*);`
  `DHAout = ff_if_top.DHAout_intf;` Modport definitions within a Generate block are not supported. For example:

```
interface myintf_if (input logic [7:0] a , input logic [7:0]  b,
    output logic [7:0] out1, output logic [7:0] out2);
generate
   begin: x
   genvar i;
      for (i = 0;i <= 7;i=i+1)
      begin : u
         modport myinst(input .ma(a[i]), input .mb(b[i]),
            output .mout1(out1[i]) , output .mout2(out2[i]));
      end
   end
endgenerate
endinterface
```

Compilation Unit and Package

- Write access to the variable defined in package/compilation unit is not supported. For example:

```
package MyPack;
typedef struct packed {
    int r;
    longint g;
    byte b;
}  MyStruct ;

MyStruct StructMyStruct;
endpackage: MyPack

import MyPack::*;
module top ( ...
...

always@(posedge clk)
StructMyStruct <= '{default:254};
```

Unsized Literals

SystemVerilog allows you to specify unsized literals without a base specifier (auto-fill literals) as single-bit values with a preceding apostrophe ('). All bits of the unsized value are set to the value of the specified bit.

```
'0, '1, 'X, 'x, 'Z, 'z // sets all bits to this value
```

In other words, this feature allows you to fill a register, wire, or any other data types with 0, 1, X, or Z in simple format.

Verilog Example	SystemVerilog equivalent
a = 4'b1111;	a = '1;

Data Types

SystemVerilog makes a clear distinction between an *object* and its *data type*. A data type is a set of values, or a set of operations that can be performed on those values. Data types can be used to declare data objects.

SystemVerilog offers the following data types, representing a hybrid of both Verilog and C:

Data Type	Description
shortint	2-state, SystemVerilog data type, 16-bit signed integer
int	2-state, SystemVerilog data type, 32-bit signed integer
longint	2-state, SystemVerilog data type, 64-bit signed integer
byte	2-state, SystemVerilog data type, 8-bit signed integer or ASCII character
bit	2-state, SystemVerilog data type, user-defined vector size
logic	4-state, SystemVerilog data type, user-defined vector size

Data types are characterized as either:

- 4-state (4-valued) data types that can hold 1, 0, X, and Z values

- 2-state (2-valued) data types that can hold 1 and 0 values

The following apply when using data types:

- The data types byte, shortint, int, integer and longint default to signed; data types bit, reg, and logic default to unsigned, as do arrays of these types.

- The signed keyword is part of Verilog. The unsigned keyword can be used to change the default behavior of signed data types.

- The Verilog compiler does not generate an error even if a 2-state data type is assigned X or Z. It treats it as a "don't care" and issues a warning.

- Do not use the syn_keep directive on nets with SystemVerilog data types. When you use data types such as bit, logic, longint, or shortint, the synthesis software might not be aware of the bit sizes on the LHS and RHS for the net. For example:

```
bit x;
    shortint y;
    assign y =x;
```

In this case, bit defaults to a 1-bit width and includes a shortint of 16-bit width. If syn_keep is applied on y, the software does not use the other 15 bits.

Typedefs

You can create your own names for type definitions that you use frequently in your code. SystemVerilog adds the ability to define new net and variable user-defined names for existing types using the typedef keyword.

Example – Simple typedef Variable Assignment

```
//TECHPUBS Example - Simple typedef Variable Assignment

module src (in1,in2,out1,out2);

input in1,in2;

output reg out1,out2;

typedef int foo;
```

```
foo a,b;


assign a = in1; assign b = in2;
always@(a,b)
   begin
      out1 = a;
      out2 = b;
   end
endmodule
```

Example – Using Multiple typedef Assignments

```
//TECHPUBS Example - Using Multiple typedef Assignments
module src (in1,in2,in3,in4,out1,out2,out3);
input [3:0] in1,in2;
input in3,in4;
output reg [3:0] out1;output reg out2,out3;
typedef bit signed [3:0] foo1;
typedef byte signed foo2;
typedef int foo3;
struct {
   foo1 a;
   foo2 b;
   foo3 c;
   } foo;


always@(in1,in2,in3,in4)
   begin
      foo.a = in1 & in2;
```

```
            foo.b = in3 | in4;

            foo.c = in3 ^ in4;

        end


    always@(foo.a,foo.b,foo.c)

        begin

            out1 = foo.a;

            out2 = foo.b;

            out3 = foo.c;

        end

    endmodule
```

Enumerated Types

The synthesis tools support SystemVerilog enumerated types in accordance with SV LRM section: 4.10; enumerated methods are not supported.

The enumerated types feature allows variables and nets to be defined with a specific set of named values. This capability is particularly useful in state-machine implementation where the states of the state machine can be verbally represented

Data Types

Enumerated types have a base data type which, by default, is int (a 2-state, 32-bit value). By default, the first label in the enumerated list has a logic value of 0, and each subsequent label is incremented by one.

For example, a variable that has three legal states:

```
enum {WAITE, LOAD, READY} State ;
```

The first label in the enumerated list has a logic value of 0 and each subsequent label is incremented by one. In the example above, State is an int type and WAITE, LOAD And READY have 32-bit int values. WAITE is 0, LOAD is 1, and READY is 2.

You can specify an explicit base type to allow enumerated types to more specifically model hardware. For example, two enumerated variables with one-hot values:

```
enum logic [2:0] {WAITE=3'b001, LOAD=3'b010,READY=3'b100} State;
```

Specifying Ranges

SystemVerilog enumerated types also allow you to specify ranges that are automatically elaborated. Types can be specified as outlined in the following table.

Syntax	Description
name	Associates the next consecutive number with the specified name.
name = C	Associates the constant C to the specified name.
name[*N*]	Generates N named constants in this sequence: *name0, name1,..., nameN-1*. N must be a positive integral number.

Syntax	Description
name[*N*] = C	Optionally assigns a constant to the generated named constants to associate that constant with the first generated named constant. Subsequent generated named constants are associated with consecutive values. N must be a positive integral number.
name[*N:M*]	Creates a sequence of named constants, starting with *nameN* and incrementing or decrementing until it reaches named constant *nameM*. N and M are non-negative integral numbers.
name[*N:M*] = C	Optionally assigns a constant to the generated named constants to associate that constant with the first generated named constants. Subsequent generated named constants are associated consecutive values. N and M must be positive integral numbers.

The following example declares enumerated variable vr, which creates the enumerated named constants register0 and register1, which are assigned the values 1 and 2, respectively. Next, it creates the enumerated named constants register2, register3, and register4 and assigns them the values 10, 11, and 12.

```
enum { register[2] = 1, register[2:4] = 10 } vr;
```

State-Machine Example

The following is an example state-machine design in SystemVerilog.

Example – State-machine Design

```
//TECHPUBS Example - State-machine Design
module enum_type_check (clk, rst, same, statemachine1_is_five,
    statemachine2_is_six, statemachine1, statemachine2, both);
input clk, rst;
output reg same, statemachine1_is_five, statemachine2_is_six;
output int statemachine1, statemachine2, both;
enum {a[0:3] = 4} my,my1;

always@(posedge clk or posedge rst)
begin
```

```
         if (rst)
            begin
               my <= a0;
            end
         else
            case(my)
               a0 :begin
                  my <= a1;
               end
               a1 :begin
                  my <= a2;
               end
               a2 :begin
                  my <= a3;
               end
               a3 :begin
                  my <= a0;
               end
            endcase
         end


         always@(posedge clk or posedge rst)
         begin
         if (rst)
            begin
               my1 <= a0;
            end
```

```
      else
         case(my1)
            a0 :begin
               my1 <= a3;
            end
            a1 :begin
               my1 <= a0;
            end
            a2 :begin
               my1 <= a1;
            end
            a3 :begin
               my1 <= a2;
            end
         endcase
   end

   always@(posedge clk)
   begin
   statemachine1 <= my;
   statemachine2 <= my1;
   both <= my + my1;
   if (my == my1)
      same <= 1'b1;
   else
      same <= 0;
   if (my == 5)
```

```
        statemachine1_is_five <= 1'b1;
    else
        statemachine1_is_five <= 1'b0;
    if (my1 == 6)
        statemachine2_is_six <= 1'b1;
    else
        statemachine2_is_six <= 1'b0;
    end
    endmodule
```

Type Casting Using Enumerated Types

By using enumerated types, you can define a type. For example:

```
typedef enum { red,green,blue,yellow,white,black } Colors;
```

The above definition assigns a unique number to each of the color identifiers and creates the new data type Colors. This new type can then be used to create variables of that type.

Valid assignment would be:

```
Colors c;

C = green;
```

Enumerated Types in Expressions

Elements of enumerated types can be used in numerical expressions. The value used in the expression is the value specified with the numerical value. For example:

```
typedef enum { red,green,blue,yellow,white,black } Colors;
integer a,b;
a = blue *3 // 6 is assigned to a
b = yellow + green; // 4 is assigned to b
```

Struct Construct

SystemVerilog adds several enhancements to Verilog for representing large amounts of data. In SystemVerilog, the Verilog array constructs are extended both in how data can be represented and for operations on arrays. A structure data type has been defined as a means to represent collections of data types. These data types can be either standard data types (such as int, logic, or bit) or, they can be user-defined types (using SystemVerilog typedef). Structures allow multiple signals, of various data types, to be bundled together and referenced by a single name.

Structures are defined under section 4.11 of IEEE Std 1800-2005 (IEEE Standard for SystemVerilog).

In the example structure floating_pt_num below, both characteristic and mantissa are 32-bit values of type bit.

```
struct {
    bit [31:0] characteristic;
    bit [31:0] mantissa;
}  floating_pt_num;
```

Alternately, the structure could be written as:

```
typedef struct {
    bit [31:0] characteristic;
    bit [31:0] mantissa;
}  flpt;
flpt floating_pt_num;
```

In the above sequence, a type flpt is defined using typedef which is then used to declare the variable floating_pt_num.

Assigning a value to one or more fields of a structure is straight-forward.

```
floating_pt_num.characteristic = 32'h1234_5678;

floating_pt_num.mantissa       = 32'h0000_0010;
```

As mentioned, a structure can be defined with fields that are themselves other structures.

```
typedef struct {
    flpt x;
    flpt y;
}  coordinate;
```

Packed Struct

Various other unique features of SystemVerilog data types can also be applied to structures. By default, the members of a structure are *unpacked*, which allows the Synopsys FPGA tools to store structure members as independent objects. It is also possible to *pack* a structure in memory without gaps between its bit fields. This capability can be useful for fast access of data during simulation and possibly result in a smaller footprint of your simulation binary.

To pack a structure in memory, use the packed keyword in the definition of the structure:

```
typedef struct packed {
    bit [31:0] characteristic;
    bit [31:0] mantissa;
} flpt;
```

An advantage of using packed structures is that one or more bits from such a structure can be selected as if the structure was a packed array. For instance, flpt[47:32] in the above declaration is the same as characteristic[15:0].

Struct members are selected using the .name syntax as shown in the following two code segments.

```
// segment 1
typedef struct {
    bit [7:0] opcode;
    bit [23:0] addr;
} instruction; // named structure type
instruction IR; // define variable
IR.opcode = 1; //set field in IR.

// segment 2
struct {
    int x,y;
} p;
p.x = 1;
```

Union Construct

A union is a collection of different data types similar to structure with the exception that members of the union share the same memory location. At any given time, you can write to any one member of the union which can then be read by the same member or a different member of that union.

Union is broadly classified as:

- Packed Union

- Unpacked Union

Currently, only packed unions are supported.

Packed Union

A packed union can only have members that are of the packed type (packed structure, packed array of logic, bit, int, etc.). All members of a packed union must be of equal size.

Syntax

Union packed
{
    member1;
    member2;
} *unionName*;

Unpacked Union

The members of an unpacked union can include both packed and unpacked types (packed/unpacked structures, arrays of packed/unpacked logic, bit, int, etc.) with no restrictions as to the size of the union members.

Syntax

Union
{
    member1;
    member2;
} *unionName*;

Example 1 – Basic Packed Union (logical operation)

```
//TECHPUBS Example - Basic Packed Union (logical operation)

typedef int unsigned UnsignInt_dt;

typedef union packed

{

    int u1;

    UnsignInt_dt u2;

}union_dt; //Union data type
```

```
module top
    (input union_dt d1,
input union_dt d2,
output union_dt q1,
output union_dt q2
);
assign q1.u1 = d1.u1 ^ d2.u1;
assign q2.u2 = d1.u2 | d2.u1;
endmodule
```

Example 2 – Basic Packed Union (arithmetic operation)

```
//TECHPUBS Example - Basic Packed Union (arithmetic operation)
typedef union packed
{
    logic [3:0][0:3]u1;
    shortint u2;
    bit signed [1:2][8:1]u3;
}union_dt; // Union data type

module top
    (input union_dt d1,
     input union_dt d2,
     output union_dt q1,
     output union_dt q2
    );
assign q1.u2 = d1.u1 + d2.u2;
assign q2.u1 = d1.u2 - d1.u1[2][1];
```

```
endmodule
```

Example 3 – Nested Packed Union

```
//TECHPUBS Example - Nested Packed Union
typedef union packed
{
   byte u1;
   bit[1:0][4:1]u2;
   union packed
   {
      logic[8:1]nu1;
      byte unsigned nu2;
   }NstUnion; //Nested Union
}NstUnion_dt;


module top
   (input NstUnion_dt d1,
    input NstUnion_dt d2,
    output NstUnion_dt q1,
    output NstUnion_dt q2
   );
assign q1 = d1.NstUnion.nu1 & d2.u2[1];
assign q2.u1 = d2.NstUnion.nu2 |~ d1.u1;
endmodule
```

Example 4 – Array of packed Union

```
//TECHPUBS Example - Array of Packed Union
typedef int int_dt;
```

```
typedef union packed
{
    int_dt u1;
    bit [0:3][1:8]u2;
}union_dt;
module top
    (input union_dt [1:0] d1, //Array of union
     input union_dt [1:0] d2, //Array of union
     output union_dt q1,
     output union_dt q2
    );
assign q1.u1 = d1[1].u1 ^ d2[0].u1;
assign q2.u2 = ~(d1[0].u2 | d2[1].u1);
endmodule
```

Limitations

The SystemVerilog compiler does not support the following union constructs:

- unpacked union

- tagged packed union

- tagged unpacked union

Currently, support is limited to packed unions, arrays of packed unions, and nested packed unions.

Static Casting

Static casting allows one data type to be converted to another data type. The static casting operator is used to change the data type, the size, or the sign:

- Type casting – a predefined data type is used as a *castingType* to change the data type.

- Size casting – a positive decimal number is used as a *castingType* to change the number of data bits.

- Sign casting – signed/unsigned are used to change the sign of data type.

- Bit-stream casting – type casting that is applied to unpacked arrays and structs. During bit-stream casting, both the left and right sides of the equation must be the same size. Arithmetic operations cannot be combined with static casting operations as is in the case of singular data types.

Syntax

castingType **'(***castingExpression***)**

Example – Type Casting of Singular Data Types

```
//TECHPUBS Example - Type Casting of Singular Data Types

typedef logic [31:0] unsigned_32bits;

typedef logic [15:0] unsigned_16bits;

module top (

//Inputs
```

```
input integer Integer,

input shortint Shortint,

//Outputs

output longint arith

);

//Arithmetic operation

assign arith = unsigned_32bits'(Integer) *
unsigned_16bits'(Shortint) ;

endmodule
```

Example – Type Casting of Aggregate Data Types

```
//TECHPUBS Example - Type Casting of Aggregate Data Types

//Data type

typedef logic Logic_3D_dt [15:0][1:0][1:0];

typedef logic Logic_1D_dt [64:1];

module top (

//Inputs

input Logic_3D_dt Logic_3D,

//Outputs

output longint arith

);

//Constant delcaration

const Logic_1D_dt Logic_1DConst = '{default:1'b1};

//Arithmetic Operation

assign arith = longint'(Logic_3D) + longint'(Logic_1DConst);

endmodule
```

Example – Bit-stream Casting

```
//TECHPUBS Example - Bit-stream Casting

typedef struct {

bit start_bit = 0;

byte data_bits;

bit stop_bit = 1; }

uart_format_dt;

typedef logic tx_format_dt[9:0] ;

module top (

//Inputs

input byte data,

//Outputs

output tx_format_dt tx_data

);

uart_format_dt uart_data;

assign uart_data.data_bits = data;

assign tx_data = tx_format_dt'(uart_data);

endmodule
```

Example – Size Casting

```
//TECHPUBS Example - Size Casting

module top (

//Inputs

input longint Longint,

input byte Byte,

//Outputs

output shortint arith1

);
```

```
//Arithmetic operation

assign arith1 = 10'(Byte + Longint);

endmodule
```

Example – Sign Casting

```
//TECHPUBS Example - Sign Casting

module top (

//Inputs

input integer Integer,

input shortint Shortint,

//Outputs

output longint arith

);

//Arithmetic operation

assign arith = unsigned'(Integer) * unsigned'(Shortint);

endmodule
```

Arrays

Topics in this section include:

-
-

Arrays

SystemVerilog uses the term *packed array* to refer to the dimensions declared before the object name (same as Verilog *vector width*). The term *unpacked array* refers to the dimensions declared after the object name (same as Verilog *array dimensions*). For example:

```
reg [7:0] foo1; //packed array
reg foo2 [7:0]; //unpacked array
```

A packed array is guaranteed to be represented as a contiguous set of bits and, therefore, can be conveniently accessed as array elements. While unpacked is not guaranteed to work so, but in terms of hardware, both would be treated or bit-blasted into a single dimension.

```
module test1 (input [3:0] data, output [3:0] dout);
    //example on packed array four-bit wide.

assign dout = data;
endmodule

module test2 (input data [3:0], output dout [3:0]);
//unpacked array of 1 bit by 4 depth;

assign dout = data;
endmodule
```

Multi-dimensional packed arrays unify and extend Verilog's notion of *registers* and *memories*:

```
reg [1:0][2:0] my_var[32];
```

Classical Verilog permitted only one dimension to be declared to the left of the variable name. SystemVerilog permits any number of such *packed* dimensions. A variable of packed array type maps 1:1 onto an integer arithmetic quantity. In the example above, each element of my_var can be used in expressions as a six-bit integer. The dimensions to the right of the name (32 in this case) are referred to as *unpacked* dimensions. As in Verilog-2001, any number of unpacked dimensions is permitted.

The general rule for multi-dimensional packed array is as follows:

```
reg/wire [matrixₙ:0] … [matrix₁:0][depth:0][width:0] temp;
```

The general rule for multi-dimensional unpacked array is as follows:

```
reg/wire temp1 [matrixₙ:0]… [matrix₁:0][depth:0]; //single bit wide
reg/wire [widthₘ:0] temp2 [matrixₙ:0]… [matrix₁:0][depth:0]; //
widthₘ bit wide
```

The general rule for multi-dimensional array, mix of packed/unpacked, is as follows:

```
reg/wire [widthₘ:0] temp3 [matrix:0]… [depth:0];

reg/wire [depth:0][width:0] temp4 [matrixₘ:0]… [matrix₁:0]
```

For example, in a multi-dimensional declaration, the dimensions declared following the type and before the name vary more rapidly than the dimensions following the name.

Multi-dimensional arrays can be used as ports of the module.

The following items are now supported for multi-dimensional arrays:

1. The assignment of a whole multi-dimensional array to another.

2. The access (reading) of an entire multi-dimensional array.

3. The assignment of an index (representing a complete dimension) of a multi-dimensional array to another.

4. The access (reading) of 3. above.

5. The assignment of a slice of a multi-dimensional array.

6. The access of a slice of a multi-dimensional array.

7. The access of a variable part-select of a multi-dimensional array.

In addition, packed arrays are supported with the access/store mechanisms listed above. Packed arrays can also be used as ports and arguments to functions and tasks. The standard multi-dimensional access of packed arrays is supported.

Unpacked array support is the same as packed array supported stated in items one through seven above.

Example – Multi-dimensional Packed Array with Whole Assignment

```
//TECHPUBS Example - Multi-dimensional Packed Array with Whole
Assignment

module test (

input [1:0] [1:0] sel,

input [1:0] [1:0] data1,

input [1:0] [1:0] data2,

input [1:0] [1:0] data3,

output reg [1:0] [1:0] out1,

output reg [1:0] [1:0] out2,

output reg [1:0] [1:0] out3 );


always @(sel,data1,data2)

   begin

      out1 = (sel[1]==11)? data1 : {11,11};

      out2 = (sel[1]==2'b11)? data2 : {11,10};

      out3 = data3;

   end

endmodule
```

Example – Multi-dimensional Packed Array with Partial Assignment

```
//TECHPUBS Example - Multi-dimensional Packed Array with Partial
Assignment

module test (

input [7:0] datain,

input [1:0][2:0][3:0] datain2,

output [1:0][1:0][1:0] array_out,

output [23:0] array_out2,

output [3:0] array_out2_first_element,

    array_out2_second_element, array_out2_zero_element,

output [1:0] array_out2_first_element_partial_slice );

assign array_out = datain;

assign array_out2 = datain2;

assign array_out2_zero_element = datain2[1][0];

assign array_out2_first_element = datain2[1][1];

assign array_out2_second_element = datain2[1][2];

assign array_out2_first_element_partial_slice =

    datain2[0][0][3-:2];

endmodule
```

Example – Multi-dimensional Packed Array with Arithmetic Ops

```
//TECHPUBS Example - Multi-dimensional Packed Array with
Arithmetic Ops

module test (

input signed [1:0][2:0] a, b,

output signed [1:0] [2:0] c, c_bar, c_mult, c_div, c_per,

output signed [1:0][2:0] d, d_bar, d_mult, d_div, d_per,

output signed e, e_bar, e_mult, e_div, e_per );

assign c = a + b;
```

```
      assign d = a[1] + b[1];
      assign e = a[1][2] + a[1][1] + a[1][0] + b[1][2] + b[1][1]
            + b[1][0];
      assign c_bar = a - b;
      assign d_bar = a[1] - b[1];
      assign e_bar = a[1][2] - a[1][1] - a[1][0] - b[1][2]
            - b[1][1] - b[1][0];
      assign c_mult = a * b;
      assign d_mult = a[1] * b[1];
      assign e_mult = a[1][2] * a[1][1] * a[1][0] * b[1][2] *
            b[1][1] * b[1][0];
      assign c_div = a / b;
      assign d_div = a[1] / b[1];
      assign e_div = a[1][2] / b[1][1];
      assign c_per = a % b;
      assign d_per = a[1] % b[1];
      assign e_per = a[1][2] % b[1][1];
      endmodule
```

Example – Packed/Unpacked Array with Partial Assignment

```
      //TECHPUBS Example - Packed/Unpacked Array with Partial Assignment
      module test (
      input [1:0] sel [1:0],
      input [63:0] data [3:0],
      input [63:0] data2 [3:0],
      output reg [15:0] out1 [3:0],
      output reg [15:0] out2 [3:0]);
```

```
      always @(sel, data)

         begin

            out1 = (sel[1]==2'b00)? data[3][63-:16] :

               ((sel[1]==2'b01)? data[2][47-:16] :

               ((sel[0]==2'b10)? data[1][(63-32)-:16] :

                  data[0][(63-48)-:16] ) );

            out2[3][15-:16] = data2[3][63-:16];

            out2[2][15-:16] = data2[3][47-:16];

            out2[1][15-:16] = data2[3][(63-32)-:16];

            out2[0][15-:8] = data2[3][(63-48)-:8];

         end

      endmodule
```

Arrays of Structures

SystemVerilog supports multi-dimensional arrays of structures which can be used in many applications to manipulate complex data structures. A multi-dimensional array of structure is a structured array of more than one dimension. The structure can be either packed or unpacked and the array of this structure can be either packed or unpacked or a combination of packed and unpacked. As a result, there are many combinations that define a multi-dimensional array of structure.

A multi-dimensional array of structure can be declared as either anonymous type (inline) or by using a typedef (user-defined data type).

Some applications where multi-dimensional arrays of structures can be used are where multi-channeled interfaces are required such as packet processing, dot-product of floating point numbers, or image processing.

Example – Multi-dimensional Array of Packed and Unpacked Structures Using typedef

```
//TECHPUBS Example - Multi-dimensional Array of Packed and
Unpacked Structures Using typedef

typedef struct {
```

```
byte r;

byte g;

byte b;

} [2:0] struct_im_t [0:1];

module mda_str (

input struct_im_t a,

input struct_im_t b,

output struct_im_t c,

input [7:0] alpha,

input [7:0] beta

);

typedef struct {

shortint r;

shortint g;

shortint b;

} [2:0] struct_im_r_t [0:1];

struct_im_r_t temp;

integer i,j;


always_comb

begin

   for(i=0;i<2;i=i+1)

   for(j=0;j<3;j=j+1)

   begin

      temp[i][j].r = a[i][j].r * alpha + b[i][j].r * beta;

      temp[i][j].g = a[i][j].g * alpha + b[i][j].g * beta;

      temp[i][j].b = a[i][j].b * alpha + b[i][j].b * beta;
```

```
        c[i][j].r = temp[i][j].r[15:8];

        c[i][j].g = temp[i][j].g[15:8];

        c[i][j].b = temp[i][j].b[15:8];

     end

  end

  endmodule
```

Example – Multi-dimensional Array of UnPacked Structures Using typedef

```
//TECHPUBS Example - Multi-dimensional Array of Unpacked
Structures Using typedef

typedef struct {

byte r;

byte g;

byte b;

} struct_im_t [2:0][1:0];

module mda_str (

input struct_im_t a,

input struct_im_t b,

output struct_im_t c,

input [7:0] alpha,

input [7:0] beta

);

typedef struct {

shortint r;

shortint g;

shortint b;

} struct_im_r_t [2:0][1:0];

struct_im_r_t temp;
```

```
        integer i,j;


        always_comb
        begin
           for(i=0;i<3;i=i+1)
           for(j=0;j<2;j=j+1)
           begin
              temp[i][j].r = a[i][j].r * alpha + b[i][j].r * beta;
              temp[i][j].g = a[i][j].g * alpha + b[i][j].g * beta;
              temp[i][j].b = a[i][j].b * alpha + b[i][j].b * beta;
              c[i][j].r = temp[i][j].r[15:8];
              c[i][j].g = temp[i][j].g[15:8];
              c[i][j].b = temp[i][j].b[15:8];
           end
        end
        endmodule
```

Example – Multi-dimensional Array of Packed Structures Using Anonymous Type

```
//TECHPUBS Example - Multi-dimensional Array of Packed Structures
Using Anonymous Type

module mda_str (

input struct packed {

logic [47:0] dest_addr;

logic [47:0] src_addr;

logic [7:0] type_len;

logic [63:0] data;

logic [2:0] crc;
```

```
} [1:0][3:0] str_pkt_in,

input sel1,

input [1:0] sel2,

output struct packed {

logic [47:0] dest_addr;

logic [47:0] src_addr;

logic [7:0] type_len;

logic [63:0] data;

logic [2:0] crc;

} str_pkt_out

);

always_comb

begin

str_pkt_out = str_pkt_in[sel1][sel2];

end

endmodule
```

Example – Multi-dimensional Array of Packed Structures Using typedef

```
//TECHPUBS Example - Multi-dimensional Array of Packed Structures
Using typedef

typedef struct packed {

logic [47:0] dest_addr;

logic [47:0] src_addr;

logic [7:0] type_len;

logic [63:0] data;

logic [3:0] crc;

} [1:0][1:0] str_pkt_mp_t;

typedef struct packed {
```

```
logic [47:0] dest_addr;

logic [47:0] src_addr;

logic [7:0] type_len;

logic [63:0] data;

logic [3:0] crc;

} str_pkt_t;

module mda_str (

input str_pkt_mp_t pkt_mp_in,

input sel1,

input sel2,

output str_pkt_t pkt_out

);

always_comb

begin

    pkt_out = pkt_mp_in[sel1][sel2];

end

endmodule
```

Array Querying Functions

SystemVerilog provides system functions that return information about a
particular dimension of an array. For information on this function, see Array
Querying Functions, on page 238.

Data Declarations

There are several data declarations in SystemVerilog: *literals, parameters,
constants, variables, nets,* and *attributes.* The following are described here:

- Constants, below

- Variables, on page 155

- Nets, on page 155

- Data Types in Parameters, on page 156

- Type Parameters, on page 160

Constants

Constants are named data variables, which never change. A typical example for declaring a constant is as follows:

```
const a = 10;

const logic  [3:0] load = 4'b1111;

const reg  [7:0] load1 = 8'h0f, dataone = '1;
```

The Verilog compiler generates an error if constant is assigned a value.

```
const shortint a = 10;
assign a = '1;      // This is illegal
```

Variables

Variables can be declared two ways:

Method 1	Method 2

shortint a, b;
logic [1:0] c, d;
	var logic [15:0] a;
	var a,b; // equivalent var logic a, b
	var [1:0] c, d; // equivalent var logic [1:0] c, d
	input var shortint datain1,datain2;
	output var logic [15:0] dataout1,dataout2;

Method 2 uses the keyword var to preface the variable. In this type of declaration, a data type is optional. If the data type is not specified, logic is inferred.

Typical module declaration:

```
module test01 (input var shortint datain1,datain2,
   output var logic [15:0] dataout1,dataout2 );
```

A variable can be initialized as follows:

```
var  a = 1'b1;
```

Nets

Nets are typically declared using the wire keyword. Any 4-state data type can be used to declare a net.

```
wire logic tmp;
```

However, a lexical restriction applies to a net or port declaration. The Verilog net type keyword wire cannot be followed by reg.

```
input wire reg a; // Illegal
```

Data Types in Parameters

In SystemVerilog with different data types being introduced, the *parameter* can be of any data type (i.e., language-defined data type, user-defined data type, and packed/unpacked arrays and structures). By default, parameter is the int data type.

Syntax

parameter *dataType varaibleName* **=** *value*

In the above syntax, *dataType* is a language-defined data type, user-defined data type, or a packed/unpacked structure or array.

Example – Parameter is of Type longint

```
//TECHPUBS Example: Parameter of Type longint

module sub

#(parameter longint ParamLongint = 64'd25)

    (input clk,

     input rst,

     input longint d1 ,

     output longint q1 );


always_ff@(posedge clk)

begin

if(rst)

    begin
```

```
            q1 <= ParamLongint;

        end

    else

        begin

            q1 <= d1;

        end

    end

    endmodule
```

Example – Parameter is of Type enum

```
    //TECHPUBS Example: Parameter of Type enum

    typedef enum {s1,s2,s3=24,s4=15,s5} enum_dt;

    module sub

    #(parameter enum_dt ParamEnum = s4)

        (input clk,

         input rst,

         input enum_dt d1,

         output enum_dt q1 );


    always_ff@(posedge clk)

    begin

    if(rst)

        begin

            q1 <= ParamEnum;

        end

    else

        begin

            q1 <= d1;
```

```
        end

    end

    endmodule
```

Example – Parameter is of Type structure

```
//TECHPUBS Example: Parameter of Type structure

typedef byte unsigned Byte_dt;

typedef struct packed

    {shortint R;

     logic signed [4:3] G;

     bit [15:0] B;

     Byte_dt Y;

    }Struct_dt;


module sub

#(parameter Struct_dt ParamStruct ='{16'd128,2'd2,12'd24,8'd123})

    (

    //Input

     input clk,

     input rst,

     input Struct_dt d1,

    //Output

     output Struct_dt q1 );


always_ff@(posedge clk or posedge rst)

begin

if(rst)
```

```
        begin

           q1 <= ParamStruct;

        end

    else

        begin

           q1 <= d1 ;

        end

    end

    endmodule
```

Example – Parameter is of Type longint Unpacked Array

```
//TECHPUBS Example: Parameter of Type longint Unpacked Array

module sub

#(parameter longint ParamMyLongint [0:1] ='{64'd1124,64'd1785})

    (input clk,

     input rst,

     input longint d1 [0:1],

     output longint q1 [0:1] );


    always_ff@(posedge clk)

    begin

    if(rst)

        begin

           q1 <= ParamMyLongint;

        end

    else

        begin
```

```
        q1 <= d1;

    end

end

endmodule
```

Type Parameters

SystemVerilog includes the ability for a parameter to also specify a data type. This capability allows modules or instances to have data whose type is set for each instance – these *type* parameters can have different values for each of their instances.

Note: Overriding a type parameter with a defparam statement is illegal.

Syntax

parameter type *typeIdentifierName* **=** *dataType***;**

localparam type *typeIdentifierName* **=** *dataType***;**

In the above syntax, *dataType* is either a language-defined data type or a user-defined data type.

Example – Type Parameter of Language-Defined Data Type

```
//TECHPUBS Example: Type Parameter of Language-Defined Data Type

//Compilation Unit

module top

#(

    parameter type PTYPE = shortint,

    parameter type PTYPE1 = logic[3:2][4:1] //parameter is of

        //2D logic type

)

(
```

```
//Input Ports

   input PTYPE din1_def,

   input PTYPE1 din1_oride,

//Output Ports

   output PTYPE dout1_def,

   output PTYPE1 dout1_oride

);

sub u1_def //Default data type

(

   .din1(din1_def),

   .dout1(dout1_def)

);

sub #

(

   .PTYPE(PTYPE1) //Parameter type is override by 2D Logic

)

u2_oride

(

   .din1(din1_oride),

   .dout1(dout1_oride)

);

endmodule

//Sub Module

module sub

#(

   parameter type PTYPE = shortint //parameter is of shortint type

)
```

```
(
//Input Ports

   input PTYPE din1,

//Output Ports

   output PTYPE dout1

);

always_comb

begin

   dout1 = din1 ;

end

endmodule

//Compilation Unit
module top
#(
   parameter type PTYPE = shortint,
   parameter type PTYPE1 = logic[3:2][4:1] //parameter is of
      //2D logic type
)
(
//Input Ports
   input PTYPE din1_def,
   input PTYPE1 din1_oride,

//Output Ports
   output PTYPE dout1_def,
   output PTYPE1 dout1_oride
);

sub u1_def //Default data type
(
   .din1(din1_def),
   .dout1(dout1_def)
);
```

```
sub #
(
    .PTYPE(PTYPE1) //Parameter type is override by 2D Logic
)
u2_oride
(
    .din1(din1_oride),
    .dout1(dout1_oride)
);

endmodule

//Sub Module
module sub
#(
    parameter type PTYPE = shortint //parameter is of shortint type
)
(
//Input Ports
    input PTYPE din1,
//Output Ports
    output PTYPE dout1
);

always_comb
begin
    dout1 = din1 ;
end
endmodule
```

Example – Type Parameter of User-Defined Data Type

```
//TECHPUBS Example: Type Parameter of User-Defined Data Type

//Compilation Unit

typedef logic [0:7]Logic_1DUnpack[2:1];

typedef struct {

    byte R;

    int B;

    logic[0:7]G;

}  Struct_dt;

module top
```

```
#(

   parameter type PTYPE = Logic_1DUnpack,

   parameter type PTYPE1 = Struct_dt

)

(

//Input Ports

   input PTYPE1    din1_oride,

//Output Ports

   output PTYPE1    dout1_oride

);

sub #

(

   .PTYPE(PTYPE1) //Parameter type is override by a structure type

)

u2_oride

(

   .din1(din1_oride),

   .dout1(dout1_oride)

);

endmodule

//Sub Module

module sub

#(

   parameter type PTYPE = Logic_1DUnpack // Parameter 1D

      // logic Unpacked data type

)

(
```

```
//Input Ports

   input PTYPE din1,

//Output Ports

   output PTYPE dout1

);

always_comb

begin

   dout1.R = din1.R;

   dout1.B = din1.B ;

   dout1.G = din1.G ;

end

endmodule

//Compilation Unit
typedef logic [0:7]Logic_1DUnpack[2:1];
typedef struct {
   byte R;
   int B;
   logic[0:7]G;
}  Struct_dt;

module top
#(
   parameter type PTYPE = Logic_1DUnpack,
   parameter type PTYPE1 = Struct_dt
)
(
//Input Ports
   input PTYPE1    din1_oride,
//Output Ports
   output PTYPE1    dout1_oride
);
```

```
sub #
(
    .PTYPE(PTYPE1) //Parameter type is override by a structure type
)
u2_oride
(
    .din1(din1_oride),
    .dout1(dout1_oride)
);

endmodule

//Sub Module
module sub
#(
    parameter type PTYPE = Logic_1DUnpack // Parameter 1D
        // logic Unpacked data type
)
(
//Input Ports
    input PTYPE din1,
//Output Ports
    output PTYPE dout1
);

always_comb
begin
    dout1.R = din1.R;
    dout1.B = din1.B ;
    dout1.G = din1.G ;
end
endmodule
```

Example – Type Local Parameter

```
//TECHPUBS Example: Type Local Parameter

//Compilation Unit

module sub

#(

parameter type PTYPE1 = shortint, //Parameter is of shortint type

parameter type PTYPE2 = longint //Parameter is of longint type

)
```

```
(

//Input Ports

   input PTYPE1 din1,

//Output Ports

   output PTYPE2 dout1

);

//Localparam type definitation

localparam type SHORTINT_LPARAM = PTYPE1;

SHORTINT_LPARAM sig1;

assign sig1 = din1;

assign dout1 = din1 * sig1;

endmodule

//Compilation Unit
module sub
#(
parameter type PTYPE1 = shortint, //Parameter is of shortint type
parameter type PTYPE2 = longint //Parameter is of longint type
)

(
//Input Ports
   input PTYPE1 din1,
//Output Ports
   output PTYPE2 dout1
);

//Localparam type definitation
localparam type SHORTINT_LPARAM = PTYPE1;
SHORTINT_LPARAM sig1;
assign sig1 = din1;
assign dout1 = din1 * sig1;
endmodule
```

Operators and Expressions

Topics in this section include:

Operators

SystemVerilog includes the C assignment operators and special bit-wise assignment operators:

+=, -=, *=, /=, %=, &=, |=, ^=, <<=, >>=, <<<=, >>>=

An assignment operator is semantically equivalent to a blocking assignment with the exception that the expression is only evaluated once.

Operator Example	Same as
A += 2;	A = A + 2;
B -= B;	B = B - A;
C *= B;	C = C * B;
D /= C;	D = D / C;
E %= D;	E = E % D;
F &= E;	F = F & E;
G |= F;	G = G | F;
H ^= G;	H = H ^ G;
I <<= H;	I = I << H;

Operator Example	Same as
`J >>= I;`	`J = J  >> I;`
`K <<<=J;`	`K = K  <<< J;`
`L >>>=K;`	`L = L  >>> K;`

In addition, SystemVerilog also has the increment/decrement operators *i++*, *i--*, *++i*, and *--i*.

Operator Example	Same as
`A++;`	A = A + 1;
`A--;`	A = A - 1;
`++A;`	Increment first and then use A
`--A;`	Decrement first and then use A

In the following code segment, out1 gets r1 and out2 gets the twice-decremented value of out1:

```
always @(*)
   begin
      out1 = r1--;
      out2 = --r1;
   end
```

Aggregate Expressions

Aggregate expressions (aggregate pattern assignments) are primarily used to initialize and assign default values to unpacked arrays and structures.

Syntax

SystemVerilog aggregate expressions are constructed from braces; an apostrophe prefixes the opening (left) brace.

'{ *listofValues* **}**

In the syntax, *listofValues* is a comma-separated list. SystemVerilog also provides a mechanism to initialize all of the elements of an unpacked array by specifying a default value within the braces using the following syntax:

'{ default: *value* **}**
'{ data type:*value* **}**
'{ index:*value* **}**

The aggregate (pattern) assignment can be used to initialize any of the following.

- a 2-dimensional unpacked array under a reset condition (see Initializing Unpacked Array Under Reset Condition example).

- all the elements of a 2-dimensional unpacked array to a default value using the default keyword under a reset condition (see Initializing Unpacked Array to Default Value example).

- a specific data type using the keyword for *type* instead of default (see Initializing Specific Data Type example).

Aggregate (pattern) assignment can also be specified in a package (see Aggregate Assignment in Package example) and in a compilation unit (see Aggregate Assignment in Compilation Unit example).

Example – Initializing Unpacked Array Under Reset Condition

```
//TECHPUBS Example - Initializing Unpacked Array Under Reset
Condition

parameter WIDTH = 2;

typedef reg [WIDTH-1:0] [WIDTH-1:0] MyReg;
```

```
module top (
    input logic Clk,
    input logic Rst,
    input MyReg DinMyReg,
    output MyReg DoutMyReg );
MyReg RegMyReg;


always@(posedge Clk, posedge Rst) begin
    if(Rst) begin
        RegMyReg <= `{2'd0, 2'd0};
        DoutMyReg <= `{2'd0, 2'd0};
    end
    else begin
        RegMyReg <= DinMyReg;
        DoutMyReg <= RegMyReg;
    end
end
endmodule
```

Example – Initializing Unpacked Array to Default Value

```
//TECHPUBS Example - Initializing Unpacked Array to Default Value
parameter WIDTH = 2;
typedef reg [WIDTH-1:0] [WIDTH-1:0] MyReg;
module top (
    input logic Clk,
    input logic Rst,
    input MyReg DinMyReg,
    output MyReg DoutMyReg );
```

```
    MyReg RegMyReg;


    always@(posedge Clk, posedge Rst) begin

        if(Rst) begin

            RegMyReg <= '{default:0};

            DoutMyReg <= '{default:0};

        end

        else begin

            RegMyReg <= DinMyReg;

            DoutMyReg <= RegMyReg;

        end

    end

    endmodule
```

Example – Initializing Specific Data Type

```
    //TECHPUBS Example - Initializing Specific Data Type

    parameter WIDTH = 2;

    typedef struct packed {

        byte r;

        byte g;

        byte b; }

    MyStruct [WIDTH-1:0];

    module top (

        input logic Clk,

        input logic Rst,

        input MyStruct DinMyStruct,

        output MyStruct DoutMyStruct );

    MyStruct StructMyStruct;
```

```
always@(posedge Clk, posedge Rst) begin

    if(Rst) begin

        StructMyStruct <= '{byte:0,byte:0};

        DoutMyStruct <= '{byte:0,byte:0};

    end

    else begin

        StructMyStruct <= DinMyStruct;

        DoutMyStruct <= StructMyStruct;

    end

end

endmodule
```

Example – Aggregate Assignment in Package

```
//TECHPUBS Example - Aggregate Assignment in Package

package MyPkg;

parameter WIDTH = 2;

    typedef struct packed {

        int r;

        longint g;

        byte b;

        int rr;

        longint gg;

        byte bb;

    } MyStruct [WIDTH-1:0];

const MyStruct VarMyStruct = '{int:1,longint:10,byte:8'h0B} ;

const MyStruct ConstMyStruct =

    '{int:1,longint:$bits(VarMyStruct[0].r),byte:8'hAB} ;
```

```
endpackage : MyPkg

import MyPkg::*;


module top (
    input logic Clk,
    input logic Rst,
    input MyStruct DinMyStruct,
    output MyStruct DoutMyStruct );
MyStruct StructMyStruct;


always@(posedge Clk, posedge Rst) begin
    if(Rst) begin
        StructMyStruct <= VarMyStruct;
        DoutMyStruct <= ConstMyStruct;
    end
    else begin
        StructMyStruct <= DinMyStruct;
        DoutMyStruct <= StructMyStruct;
    end
end
endmodule
```

Example – Aggregate Assignment in Compilation Unit

```
//TECHPUBS Example - Aggregate Assignment in Compilation Unit
// Start of compilation unit
parameter WIDTH = 2;
    typedef struct packed {
        int r;
```

```
        longint g;

        byte b;

        int rr;

        longint gg;

        byte bb;

    } MyStruct [WIDTH-1:0];

const MyStruct VarMyStruct = '{int:1,longint:10,byte:8'h0B} ;

const MyStruct ConstMyStruct =

    '{int:1,longint:$bits(VarMyStruct[0].r),byte:8'hAB} ;


module top (

    input logic Clk,

    input logic Rst,

    input MyStruct DinMyStruct,

    output MyStruct DoutMyStruct );

MyStruct StructMyStruct;


always@(posedge Clk, posedge Rst)

begin

    if(Rst) begin

        StructMyStruct <= VarMyStruct;

        DoutMyStruct <= ConstMyStruct;

    end

    else begin

        StructMyStruct <= DinMyStruct;

        DoutMyStruct <= StructMyStruct;

    end
```

```
    end

    endmodule
```

Streaming Operator

The streaming operator (**>>** or **<<**) packs the bit-stream type to a particular sequence of bits in a user-specified order. Bit-stream types can be any integral, packed or unpacked type or structure. The streaming operator can be used on either the left or right side of the expression.

The streaming operator determines the order of bits in the output data stream:

- The left-to-right operator (**>>**) arranges the output data bits in the same order as the input bit stream

- The right-to-left operator (**<<**) arranges the output data bits in reverse order from the input bit stream

Syntax

streamingExpression **::= {** *streamOperator* [*sliceSize*] *streamConcatenation* **}**

    streamOperator **::= >>** | **<<**

    sliceSize **::=** *dataType* | *constantExpression*

    streamConcatenation **::= {***streamExpression* {**,** *streamExpression*} **}**

        streamExpression **::=** *arrayRangeExpression*

When an optional *sliceSize* value is included, the stream is broken up into the slice-size segments prior to performing the specified streaming operation. By default, the *sliceSize* value is 1.

Usage

The streaming operator is used to:

- Reverse the entire data stream

- Bit-stream from one data type to other

When the slice size is larger than the data stream, the stream is left-justified and zero-filled on the right. If the data stream is larger than the left side variable, an error is reported.

Example – Packed type inputs/outputs with RHS operator

```
//TECHPUBS Example: Packed type inputs/outputs with RHS operator

module streaming

(

input longint a,

output longint str_rev,

output longint str

);


assign str_rev = {<< {a}};

assign str = {>> {a}};


endmodule
```

Example – Unpacked type inputs/outputs with RHS operator

```
//TECHPUBS Example: Unpacked type inputs/outputs with RHS operator

typedef logic [5:0]my_dt [1:0];


module streaming

(

input logic [5:0] a[1:0], //same layout - size same as the output

input logic [3:0] b[2:0], //different layout - same size as output

input logic [2:0]c[1:0], //different layout and size

output my_dt str_rev1,

output my_dt str_rev_difflay,
```

```
output my_dt str_rev_less

);


assign str_rev1 = {<<{a}};

assign str_rev_difflay = {<< {b}};

assign str_rev_less = {<< {c,2'b11}};


endmodule
```

Example – Packed type inputs/outputs with LHS operator

```
//TECHPUBS Example: Packed type inputs/outputs with LHS operator

module streaming

(

input byte a,

output byte str_rev,

output byte str

);


assign {>>{str}} = a;

assign {<<{str_rev}} = a;


endmodule
```

Example – Slice-size streaming with RHS operator

```
//TECHPUBS Example: Slice-size streaming with RHS operator

typedef shortint shortint_dt [2:1];

typedef byte byte_dt [1:2][3:2];

typedef struct {
```

```
        logic [3:0] a [2:1];

        byte b;

        shortint c[4:2]; }

    struct_dt;

    module streaming (

        input shortint_dt a,

        input  byte_dt b,

        output struct_dt c_pack,

        output struct_dt c_unpack );

    assign c_pack = {<< 5 {a}};

    assign c_unpack = {<< 2 {b}};

    endmodule
```

Example – Slice-size streaming with LHS slice operation

```
    //TECHPUBS Example: Slice-size streaming with LHS slice operation

    module streaming

    (

    input logic a[1:8],

    output logic signed [1:4] str_rev[1:2],

    output logic signed [1:4] str[1:2]

    );


    assign {>>4{str}} = a;

    assign {<<4{str_rev}} = a;


    endmodule
```

Set Membership Operator

The set membership operator, also referred to as the *inside* operator, returns the value TRUE when the expression value (i.e., the LHS of the operator) is present in the value list of the RHS operator. If the expression value is not present in the RHS operator, returns FALSE.

Syntax

(*expressionValue***) inside {***listofValues***}**

> *expressionValue* **::=** *singularExpression*
>
> *listofValues* **::=** *rangeofValues***,** *expressions***,** *arrayofAggregateTypes*

Example – Inside operator with dynamically changing input at LHS operator

```
//TECHPUBS Example - Inside operator with dynamic input at LHS
operator

module top

(

//Input

input byte din,

//Output

output logic dout

);


assign dout = din inside {8'd2, -8'd3, 8'd5};

endmodule
```

Example – Inside operator with expression at LHS operator

```
//TECHPUBS Example - Inside operator with expression at LHS
operator

module top

(
```

```
//Input

input byte din1,

input byte din2,

//Output

output logic dout

);


assign dout = (din1 | din2) inside {14,17,2,20};

endmodule
```

Example – Inside operator with dynamically changing input at LHS and RHS operators

```
//TECHPUBS Example – Inside operator with dynamic input at LHS and
RHS operators

module top

(

//Input

input byte din1,

input byte din2,

//Output

output logic dout

);


assign dout = (din1) inside {din2,105,-121,-116};

endmodule
```

Example – Inside operator with array of parameter at LHS operator

```
//TECHPUBS Example – Inside operator with array of parameter at LHS
operator

module top
```

```
(
//Input
input byte din1,
//Output
output logic dout
);


parameter byte param1[1:0] = '{8'd12,8'd111};
assign dout = (din1) inside {param1,121,-16};
endmodule
```

Type Operator

SystemVerilog provides a type operator as a way of referencing the data type of a variable or an expression.

Syntax

type(*dataType* | *expression***)**

>   *dataType* – a user-defined data type or language-defined data type

>   *expression* – any expression, variable, or port

An e*xpression* inside the type operator results in a self-determined type of expression; the expression is not evaluated. Also the *expression* cannot contain any hierarchical references.

Data Declaration

The type operator can be used while declaring signals, variables, or ports of a module/interface or a member of that interface.

Example – Using Type Operator to Declare Input/Output Ports

```
typedef logic signed[4:1]logicdt;
// Module top
module top(
    input type(logicdt) d1,
    output type(logicdt) dout1 );
type(logicdt) sig;
var type(logicdt) sig1;
assign sig  = d1;
assign sig1= d1+1'b1;
assign dout1= sig + sig1;
endmodule
```

Data Type Declaration

Defining of the user-defined data type can have the type operator, wherein a variable or another user-defined data type can be directly referenced while defining a data type using the type operator. The data type can be defined in the compilation unit, package, or inside the module or interface.

Example – Using Type Operator to Declare Unpacked Data Type

```
typedef logic[4:1] logicdt;
typedef type(logicdt)Unpackdt[2:1];

module top(
    input Unpackdt d1,
    output Unpackdt dout1 );
assign dout1[2] = d1[2];
assign dout1[1] = d1[1];
endmodule
```

Type Casting

The type operator can be used to directly reference the data type of a variable or port, or can be user-defined and used in type casting to convert either signed to unsigned or unsigned to signed.

Example – Using Type Operator to Reference Data Type

```
typedef logic [20:0]dt;
//Module top
module top (
    input byte d1,d2,
    output int unsigned dout1 );
assign dout1 = type(dt)'(d1 * d2);
endmodule
```

Defining Type Parameter/Local Parameter

The type operator can be used when defining a Type parameter to define the data type. The definition can be overridden based on user requirements.

Example – Using Type Operator to Declare Parameter Type Value

```
// Module top
module top(
    input byte a1,
    input byte a2,
    output shortint dout1 );
parameter type dtype = type(a1);
dtype sig1;
assign sig1 = a1;
assign dout1 = ~sig1;
endmodule
```

Comparison and Case Comparison

The type operator can be used to compare two types when evaluating a condition or a case statement.

Example – Using Type Operator in a Comparison

```
// Module top
module top (
    input byte d1,
    input shortint d2,
    output shortint dout1 );
```

```
always_comb begin
   if(type(d1) == type(d2))
      dout1 = d1;
   else
      dout1 = d2;
end
endmodule
```

Limitations

The type operator is not supported on complex expressions (for example type(d1*d2)).

Procedural Statements and Control Flow

Topics in this section include

- Do-While Loops, below
- For Loops, on page 188
- Unnamed Blocks, on page 191
- Block Name on end Keyword, on page 191
- Unique and Priority Modifiers, on page 192

Do-While Loops

The while statement executes a loop for as long as the loop-control test is true. The control value is tested at the *beginning* of each pass through the loop. However, a while loop does not execute at all if the test on the control value is false the first time the loop is encountered. This top-testing behavior can require extra coding prior to beginning the while loop, to ensure that any output variables of the loop are consistent.

SystemVerilog enhances the for loop and adds a do-while loop, the same as in C. The control on the do-while loop is tested at the *end* of each pass through the loop (instead of at the beginning). This implies that each time the loop is encountered in the execution flow, the loop statements are executed at least once.

Because the statements within a do-while loop are going to execute at least once, all the logic for setting the outputs of the loop can be placed inside the loop. This bottom-testing behavior can simplify the coding of while loops, making the code more concise and more intuitive.

Example – Simple Do-while Loop

```
//TECHPUBS Example - Simple do-while Loop

module src (in1,in2,out);

input [7:0] in1,in2;

output reg [7:0] out;

integer i;


always @ (in1,in2)

begin

   i = 0;

   do

      begin

         out[i] = in1[i] + in2[i];

         i = i+1;

      end

   while (i < 8 );

end

endmodule
```

Example – Do-while with If Else Statement

```
//TECHPUBS Example - Do-while with if-else Statement

module src (out, a, b, c, d, sel);

output [3:0] out;

input [3:0] a, b, c, d;
```

```
      input [3:0] sel;

      reg [3:0] out;

      integer i;


      always @ (a or b or c or d or sel)
         begin
         i=0;
         out = 4'b0000;
            do
               begin
                  if(sel == 4'b0001) out[i] = a[i];
                  else if(sel == 4'b0010) out[i] = b[i];
                  else if(sel == 4'b0100) out[i] = c[i];
                  else if(sel == 4'b1000) out[i] = d[i];
                  else out = 'bx;
               i= i+1;
               end
            while (i < 4);
         end
      endmodule
```

Example – Do-while with Case Statement

```
   //TECHPUBS Example - Do-while with case Statement
   module src (out, a, b, c, d, sel);
   output [3:0] out;
   input [3:0] a, b, c, d;
   input [3:0] sel;
   reg [3:0] out;
```

```
    integer i;


    always @ (a or b or c or d or sel)
       begin
       i=0;
       out = 3'b000;
          do
             begin
                case (sel)
                   4'b0001: out[i] = a[i];
                   4'b0010: out[i] = b[i];
                   4'b0100: out[i] = c[i];
                   4'b1000: out[i] = d[i];
                   default: out = 'bx;
                endcase
             i= i+1;
             end
          while (i < 4);
       end
    endmodule
```

For Loops

SystemVerilog simplifies declaring local variables for use in for loops. The declaration of the for loop variable can be made within the for loop. This eliminates the need to define several variables at the module level, or to define local variables within named begin...end blocks as shown in the following example.

Example – Simple for Loop

```
//TECHPUBS Example - Simple for Loop

module simpleloop (output reg [7:0]y, input [7:0]i, input clock);

always@(posedge clock)

begin : loop

    for (int count=0; count < 8; count=count+1) // SV code

    y[count]=i[count];

end

endmodule
```

A variable defined as in the example above, is local to the loop. References to the variable name within the loop see the local variable, however, reference to the same variable outside the loop encounters an error. This type of variable is created and initialized when the for loop is invoked, and destroyed when the loop exits.

SystemVerilog also enhances for loops by allowing more than one initial assignment statement. Multiple initial or step assignments are separated by commas as shown in the following example.

Example – For Loop with Two Variables

```
//TECHPUBS Example - For Loop with Two Variables

module twovarinloop (in1, in2, out1, out2);

parameter p1 = 3;

input [3:0] in1;

input [3:0] in2;

output [3:0] out1;

output [3:0] out2;

reg [3:0] out1;

reg [3:0] out2;


always @*
```

```
begin

   for (int i = 0, int j = 0; i <= p1; i++)

   begin

      out1[i] = in1[i];

      out2[j] = in2[j];

      j++;

   end

end

endmodule
```

Unnamed Blocks

SystemVerilog allows local variables to be declared in unnamed blocks.

Example – Local Variable in Unnamed Block

```
//TECHPUBS Example - Local Variable in Unnamed Block
module test(in1,out1);
input [2:0] in1;
output [2:0] out1;
integer i;
wire [2:0] count;
reg [2:0] temp;
assign count = in1;


always @ (count)
begin   // unnamed block
   integer i; //local variable
   for (i=0; i < 3; i = i+1)
      begin : foo
      temp = count + 1;
   end
end
assign out1 = temp;
endmodule
```

Block Name on end Keyword

SystemVerilog allows a block name to be defined after the end keyword when
the name matches the one defined on the corresponding begin keyword. This
means, you can name the start and end of a begin statement for a block. The

additional name does not affect the block semantics, but does serve to enhance code readability by documenting the statement group that is being completed.

Example – Including Block Name with end Keyword

```
//TECHPUBS Example - Including Block Name with end Keyword

module src (in1,in2,out1,out2);

input in1,in2;

output reg out1,out2;

reg a,b;

always@(in1,in2)

   begin : foo_in

      a = in1 & in2;

      b = in2 | in1;

   end : foo_in

always@(a,b)

   begin : foo_value

      out1 = a;

      out2 = b;

   end : foo_value

endmodule
```

Unique and Priority Modifiers

SystemVerilog adds unique and priority modifiers to use in case statements. The Verilog full_case and parallel_case statements are located inside of comments and are ignored by the Verilog simulator. For synthesis, full_case and parallel_case directives instruct the tool to take certain actions or perform certain optimizations that are unknown to the simulator.

To prevent discrepancies when using full_case and parallel_case directives and to ensure that the simulator has the same understanding of them as the synthesis tool, use the priority or unique modifier in the case statement. The priority and unique keywords are recognized by all tools, including the Verilog simulators, allowing all tools to have the same information about the design.

The following table shows how to substitute the SystemVerilog unique and priority modifiers for Verilog full_case and parallel_case directives for synthesis.

Verilog using full_case, parallel_case	SystemVerilog using unique/priority case modifiers

`case (...)`
`...`
`endcase`
	`case (...)`
	`...`
	`endcase`

`case (...) //full_case`
`...`
`endcase`
	`priority case (...)`
	`...`
	`endcase`

`case (...) //parallel_case`
`...`
`endcase`
	`unique case (...)`
	`...`
	`default : ...`
	`endcase`

`case (...) //full_case`
`parallel_case`
`...`
`endcase`
	`unique case (...)`
	`...`
	`endcase`

Example – Unique Case

```
//TECHPUBS Example - Unique case

module src (out, a, b, c, d, sel);

output out;

input a, b, c, d;

input [3:0] sel;

reg out;
```

```
always @ (a,b,c,d,sel)

   begin

      unique case (sel)

         4'b0001: out = c;

         4'b0010: out = b;

         4'b0100: out = d;

         4'b1000: out = a;

      endcase

   end

endmodule
```

Example – Priority Case

```
//TECHPUBS Example - Priority case

module src (out, a, b, c, d, sel);

output out;

input a, b, c, d;

input [3:0] sel;reg out;


always @ (a,b,c,d,sel)

   begin

      priority case (sel)

         4'b0000: out = c;

         4'b0001: out = b;

         4'b0100: out = d;

         4'b1000: out = a;

      endcase

   end

endmodule
```

Processes

In Verilog, an "if" statement with a missing "else" condition infers an unintentional latch element, for which the Synopsys FPGA compiler currently generates a warning. Many commercially available compilers do not generate any warning, causing a serious mismatch between intention and inference. SystemVerilog adds three specialized procedural blocks that reduce ambiguity and clearly indicate the intent:

- always_comb, on page 195

- always_latch, on page 198

- always_ff, on page 200

Use them instead of the Verilog general purpose always procedural block to indicate design intent and aid in the inference of identical logic across synthesis, simulation, and formal verification tools.

always_comb

The SystemVerilog always_comb process block models combinational logic, and the logic inferred from the always_comb process must be combinational logic. The Synopsys FPGA compiler warns you if the behavior does not represent combinational logic.

The semantics of an always_comb block are different from a normal always block in these ways:

- It is illegal to declare a sensitivity list in tandem with an always_comb block.

- An always_comb statement cannot contain any block, timing, or event controls and fork, join, or wait statements.

Note the following about the always_comb block:

- There is an inferred sensitivity list that includes all the variables from the RHS of all assignments within the always_comb block and variables used to control or select assignments See Examples of Sensitivity to LHS and RHS of Assignments, on page 198.

- The variables on the LHS of the expression should not be written by any other processes.

- The always_comb block is guaranteed to be triggered once at time zero after the initial block is executed.

- always_comb is sensitive to changes within the contents of a function and not just the function arguments, unlike the always@(*) construct of Verilog 2001.

Example – always_comb Block

```
//TECHPUBS Example - always_comb Block

module test01 (a, b, out1);

input a,b;

output out1;

reg out1;

always_comb

begin

   out1 = a & b;

end

endmodule
```

Invalid Use of always_comb Block

The following code segments show use of the construct that are *NOT VALID*.

```
always_comb @(a or b) //Wrong. Sensitivity list is inferred not
   //declared
begin
   foo;
end

always_comb
begin
   @clk out <=in; //Wrong to use trigger within this always block
end

always_comb
begin
```

```
      fork //Wrong to use fork-join within this always block
      out <=in;
      join
   end

   always_comb
   begin
      if(en)mem[waddr]<=data; //Wrong to use trigger conditions
         //within this block
   end
```

Examples of Sensitivity to LHS and RHS of Assignments

In the following code segment, sensitivity only to the LHS of assignments causes problems.

```
always @(y)
   if (sel)
      y= a1;
   else
      y= a0;
```

In the following code segment, sensitivity only to the RHS of assignments causes problems.

```
always @(a0, a1)
   if (sel)
      y= a1;
   else
      y= a0;
```

In the following code segment, sensitivity to the RHS of assignments and variables used in control logic for assignments produces correct results.

```
always @(a0, a1, sel)
   if (sel)
      y= a1;
   else
      y= a0;
```

always_latch

The SystemVerilog always_latch process models latched logic, and the logic inferred from the always_latch process must only be latches (of any kind). The Synopsys FPGA compiler warns you if the behavior does not follow the intent.

Note the following:

- It is illegal for always_latch statements to contain a sensitivity list, any block, timing, or event controls, and fork, join, or wait statements.

- The sensitivity list of an always_latch process is automatically inferred by the compiler and the inferring rules are similar to the always_comb process (see always_comb, on page 195).

Example – always_latch Block

```
//TECHPUBS Example - always_latch Block

module Test01 (a,b,clk,out1);

input a,b,clk;

output out1;

reg out1;


always_latch

begin

    if(clk)

    begin

        out1 <= a & b;

    end

end

endmodule
```

Invalid Use of always_latch Block

The following code segments show use of the construct that are *NOT VALID*.

```
always_latch
begin
   if(en)
      treg<=1;
   else
      treg<=0; //Wrong to use fully specified if statement
end

always_latch
begin
   @(clk)out <=in; //Wrong to use trigger events within this
      //always block
end
```

always_ff

The SystemVerilog always_ff process block models sequential logic that is triggered by clocks. The compiler warns you if the behavior does not represent the intent. The always_ff process has the following restrictions:

- An always_ff block must contain only one event control and no blocking timing controls.

- Variables on the left side of assignments within an always_ff block must not be written to by any other process.

Example – always_ff Block

```
//TECHPUBS Example - always_ff Block

module Test01 (a,b,clk,out1);

input a,b,clk;

output out1;

reg out1;

always_ff@(posedge clk)

   out1 <= a & b;

endmodule
```

Invalid Use of always_ff Block

The following code segments show use of the construct that are *NOT VALID*.

```
always_ff @(posedge clk or negedge rst)
begin
   if(rst)
      treg<=in; //Illegal; wrong polarity for rst in the
         //sensitivity list and the if statement
end

always_ff
begin
   @(posedgerst)treg<=0;
   @(posedgeclk)treg<=in; //Illegal; two event controls
end

always_ff @(posedge clk or posedge rst)
begin
   treg<=0; //Illegal; not clear which trigger is to be
               // considered clk or rst
end
```

Tasks and Functions

Support for task and function calls includes the following:

-
-
-

Implicit Statement Group

Multiple statements in the task or function definition do not need to be placed within a begin…end block. Multiple statements are implicitly grouped, executed sequentially as if they are enclosed in a begin…end block.

```
/* Statement grouping */
function int incr2(int a);
   incr2 = a + 1;
   incr2 = incr2 + 1;
endfunction
```

Formal Arguments

This section includes information on passing formal arguments when calling functions or tasks. Topics include:

-
-
-

Passing Arguments by Name

When a task or function is called, SystemVerilog allows for argument values to be passed to the task/function using formal argument names; order of the formal arguments is not important. As in instantiations in Verilog, named argument values can be passed in any order, and are explicitly passed through to the specified formal argument. The syntax for the named argument passing is the same as Verilog's syntax for named port connections to a module instance. For example:

```
/* General functions */
function [1:0] inc(input [1:0] a);
   inc = a + 1;
endfunction
function [1:0] sel(input [1:0] a, b, input s);
   sel = s ? a : b;
endfunction

/* Tests named connections on function calls */
assign z0 = inc(.a(a));
assign z2 = sel(.b(b), .s(s), .a(a));
```

Default Direction and Type

In SystemVerilog, input is the default direction for the task/function declaration. Until a formal argument direction is declared, all arguments are assumed to be inputs. Once a direction is declared, subsequent arguments will be the declared direction, the same as in Verilog.

The default data type for task/function arguments is logic, unless explicitly declared as another variable type. (In Verilog, each formal argument of a task/function is assumed to be reg). For example:

```
/* Tests default direction of argument */
function int incr1(int a);
   incr1 = a + 1;
endfunction
```

In this case, the direction for a is input even though this is not explicitly defined.

Default Values

SystemVerilog allows an optional default value to be defined for each formal argument of a task or function. The default value is specified using a syntax similar to setting the initial value of a variable. For example:

```
function int testa(int a = 0, int b, int c = 1);
   testa = a + b + c;
endfunction

task testb(int a = 0, int b, int c = 1, output int d);
   d = a + b + c;
endtask
```

When a task/function is called, it is not necessary to pass a value to the arguments that have default argument values. If nothing is passed to the task/function for that argument position, the default value is used. Specifying default argument values allows a task/function definition to be used in multiple ways. Verilog requires that a task/function call have the exact same number of argument expressions as the number of formal arguments. SystemVerilog allows the task/function call to have fewer argument expressions than the number of formal arguments. A task/function call must pass a value to an argument, if the formal definition of the argument does not have a default value. Consider the following examples:

```
/* functions With positional associations and missing arguments */
assign a = testa(,5); /* Same as testa(0,5,1) */
assign b = testa(2,5); /* Same as testa(2,5,1) */
assign c = testa(,5,); /* Same as testa(0,5,1) */
assign d = testa(,5,7); /* Same as testa(0,5,7) */
assign e = testa(1,5,2); /* Same as testa(1,5,2) */

/* functions With named associations and missing arguments */
assign k = testa(.b(5)); /* Same as testa(0,5,1) */
assign l = testa(.a(2),.b(5)); /* Same as testa(2,5,1) */
assign m = testa(.b(5)); /* Same as testa(0,5,1) */
assign n = testa(.b(5),.c(7)); /* Same as testa(0,5,7) */
assign o = testa(.a(1),.b(5),.c(2)); /* Same as testa(1,5,2) */
```

In general, tasks are not supported outside the scope of a procedural block (even in previous versions). This is primarily due to the difference between tasks and function.

Here are some task examples using default values:

```
always @(*)
begin
/* tasks With named associations and missing arguments */
testb(.b(5),.d(f)); /* Same as testb(0,5,1) */
testb(.a(2),.b(5),.d(g)); /* Same as testb(2,5,1) */
testb(.b(5),.d(h)); /* Same as testb(0,5,1) */
testb(.b(5),.c(7),.d(i)); /* Same as testb(0,5,7) */
testb(.a(1),.b(5),.c(2),.d(j)); /* Same as testb(1,5,2) */

/* tasks With positional associations and missing arguments */
testb(,5,,p); /* Same as testb(0,5,1) */
testb(2,5,,q); /* Same as testb(2,5,1) */
testb(,5,,r); /* Same as testb(0,5,1) */
testb(,5,7,s); /* Same as testb(0,5,7) */
testb(1,5,2,t); /* Same as testb(1,5,2) */
```

endtask /endfunction Names

SystemVerilog allows a name to be specified with the endtask or endfunction
keyword. The syntax is:

endtask : *taskName*

endfunction : *functionName*

The space before and after the colon is optional. The name specified must be
the same as the name of the corresponding task or function as shown in the
following example.

```
/* Function w/ statement grouping, also has an endfunction label */

function int incr3(int a);
   incr3 = a + 1;
   incr3 = incr3 + 1;
   incr3 = incr3 + 1;
endfunction : incr3

/* Test with a task - also has an endtask label */
task task1;
input [1:0] in1,in2,in3,in4;
output [1:0] out1,out2;
   out1 = in1 | in2;
   out2 = in3 & in4;
endtask : task1
```

```
/* Test with a task - some default values */
task task2(
input [1:0] in1=2'b01,in2= 2'b10,in3 = 2'b11,in4 = 2'b11,
output [1:0] out1 = 2'b10,out2);

   out2 = in3 & in4;
endtask : task2

/* Tests default values for arguments */
function int dflt0(input int a = 0, b = 1);
   dflt0 = a + b;
endfunction

/* Call to function with default direction */
assign z1 = incr1(3);
assign z3 = incr2(3);
assign z4 = incr3(3);
assign z9 = dflt0();
assign z10 = dflt0(.a(7), .b());
always @(*)
begin
   task1(.in1(in1), .out2(z6), .in2(in2), .out1(z5),
      .in3(in3), .in4(in4));
   task1(in5, in6, in7, in8, z7, z8);
   task2(in5, in6, in7, in8, z11, z12);
   task2(in5, in6, , , z13, z14);
   task2(.out1(z15), .in1(in5), .in2(in6), .out2(z16),
      .in3(in7), .in4(in8));
   task2(.out2(z18), .in2(in6), .in1(in5), .in3(),
      .out1(z17), .in4());
end
```

Hierarchy

Topics in this section include:

- Compilation Units, below

- Packages, on page 213

- Port Connection Constructs, on page 222

- Extern Module, on page 224

Compilation Units

Compilation units allow declarations to be made outside of a package, module, or interface boundary. These units are visible to all modules that are compiled at the same time.

A compilation unit's scope exists only for the source files that are compiled at the same time; each time a source file is compiled, a compilation unit scope is created that is unique to only that compilation.

Syntax

//$unit definitions

*declarations***;**

//End of $unit

module ();
. . .
. . .
. . .
endmodule

In the above syntax, declarations can be variables, nets, constants, user-defined data types, tasks, or functions

Usage

Compilation units can be used to declare variables and nets, constants, user-defined data types, tasks, and functions as noted in the following examples.

A variable can be defined within a module as well as within a compilation unit. To reference the variable from the compilation unit, use the **$unit::***variableName* syntax. To resolve the scope of a declaration, local declarations must be searched first followed by the declarations in the compilation unit scope.

Example – Compilation Unit Variable Declaration

```
//TECHPUBS Example - Compilation Unit Variable Declaration

//$unit begins

logic foo_logic = 1'b1;
```

```
//$unit ends

module test (

input logic data1,

input clk,

output logic out1 );


always @(posedge clk)

begin

    out1 <= data1 ^ foo_logic;

end

endmodule
```

Example – Compilation Unit Net Declaration

```
//TECHPUBS Example - Compilation Unit Net Declarations

//$unit

wire foo = 1'b1;

//End of $unit

module test (

input data,

output dout );

assign dout = data * foo;

endmodule
```

Example – Compilation Unit Constant Declaration

```
//TECHPUBS Example - Compilation Unit Constant Declaration

//$unit begin

const bit foo_bit = "11";

const byte foo_byte = 8'b00101011;
```

```
//$unit ends

module test (clk, data1, data2, out1, out2);

input clk;

input bit data1;

input byte data2;

output bit out1;

output byte out2;


always @(posedge clk)

begin

   out1 <= data1 | foo_bit;

   out2 <= data2 & foo_byte;

end

endmodule
```

Example – Compilation Unit User-defined Datatype Declaration

```
//TECHPUBS Example - Compilation Unit User-defined Datatype
Declaration

//$unit begins

typedef struct packed {

int a;

int b;} my_struct;

//End of $unit

module test (p,q,r);

input my_struct p;

input my_struct q;

output int r;

assign r = p.a * q.b;
```

```
endmodule
```

Example – Compilation Unit Task Declaration

```
//TECHPUBS Example - Compilation Unit Task Declaration
parameter FACT_OP = 2;
task automatic factorial(input integer operand,
    output [1:0] out1);
integer nFuncCall = 0;
begin
    if (operand == 0)
    begin
        out1 = 1;
    end
    else
    begin
        nFuncCall++;
        factorial((operand-1), out1);
        out1 = out1 * operand;
    end
end
endtask

module src (input [1:0] a, input [1:0] b, output logic [2:0] out);
logic [1:0] out_tmp;
always_comb
factorial(FACT_OP,out_tmp);
assign out = a + b + out_tmp;
endmodule
```

Example – Compilation Unit Function Declaration

```
//TECHPUBS Example - Compilation Unit Function Declaration

parameter fact = 2;

function automatic [63:0] factorial;

input [31:0] n;

    if (n==1)

        return (1);

    else

        return (n * factorial(n-1));

endfunction


module src (input [1:0] a, input [1:0] b, output logic [2:0] out);

always_comb

begin

    out = a + b + factorial(fact);

end

endmodule
```

Example – Compilation Unit Access

```
//TECHPUBS Example - Compilation Unit Access

//$unit_4_state begin

logic foo_logic = 1'b1;

//$unit_4_state ends

module test (

input logic data1,

input clk,

output logic out1,out1_local );

//local variables
```

```
    logic foo_logic = 1'b0;

    ///////

    always @(posedge clk)

    begin

        out1 <= data1 ^ $unit::foo_logic; //Referencing

            //the compilation unit value.

        out1_local <= data1 ^ foo_logic; //Referencing the

            //local variable.

    end

    endmodule
```

Example – Compilation Unit Scope Resolution

```
    //TECHPUBS Example - Compilation Unit Scope Resolution

    //$unit begins

    parameter width = 4;

    //$unit ends

    module test (data,clk,dout);

    parameter width = 8; // local parameter

    input logic [width-1:0] data;

    input clk;

    output logic [width-1:0] dout;


    always @(posedge clk)

    begin

        dout <= data;

    end

    endmodule
```

To use the compilation unit for modules defined in multiple files, enable the Multiple File Compilation Unit check box on the Verilog tab of the Implementation Options dialog box as shown below.
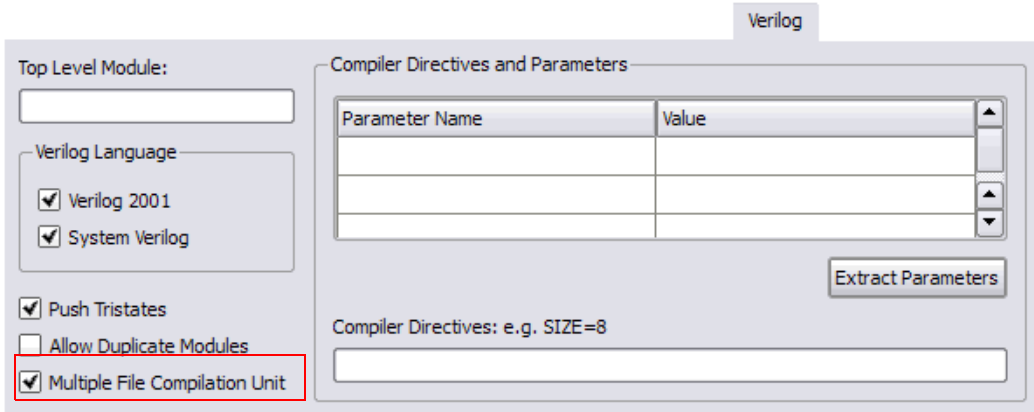
You can also enable this compiler directive by including the following Tcl command in your project (prj) file:

```
set_option -multi_file_compilation_unit 1
```

Limitations

Compilation unit elements can only be accessed or read, and cannot appear between module and endmodule statements.

Packages

Packages permit the sharing of language-defined data types, typedef user-defined types, parameters, constants, function definitions, and task definitions among one or more compilation units, modules, or interfaces. The concept of packages is leveraged from the VHDL language.

Syntax

SystemVerilog packages are defined between the keywords package and endpackage.

package packageIdentifier**;**

    packageItems

endpackage : packageIdentifier

PackageItems includes user-defined data types, parameter declarations, constant declarations, task declarations, function declarations, and import statements from other packages. To resolve the scope of any declaration, the local declarations are always searched before declarations in packages.

Referencing Package Items

As noted in the following examples, package items can be referenced by:

- Direct reference using a scope resolution operator (::). The scope resolution operator allows referencing a package by the package name and then selecting a specific package item.

- Importing specific package items using an import statement to import specific package items into a module.

- Importing package items using a wildcard (*) instead of naming a specific package item.

Example – Direct Reference Using Scope Resolution Operator (::)

```
//TECHPUBS Example - Direct Reference Using Scope Resolution
Operator (::)

package mypack;

logic foo_logic = 1'b1;

endpackage

module test (

input logic data1,

input clk,

output logic out1 );


always @(posedge clk)

begin
```

```
        out1 <= data1 ^ mypack::foo_logic;

    end

    endmodule
```

Example – Importing Specific Package Items

```
//TECHPUBS Example - Importing Specific Package Items

package mypack;

logic foo_logic = 1'b1;

endpackage

module test (

input logic data1,

input clk,

output logic out1 );

import mypack::foo_logic;


always @(posedge clk)

begin

    out1 <= data1 ^ foo_logic;

end

endmodule
```

Example – Wildcard (*) Import Package Items

```
//TECHPUBS Example - Wildcard (*) Import Package Items

package mypack;

logic foo_logic = 1'b1;

endpackage

module test (

input logic data1,
```

```
    input clk,

    output logic out1 );

    import mypack::*;


    always @(posedge clk)

    begin

        out1 <= data1 ^ foo_logic;

    end

    endmodule
```

Example – User-defined Data Types (typedef)

```
//TECHPUBS Example - User-defined Data Types (typedef)

package mypack;

typedef struct packed {

    int a;

    } my_struct;

endpackage

import mypack::my_struct;


module test (inp1,inp2,out);

input my_struct inp1;

input my_struct inp2;

output int out;

assign out = inp1.a * inp2.a;

endmodule
```

Example – Parameter Declarations

```
//TECHPUBS Example - Parameter Declarations
```

```
package mypack;

parameter a_width = 4;

parameter b_width = 4;

localparam product_width = a_width+b_width;

endpackage

import mypack::*;


module test (

input [a_width-1:0] a,

input [b_width-1:0] b,

output [product_width-1:0] c );

assign c = a * b;

endmodule
```

Example – Constant Declarations

```
//TECHPUBS Example - Constant Declarations

package my_pack;

const logic foo_logic = 1'b1;

endpackage

import my_pack::*;


module test (

input logic inp,

input clk,

output logic out );


always @(posedge clk)

begin
```

```
        out <= inp ^ foo_logic;
    end

    endmodule
```

Example – Task Declarations

```
    //TECHPUBS Example - Task Declarations

    package mypack;

    parameter FACT_OP = 2;

        task automatic factorial(input integer operand,

            output [1:0] out1);

        integer nFuncCall = 0;

        begin

        if (operand == 0)

            begin

                out1 = 1;

            end

        else

            begin

                nFuncCall++;

                factorial((operand-1), out1);

                out1 = out1 * operand;

            end

        end

        endtask

    endpackage

    import mypack::*;


    module src (input [1:0] a, input [1:0] b,
```

```
      output logic [2:0] out );
logic [1:0] out_tmp;


always_comb
factorial(FACT_OP,out_tmp);
assign out = a + b + out_tmp;
endmodule
```

Example – Function Declarations

```
//TECHPUBS Example - Function Declarations
package automatic_func;
parameter fact = 2;
function automatic [63:0] factorial;
input [31:0] n;
if (n==1)
   return (1);
else
   return (n * factorial(n-1));
endfunction
endpackage


import automatic_func::*;
module src (input [1:0] a, input [1:0] b,
   output logic [2:0] out );
always_comb
begin
   out = a + b + factorial(fact);
end
```

```
endmodule
```

Example – import Statements from Other Packages

```
//TECHPUBS Example - Import Statements from Other Packages

package param;

parameter fact = 2;

endpackage

package automatic_func;

import param::*;

function automatic [63:0] factorial;

input [31:0] n;

   if (n==1)

      return (1);

   else

      return (n * factorial(n-1));

endfunction

endpackage


import automatic_func::*;

import param::*;

module src (input [1:0] a, input [1:0] b,

   output logic [2:0] out );

always_comb

begin

   out = a + b + factorial(fact);

end

endmodule
```

Example – Scope Resolution

```
//TECHPUBS Example - Scope Resolution

//local parameter overrides package parameter value (dout <=
data[7:0];)

package mypack;

parameter width = 4;

endpackage


import mypack::*;

module test (data,clk,dout);

parameter width = 8; // local parameter

input logic [width-1:0] data;

input clk;

output logic [width-1:0] dout;


always @(posedge clk)

begin

    dout <= data;

end

endmodule
```

Limitations

The variables declared in packages can only be accessed or read; package
variables cannot be written between a module statement and its end module
statement.

Port Connection Constructs

Instantiating modules with a large number of ports is unnecessarily verbose and error-prone in Verilog. The SystemVerilog *.name* and ".*" constructs extend the 1364 Verilog feature of allowing named port connections on instantiations, to implicitly instantiate ports.

.name Connection

The SystemVerilog *.name* connection is semantically equivalent to a Verilog named port connection of type *.port_identifier(name)*. Use the *.name* construct when the name and size of an instance port are the same as those on the module. This construct eliminates the requirement to list a port name twice when both the port name and signal name are the same and their sizes are the same as shown below:

```
module myand(input [2:0] in1, in2, output [2:0] out);
...
endmodule

module foo (….ports….)
wire [2:0] in1, out;
wire [7:0] tmp;
wire [7:0] in2 = tmp;
myand mand1(.in1, .out, .in2(tmp[2:0]));  // valid
```

Note: SystemVerilog *.name* connection is currently not supported for mixed-language designs.

Restrictions to the *.name* feature are the same as the restrictions for named associations in Verilog. In addition, the following restrictions apply:

- Named associations and positional associations cannot be mixed:

```
myand mand2(.in1, out, tmp[2:0]);
```

The syntax above is not valid because …

- Sizes must match in mixed named and positional associations. The example below is not valid because of the size mismatch on in2.

```
myand mand3(.in1, .out, .in2);
```

- The identifier referred by the *.name* must not create an implicit declaration, regardless of the compiler directive '*default_nettype*.

- You cannot use the *.name* connection to create an implicit cast.

- Currently, the *.name* port connection is not supported for mixed HDL source code.

.* Connection

The SystemVerilog ".*" connection is semantically identical to the default *.name* connection for every port in the instantiated module. Use this connection to implicitly instantiate ports when the instance port names and sizes match the connecting module's variable port names and sizes. The implicit .* port connection syntax connects all other ports on the instantiated module.Using the .* connection facilitates the easy instantiation of modules with a large number of ports and wrappers around IP blocks.

The ".*" connection can be freely mixed with *.name* and *.port_identifier*(*name*) type connections. However, it is illegal to have more than one ".*" expression per instantiation.

The use of ".*" facilitates easy instantiation of modules with a large number of ports and wrappers around IP blocks as shown in the code segment below:

```
module myand(input [2:0] in1, in2, output [2:0] out);
...
endmodule

module foo (….ports….)
wire [2:0] in1, in2, out;
wire [7:0] tmp;

myand and1(.*); // Correct usage, connect in1, in2, out
myand and2(.in1, .*) // Correct usage, connect in2 and out
myand and3(.in1(tmp[2:0]), .*); // Correct Usage, connect
    // in2 and out
myand and5(.in1, .in2, .out, .*); //Correct Usage, ignore the .*
```

Note: SystemVerilog ".*" connection is currently not supported for mixed-language designs.

Restrictions to the .* feature are the same as the restrictions for the *.name* feature. See *.name Connection, on page 222*. In addition, the following restrictions apply:

- Named associations and positional associations cannot be mixed. For example

    ```
    myand and4(in1, .*);
    ```

    is illegal (named and positional connections cannot be mixed)

- Named associations where there is a mismatch of variable sizes or names generate an error.

- You can only use the .* once per instantiation, although you can mix the .* connection with *.name* and *.port_identifier(name)* type connections.

- If you use a .* construction but all remaining ports are explicitly connected, the compiler ignores the .* construct.

- Currently, the .* port connection is not supported for mixed HDL source code.

Extern Module

SystemVerilog simplifies the compilation process by allowing you to specify a prototype of the module being instantiated. The prototype is defined using the extern keyword, followed by the declaration of the module and its ports. Either the Verilog-1995 or the Verilog-2001 style of module declaration can be used for the prototype.

The extern module declaration can be made in any module, at any level of the design hierarchy. The declaration is only visible within the scope in which it is defined. Support is limited to declaring extern module outside the module.

Syntax

extern module *moduleName* **(***direction port1***,** *direction portVector port2***,**
*direction port3***);**

Example 1 – Extern Module Instantiation

```
//TECHPUBS Example - Extern Module Instantiation

extern module top (input logic clock, load,
```

```
      input reset, input logic [3:0] d,

      output logic [3:0] cnt);

   module top ( .* );

   always @(posedge clock or posedge reset)

      begin

      if (reset)

         cnt <= 0;

      else if (load)

         cnt <= d;

      else cnt <= cnt + 1;

      end

   endmodule
```

Example 2 – Extern Module Reference

```
   //TECHPUBS Example - Extern Module Reference

   extern module counter (clock, load, reset, d, cnt);

   module top (clock, load, reset, d, cnt);

   input logic clock, load;

   input reset;

   input logic [3:0] d;

   output logic [3:0] cnt;

   counter cnt1 (.clock(clock), .load(load), .reset(reset),

      .d(d), .cnt(cnt) );

   endmodule

   module counter (clock, load, reset, d, cnt );

   input logic clock, load;

   input reset;

   input logic [3:0] d;
```

```
output logic [3:0] cnt;

always @(posedge clock or posedge reset)

begin

   if (reset)

      cnt <= 0;

   else if (load)

      cnt <= d;

   else cnt <= cnt + 1;

end

endmodule
```

Limitations

An extern module declaration is not supported within a module.

Interface

Topics in this section include:

- Interface Construct, below
- Modports, on page 233
- Limitations and Non-Supported Features, on page 235

Interface Construct

SystemVerilog includes enhancements to Verilog for representing port lists and port connection lists characterized by name repetition with a single name to reduce code size and simplify maintenance. The interface and modport structures in SystemVerilog perform this function. The interface construct includes all of the characteristics of a module with the exception of module instantia-

tion; support for interface definitions is the same as the current support for module definitions. Interfaces can be instantiated and connected to client modules using generates.

Interface Definition: Internal Logic and Hierarchical Structure

Per the SystemVerilog standard, an interface definition can contain any logic that a module can contain with the exception that interfaces cannot contain module instantiations. An interface definition can contain instantiations of other interfaces. Like modules, interface port declaration lists can include interface-type ports. Synthesis support for interface logic is the same as the current support for modules.

Port Declarations and Port Connections for Interfaces

Per the SystemVerilog standard, interface port declaration and port connection syntax/semantics are identical to those of modules.

Interface Member Types

The following interface member types are visible to interface clients:

- 4-State var types: reg, logic, integer

- 2-State var types: bit, byte, shortint, int, longint

- Net types: wire, wire-OR, and wire-AND

- Scalars and 1-dimensional packed arrays of above types

- Multi-dimensional packed and unpacked arrays of above types

- SystemVerilog struct types

Interface Member Access

The members of an interface instance can be accessed using the syntax:

interfaceRef.interfaceMemberName

In the above syntax, *interfaceRef* is either:

- the name of an interface-type port of the module/interface containing the member access

- the name of an interface instance that is instantiated directly within the module/interface containing the member access.

Note that reference to interface members using full hierarchical naming is not supported and that only the limited form described above for instances at the current level of hierarchy is supported.

Access to an interface instance by clients at lower levels of the design hierarchy is achieved by connecting the interface instance to a compatible interface-type port of a client instance and connecting this port to other compatible interface-type ports down the hierarchy as required. This chaining of interface ports can be done to an arbitrary depth. Note that interface instances can be accessed only by clients residing at the same or lower levels of the design hierarchy.

Interface-Type Ports

Interface-type ports are supported as described in the SystemVerilog standard, and generic interface ports are supported. A modport qualifier can appear in either a port declaration or a port connection as described in the SystemVerilog standard. Interface-type ports:

- can appear in either module or interface port declarations

- can be used to access individual interface items using "." syntax:

    interfacePortname.interfaceMemberName

- can be connected directly to compatible interface ports of module/interface instances

Interface/Module Hierarchy

Interfaces can be instantiated within either module or interface definitions. See Interface Member Access for additional details on hierarchical interface port connections.

Interface Functions and Tasks

Import-only functions and tasks (using import keyword in modport) are supported.

Element access outside the interface

Interface can have a collection of variables or nets, and this collection can be of a language-defined data type, user-defined data type, or array of language and user-defined data type. All of these variables can be accessed outside the interface.

The following example illustrates accessing a 2-dimensional structure type defined within the interface that is being accessed from another module.

Example – Accessing a 2-dimensional structure

```
typedef struct
{
   byte st1;
}Struct1D_Dt[1:0][1:0];
```

```
//Interface Definition
interface intf(
   input bit clk,
   input bit rst
);

   Struct1D_Dt i1; //2D - Structure type
   modport MP( input i1,input clk,input rst); //Modport Definition
endinterface

//Sub1 Module definition
module sub1(
   intf INTF1, //Interface
   input int d1
);

   assign INTF1.i1[1][1].st1 = d1[7:0];
   assign INTF1.i1[1][0].st1 = d1[15:8];
   assign INTF1.i1[0][1].st1 = d1[23:16];
   assign INTF1.i1[0][0].st1 = d1[31:24];
endmodule

//Sub2 Module definition
module sub2(
   intf.MP IntfMp, //Modport Interface
   output byte dout[3:0]
);

always_ff@(posedge IntfMp.clk)
begin
   if(IntfMp.rst)
   begin
      dout <= '{default:'1};
   end
   else begin
      dout[3] <= IntfMp.i1[1][1].st1;
      dout[2] <= IntfMp.i1[1][0].st1;
      dout[1] <= IntfMp.i1[0][1].st1;
      dout[0] <= IntfMp.i1[0][0].st1;
   end
end
endmodule

//Top Module definition
module top(
   input bit clk,
   input bit rst,
   input int d1,
```

```
        output byte dout[3:0]
    );
    intf intu1(.clk(clk),.rst(rst));
    sub1 sub1u1(.INTF1(intu1),.d1(d1));
    sub2 sub2u1(.IntfMp(intu1.MP),.dout(dout));
    endmodule
```

Nested Interface

With the nested interface feature, nesting of interface is possible by either
instantiating one interface in another or by using one interface as a port in
another interface. Generic interface is not supported for nested interface;
array of interface when using interface as a port also is not supported.

The following example illustrates the use of a nested interface. In the
example, one interface is instantiated within another interface and this top-
level interface is used in the modules.

Example – Nested Interface

```
    //intf1 Interface definition
    interface intf1;
        byte i11;
        byte i12;
    endinterface

    //IntfTop Top Interface definition
    interface IntfTop;
        intf1 intf1_u1(); //Interface instantiated
        shortint i21;
    endinterface

    //Sub1 Module definition
    module sub1(
        input byte d1,
        input byte d2,
        IntfTop intfN1
    );
    assign intfN1.intf1_u1.i11 = d1; //Nested interface being accessed
    assign intfN1.intf1_u1.i12 = d2; //Nested interface being accessed
    endmodule
```

```
    //Sub2 Module definition
    module sub2(
        IntfTop intfN2
    );
    assign intfN2.i21 = intfN2.intf1_u1.i11 + intfN2.intf1_u1.i12;
    //Nested
        //interface being accessed
    endmodule

    //Sub3 Module definition
    module sub3(
        IntfTop intfN3,
        output shortint dout
    );
    assign dout = intfN3.i21;
    endmodule

    //Top Module definition
    module top(
        input byte d1,
        input byte d2,
        output shortint dout
    );
    IntfTop IntfTopU1();
        sub1 sub1U1(.d1(d1),.d2(d2),.intfN1(IntfTopU1));
        sub2 sub2U1(.intfN2(IntfTopU1));
        sub3 sub3U1(.intfN3(IntfTopU1), .dout(dout));
    endmodule
```

Arrays of Interface Instances

In Verilog, multiple instances of the same module can be created using the array of instances concept. This same concept is extended for the interface construct in SystemVerilog to allow multiple instances of the same interface to be created during component instantiation or during port declaration. These arrays of interface instances and slices of interface instance arrays can be passed as connections to arrays of module instances across modules.

The following example illustrates the use of array of interface instance both during component instantiation and during port declaration.

Example – Array of interface during port declaration

```
//intf Interface Definition
interface intf;
   byte i1;
endinterface

//Sub1 Module definition
module sub1(
   intf IntfArr1 [3:0], //Array of interface during port
declaration
   input byte d1[3:0]
);
assign IntfArr1[0].i1 = d1[0];
assign IntfArr1[1].i1 = d1[1];
assign IntfArr1[2].i1 = d1[2];
assign IntfArr1[3].i1 = d1[3];
endmodule

//Sub2 Module definition
module sub2(
   intf IntfArr2[3:0], //Array of interface during port
declaration
   output byte dout[3:0]
);
assign dout[0] = IntfArr2[0].i1;
assign dout[1] = IntfArr2[1].i1;
assign dout[2] = IntfArr2[2].i1;
assign dout[3] = IntfArr2[3].i1;
endmodule

//Top module definition
module top(
   input byte d1[3:0],
   output byte dout[3:0]
);
intf intfu1[3:0](); //Array of interface instances
   sub1 sub1u1(intfu1,d1);
   sub2 sub2u1(intfu1,dout);
endmodule
```

Modports

Modport expressions are supported, and modport selection can be done in either the port declaration of a client module or in the port connection of a client module instance.

If a modport is associated with an interface port or instance through a client
module, the module can only access the interface members enumerated in
the modport. However, per the SystemVerilog standard, a client module is not
constrained to use a modport, in which case it can access any interface
members.

Modport Keywords

The input, output, inout, and import access modes are parsed without errors. The
signal direction for input, output, and inout is ignored during synthesis, and the
correct signal polarity is inferred from how the interface signal is used within
the client module. The signal polarity keywords are ignored because the
precise semantics are currently not well-defined in the SystemVerilog
standard, and simulator support has yet to be standardized.

Example – Instantiating an interface Construct

```
//TECHPUBS Example - Instantiating an interface Construct

//TECHPUBS The following example defines, accesses, and
instantiates an interface construct.

interface intf(input a, input b); //define the interface

logic a1, b1;

assign a1 = a;

assign b1 = b;

modport write (input a1, input b1); //define the modport

endinterface


module leaf(intf.write foo, output logic q); //access the intf
interface

assign q = foo.a1 + foo.b1;

endmodule


module top(input a, input b, output q);

intf inst_intf (a,b); //instantiate the intf interface
```

```
leaf leaf_inst (inst_intf.write,q);

endmodule
```

Limitations and Non-Supported Features

The following restrictions apply when using interface/modport structures:

- Declaring interface within another interface is not supported

- Direction information in modports has no effect on synthesis.

- Exported (export keyword) interface functions and tasks are not supported.

- Virtual interfaces are not supported.

- Full hierarchical naming of interface members is not supported.

- Modports defined within generate statements are not supported.

System Tasks and System Functions

Topics in this section include:

$bits System Function

SystemVerilog supports a $bits system function which returns the number of bits required to hold an expression as a bit stream. The syntax is:

> **$bits(***datatype***)**

> **$bits(***expression***)**

In the above syntax, *datatype* can be any language-defined data type (reg, wire, integer, logic, bit, int, longint, or shortint) or user-defined datatype (typedef, struct, or enum) and *expression* can be any value including packed and unpacked arrays.

The $bits system function is synthesizable and can be used with any of the following applications:

- Port Declaration
- Variable Declaration
- Constant Definition
- Function Definition

System tasks and system functions are described in Section 22 of IEEE Std 1800-2005 (IEEE Standard for SystemVerilog); $bits is described in Section 22.3.

Example – $bits System Function

```
//TECHPUBS Example - $bits System Function

module top (input logic Clk,

    input logic Rst,

    input logic [7:0] LogicIn,
```

```
      output logic [$bits(LogicIn)-1:0] LogicOut,

      output logic [7:0] LogicConstSize );

   logic [7:0] logic_const = 8'd0;


   always@(posedge Clk, posedge Rst) begin

      if(Rst) begin

         LogicConstSize <= 'd0;

         LogicOut <= logic_const;

      end

      else begin

         LogicConstSize <= $bits(logic_const);

         LogicOut <= $bits(LogicIn)-1 ^ LogicIn;

      end

   end

   endmodule
```

Example – $bits System Function within a Function

```
   //TECHPUBS Example - $bits System Function within a Function

   module top (input logic Clk,

      input logic Rst,

      input logic [7:0] LogicIn,

      output logic [$bits(LogicIn)-1:0] LogicOut,

      output logic [7:0] LogicSize  );

   function logic [$bits(LogicIn)-1:0]

      incr_logic (logic [7:0] a);

   incr_logic = a + 1;

   endfunction
```

```
always@(posedge Clk, posedge Rst) begin

   if(Rst) begin

      LogicSize <= 'd0;

      LogicOut <= 'd0;

   end

   else begin

      LogicSize <= $bits(LogicIn);

      LogicOut <= incr_logic(LogicIn);

   end

end

endmodule
```

Array Querying Functions

SystemVerilog provides system functions that return information about a particular dimension of an array.

Syntax

arrayQuery **(***arrayIdentifier*[**,***dimensionExpression*]**);**
arrayQuery **(***dataTypeName*[**,***dimensionExpression*]**);**
$dimensions | $unpacked_dimensions (*arrayIdentifier* | *dataTypeName***)**

In the above syntax, *arrayQuery* is one of the following array querying functions:

- **$left** - Returns the left bound (MSB) of the dimension.

- **$right** - Returns the right bound (LSB) of the dimension.

- **$low** – Returns the lowest value of the left and right bound dimension.

- **$high** – Returns the highest value of the left and right bound dimension.

- **$size** – Returns the number of elements in a given dimension.

- **$increment** – Returns a value "1" when the left bound is greater than or equal to the right bound, else it returns a value "-1".

In the third syntax example, $dimensions returns the total number of packed and unpacked dimensions in a given array, and $unpacked_dimensions returns the total number of unpacked dimensions in a given array. The variable *dimensionExpression*, by default, is "1". The order of dimension expression increases from left to right for both unpacked and packed dimensions, starting with the unpacked dimension for a given array.

Example 1 – Array Querying Function $left and $right Used on Packed 2D-data Type

```
//TECHPUBS Example - Array Querying Function $left and $right Used
on Packed 2D-data Type

module top

(

//Input

input logic[1:0][3:1]d1,

//Output

output byte q1_left,

output byte q1_right,

output byte q1_leftdimension

);

assign q1_left = $left(d1);

assign q1_right = $right(d1);

assign q1_leftdimension =$left(d1,2); // Dimension expression

    // returns value of the second dimension[3:1]

endmodule
```

Example 2 – Array Querying Function $low and $high Used on Unpacked 3D-data Type

```
//TECHPUBS Example - Array Querying Function $low and $high Used on
Unpacked 3D-data Type

module top

(
```

```
//Input

input logic d1[2:1][1:5][4:8],

//Output

output byte q1_low,

output byte q1_high,

output byte q1_lowdimension

);

assign q1_low = $low(d1);

assign q1_high = $high(d1);

assign q1_lowdimension = $low(d1,3); // Dimension expression

    // returns value for the third dimension (i.e.,[4:8])

endmodule
```

Example 3 – Array Querying Function $size and $increment Used on a Mixed Array

```
//TECHPUBS Example - Array Querying Function $size and $increment
Used on a Mixed Array

module top

(

//Input

input byte d1[4:1],

//Output

output byte q1_size,

output byte q1_increment );

assign q1_size = $size(d1);

assign q1_increment = $increment(d1);

endmodule
```

Example 4 – Array Querying Function $dimensions and $unpacked_dimensions Used on a Mixed Array

```
//TECHPUBS Example - Array Querying Function $dimensions and
$unpacked_dimensions Used on a Mixed Array

module top

(

//Input

input bit [1:2][4:1]d1[3:2][4:1],

//Output

output byte q1_dimensions,

output byte q1_unpacked_dimensions );

assign q1_dimensions = $dimensions(d1);

assign q1_unpacked_dimensions = $unpacked_dimensions(d1);

endmodule
```

Example 5 – Array Querying Function with Data Type as Input

```
//TECHPUBS Example - Array Querying Function with Data Type as
Input

//Data type

typedef bit [1:2][4:1]bit_dt[3:2][4:1];

module top

(

//Output

output byte q1_left,

output byte q1_low );

assign q1_left = $left(bit_dt);

assign q1_low = $low(bit_dt);

endmodule
```

Generate Statement

The synthesis tools support the Verilog 2005 generate statement, which conforms to the Verilog 2005 LRM. The tools also support defparam, parameter, and function and task declarations within generate statements. The naming scheme for registers and instances is also enhanced to include closer correlation to specified generate symbolic hierarchies. Generated data types have unique identifier names and can be referenced hierarchically. Generate statements are created using one of the following three methods: generate-loop, generate-conditional, or generate-case.

Note: The generate statement is a Verilog 2005 feature; to use this statement with the FPGA synthesis tools, you must enable System-Verilog for your project.

Example 1 – Shift Register Using generate-for

```
//TECHPUBS Example: Shift Register Using generate-for

module sh_r #(

   parameter width = 8,

   pipe_num = 3 )

      (input clk,

       input[width-1:0]din,

       output[width-1:0] dout );

genvar i;

generate

   for(i=0;i<pipe_num;i=i+1)

   begin:u

   reg [width-1:0] sh_r;

      if(i==0)

      begin

         always @ (posedge clk)
```

```
            sh_r <= din;

        end

        else

        begin

            always @ (posedge clk)

                sh_r <= u[i-1].sh_r;

        end

    end

endgenerate

assign dout = u[pipe_num-1].sh_r;

endmodule
```

Example 2 – Accessing Variables Declared in a generate-if

```
//TECHPUBS Example:  Accessing Variables Declared in a generate-if

module test #(

    parameter width = 8,

        sel = 0 )

            (input [width-1:0] a,

             input [width-1:0] b,

             input clk,

             output [(2*width)-1:0] c,

             output bit_acc,

             output [width-3:0] prt_sel );

    genvar i;

    reg [width-1:0] t_r;

generate

    if(sel == 0)

    begin:u
```

```
          wire [width-1:0] c;

          wire [width-1:0] t;

          assign {c,t} = {~t_r,a|b};

       end

       else

       begin:u

          wire [width-1:0] c;

          wire [width-1:0] t;

          assign {c,t} = {~t_r,a^b};

       end

    endgenerate

    always @ (posedge clk)

    begin

        t_r <= u.t;

       end

    assign c = u.c;

    assign bit_acc = u.t[0];

       assign prt_sel = u.t[width-1:2];

    endmodule
```

Example 3 – Accessing Variables Declared in a generate-case

```
//TECHPUBS Example: Accessing Variables Declared in a generate-
case

module test #(

   parameter mod_sel = 1,

   mod_sel2 = 3 )

       (input [7:0] a1,
```

```
         input [7:0] b1,

         output [7:0] c1,

         input [1:0][3:1] a2,

         input [1:0][3:1] b2,

         output [1:0][3:1] c2 );
  typedef logic [7:0] my_logic1_t;

  typedef logic [1:0][3:1] my_logic2_t;

  generate

  case(mod_sel)

      0:

      begin:u1

         my_logic1_t c1;

         assign c1 = a1 + b1;

      end

      1:

      begin:u1

         my_logic2_t c2;

         assign c2 = a2 + b2;

      end

      default:

      begin:def

         my_logic1_t c1;

         assign c1 = a1 + b1;

      end

  endcase

  endgenerate

  generate
```

```
case(mod_sel2)

   0:

   begin:u2

      my_logic1_t c1;

      assign c1 = a1 + b1;

   end

   1:

   begin:u2

      my_logic2_t c2;

      assign c2 = a2 + b2;

   end

   default:

   begin:def2

      my_logic1_t c1;

      assign c1 = a1 * b1;

   end

endcase

endgenerate

assign c2 = u1.c2;

assign c1 = def2.c1;

endmodule
```

Limitations

The following generate statement functions are not currently supported:

- Defparam support for generate instances
- Hierarchical access for interface
- Hierarchical access of function/task defined within a generate block

---

Note: Whenever the generate statement contains symbolic hierarchies separated by a hierarchy separator (.), the instance name includes the (\) character before this hierarchy separator (.).

Conditional Generate Constructs

The if-generate and case-generate conditional generate constructs allow the selection of, at most, one generate block from a set of alternative generate blocks based on constant expressions evaluated during elaboration. The generate and endgenerate keywords are optional.

Generate blocks in conditional generate constructs can be either named or unnamed and can consist of only a single item. It is not necessary to enclose the blocks with begin and end keywords; the block is still a generate block and, like all generate blocks, comprises a separate scope and a new level of hierarchy when it is instantiated. The if-generate and case-generate constructs can be combined to form a complex generate scheme.

Note: Conditional generate constructs are a Verilog 2005 feature; to use these constructs with the FPGA synthesis tools, you must enable SystemVerilog for your project.

Example 1 – Conditional Generate: if-generate

```
// test.v
module test
#  (parameter width = 8,
    sel = 2 )

   (input clk,
    input [width-1:0] din,
    output [width-1:0] dout1,
    output [width-1:0] dout2 );

if(sel == 1)
   begin:sh
   reg [width-1:0] sh_r;

   always_ff @ (posedge clk)
      sh_r <= din;
   end
else
   begin:sh
      reg [width-1:0] sh_r1;
      reg [width-1:0] sh_r2;
```

```
        always_ff @ (posedge clk)
        begin
            sh_r1 <= din;
            sh_r2 <= sh_r1;
        end
    end

    assign dout1 = sh.sh_r1;
    assign dout2 = sh.sh_r2;

    endmodule
```

Example 2 – Conditional Generate: case-generate

```
    // top.v
    module top
    #  (parameter mod_sel = 3,
        mod_sel2 = 3,
        width1 = 8,
        width2 = 16 )

       (input [width1-1:0] a1,
        input [width1-1:0] b1,
        output [width1-1:0] c1,
        input [width2-1:0] a2,
        input [width2-1:0] b2,
        output [width2-1:0] c2 );

    case(mod_sel)
       0:
          begin:u1
             my_or u1(.a(a1),.b(b1),.c(c1) );
          end
       1:
          begin:u1
             my_and u2(.a(a2),.b(b2),.c(c2) );
          end
       default:
          begin:u1
             my_or u1(.a(a1),.b(b1),.c(c1) );
          end
    endcase

    case(mod_sel2)
       0:
          begin:u3
             my_or u3(.a(a1),.b(b1),.c(c1) );
          end
```

```
        1:
          begin:u4
             my_and u4(.a(a2),.b(b2),.c(c2) );
          end
        default:
          begin:def
             my_and u2(.a(a2),.b(b2),.c(c2) );
          end
     endcase
     endmodule

     // my_and.v
     module my_and
     # (parameter width2 = 16 )

        (input [width2-1:0] a,
         input  [width2-1:0] b,
         output [width2-1:0] c
        );

     assign c = a & b;
     endmodule

     // my_or.v
     module  my_or
     #  (parameter width = 8)

        (input [width-1:0] a,
         input [width-1:0] b,
         output [width-1:0] c );

     assign c = a | b;
     endmodule
```

Assertions

The parsing of SystemVerilog Assertions (SVA) is supported as outlined in the following table.

Assertion Construct	Support Level	Comment
Immediate assertions	Supported	
Concurrent assertions	Partially Supported, Ignored	Multiclock properties are not supported
Boolean expressions	Partially Supported, Ignored	In the boolean expressions, $rose function having a clocking event is not supported.
Sequence	Supported, ignored	
Declaring sequences	Partially Supported, Ignored	Sequence with ports declared in global space is not supported
Sequence operations	Partially Supported, Ignored	All variations of first_match, within and intersect in a sequence is not supported.
Manipulating data in a sequence	Partially Supported, Ignored	More than one assignment in the parenthesis is not supported.
Calling subroutines on sequence match	Partially Supported, Ignored	Calling of more than one tasks is not supported
System functions	Partially Supported	System functions $onehot, $onehot1, and $countones supported; $isunknown not supported
Declaring properties	Partially Supported, Ignored	Declaring of properties in a package and properties with ports declared in global space are not supported
Multiclock support	Not Supported	
Clock resolutions	Partially Supported, Ignored	Default clocking is not supported

Assertion Construct	Support Level	Comment
Binding properties to scopes or instances	Not Supported	
Expect statement	Not Supported	
Clocking blocks and concurrent assertions	Not Supported	

SVA System Functions

SystemVerilog assertion support includes the $onehot, $onehot0, and $countones system functions. These functions check for specific characteristics on a particular signal and return a single-bit value.

- $onehot returns true when only one bit of the expression is true.

- $onehot0 returns true when no more than one bit of the expression is high (either one bit high or no bits are high).

- $countones returns true when the number of ones in a given expression matches a predefined value.

Syntax

$onehot (*expression***)**

$onehot0 (*expression***)**

$countones (*expression***)**

Example 1 – System Function within if Statement

The following example shows a $onehot/$onehot0 function used inside an if statement and ternary operator.

```
module top
    (
    //Input
    input byte d1,
    input byte d2,
    input shortint d3,
```

```
        //Output
        output byte dout1,
        output byte dout2
        );
    byte sig1;
    assign sig1 = d1 + d2;

    //Use of $onehot
    always_comb begin
        if($onehot(sig1))
            dout1 = d3[7:0];
        else
            dout1 = d3[15:8];
    end

    byte sig2;
    assign sig2 = d1 ^ d2;
    //Use of $onehot0
    assign dout2 = $onehot0(sig2)? d3[7:0] : d3[15:8];

    endmodule
```

Example 2 – System Function with Expression

The following example includes an expression, which is evaluated to a single-bit value, as an argument to a system function.

```
    module top
        (
        //Input
        input byte d1,
        input byte d2,
        input shortint d3,
        //Output
        output byte dout1,
        output byte dout2
        );

    //Use of $onehot with Expression inside onehot function
    always@*
    begin
        if($onehot((d1 == d2) ? d1[3:0] : d1[7:4]))
            dout1 = d3[7:0];
        else
            dout1 = d3[15:8];
    end
```

```
    //Use of $onehot0 with AND operation inside onehot function
    assign dout2 = $onehot0(d1 & d2 )? d3[7:0] : d3[15:8];

    endmodule
```

Example 3 – Ones Count

In the following example, a 4-bit count is checked for two and only two bits
set to 1 which, when present, returns true.

```
    module top(
        input clk,
        input rst,
        input byte d1,
        output byte dout
    );
    logic[3:0] count;

    always_ff@(posedge clk)begin
        if(rst)
            count <= '0;
        else
            count <= count + 1'b1;
    end

    assign dout = $countones(count) == 3'd2 ? d1 : ~d1;
    endmodule
```

Keyword Support

This table lists supported SystemVerilog keywords in the Synopsys FPGA synthesis tools:

always_comb	always_ff	always_latch	assert*
assume*	automatic	bind*	bit
break	byte	checker*	clocking*
const	continue	cover*	do
endchecker*	endclocking*	endinterface	endproperty*
endsequence*	enum	expect*	extern
final*	function	global*	import
inside	int	interface	intersect*
let*	logic	longint	modport
packed	package	parameter	priority
property*	restrict*	return	sequence*
shortint	struct	task	throughout*
timeprecision*	timeunit*	typedef	union
unique	void	within*	

* Reserved keywords for SystemVerilog assertion parsing; cannot be used as identifiers or object names

CHAPTER 3

VHDL Language Support

This chapter discusses how you can use the VHDL language to create HDL source code for the synthesis tool:

Language Constructs

This section generally describes how the synthesis tool relates to different VHDL language constructs. The topics include:

- Supported VHDL Language Constructs, on page 258
- Unsupported VHDL Language Constructs, on page 259
- Partially-supported VHDL Language Constructs, on page 260
- Ignored VHDL Language Constructs, on page 260

Supported VHDL Language Constructs

The following is a compact list of language constructs that are supported.

- Entity, architecture, and package design units
- Function and procedure subprograms
- All IEEE library packages, including:
  - std_logic_1164
  - std_logic_unsigned
  - std_logic_signed
  - std_logic_arith
  - numeric_std and numeric_bit
  - standard library package (std)
- In, out, inout, buffer, linkage ports
- Signals, constants, and variables
- Aliases
- Integer, physical, and enumeration data types; subtypes of these
- Arrays of scalars and records
- Record data types
- File types
- All operators (-, -, *, /, **, mod, rem, abs, not, =, /=, <, <=, >, >=, and, or, nand, nor, xor, xnor, sll, srl, sla, sra, rol, ror, &)

> **Note:** With the ** operator, arguments are compiler constants. When the left operand is 2, the right operand can be a variable.

- Sequential statements: signal and variable assignment, wait, if, case, loop, for, while, return, null, function, and procedure call

- Concurrent statements: signal assignment, process, block, generate (for and if), component instantiation, function, and procedure call

- Component declarations and four methods of component instantiations

- Configuration specification and declaration

- Generics; attributes; overloading

- Next and exit looping control constructs

- Predefined attributes: t'base, t'left, t'right, t'high, t'low, t'succ, t'pred, t'val, t'pos, t'leftof, t'rightof, integer'image, a'left, a'right, a'high, a'low, a'range, a'reverse_range, a'length, a'ascending, s'stable, s'event

- Unconstrained ports in entities

- Global signals declared in packages

Unsupported VHDL Language Constructs

If any of these constructs are found, an error message is reported and the synthesis run is cancelled.

- Register and bus kind signals

- Guarded blocks

- Expanded (hierarchical) names

- User-defined resolution functions. The synthesis tool only supports the resolution functions for std_logic and std_logic_vector.

- Slices with range indices that do not evaluate to constants

Partially-supported VHDL Language Constructs

When one of the following constructs in encountered, compilation continues, but will subsequently error out if logic must be generated for the construct.

- real data types (real data expressions are supported in VHDL-2008 IEEE float_pkg.vhd) – real data types are supported as constant declarations or as constants used in expressions as long as no floating point logic must be generated

- access types

- null arrays – null arrays are allowed as operands in concatenation expressions

Ignored VHDL Language Constructs

The synthesis tool ignores the following constructs in your design. If found, the tool parses and ignores the construct (provided that no logic is required to be synthesized) and continues with the synthesis run.

- disconnect

- assert and report

- initial values on inout ports

VHDL Language Constructs

This section describes the synthesis language support that the synthesis tool provides for each VHDL construct. The language information is taken from the most recent VHDL Language Reference Manual (Revision ANSI/IEEE Std 1076-1993). The section names match those from the LRM, for easy reference.

- Data Types

- Declaring and Assigning Objects in VHDL

- VHDL Dynamic Range Assignments

- Signals and Ports

- Variables

- VHDL Constants

- Libraries and Packages

- Operators

- VHDL Process

- Common Sequential Statements

- Concurrent Signal Assignments

- Resource Sharing

- Combinational Logic

- Sequential Logic

- Component Instantiation in VHDL

- VHDL Selected Name Support

- User-defined Function Support

- Demand Loading

Data Types

Predefined Enumeration Types

Enumeration types have a fixed set of unique values. The two predefined data types – bit and Boolean, as well as the std_logic type defined in the std_logic_1164 package are the types that represent hardware values. You can declare signals and variables (and constants) that are vectors (arrays) of these types by using the types bit_vector, and std_logic_vector. You typically use std_logic and std_logic_vector, because they are highly flexible for synthesis and simulation.

std_logic Values	Treated by the synthesis tool as...
'U' (uninitialized)	don't care
'X' (forcing unknown)	don't care
'0' (forcing logic 0)	logic 0

std_logic Values	Treated by the synthesis tool as...
'1' (forcing logic 1)	logic 1
'Z' (high impedance)	high impedance
'W' (weak unknown)	don't care
'L' (weak logic 0)	logic 0
'H' (weak logic 1)	logic 1
'-' (don't care)	don't care

bit Values	Treated by the synthesis tool a...
'0'	logic 0
'1'	logic 1

boolean Values	Treated by the synthesis tool as...
false	logic 0
true	logic 1

User-defined Enumeration Types

You can create your own enumerated types. This is common for state machines because it allows you to work with named values rather than individual bits or bit vectors.

Syntax

type *type_name* **is (***value_list***) ;**

Examples

```
type states is ( state0, state1, state2, state3);
type traffic_light_state is ( red, yellow, green);
```

Integers

An integer is a predefined VHDL type that has 32 bits. When you declare an object as an integer, restrict the range of values to those you are using. This results in a minimum number of bits for implementation and on ports.

Data Types for Signed and Unsigned Arithmetic

For signed arithmetic, you have the following choices:

- Use the std_logic_vector data type defined in the std_logic_1164 package, and the package std_logic_signed.

- Use the signed data type, and signed arithmetic defined in the package std_logic_arith.

- Use an integer subrange (for example: signal mysig: integer range -8 to 7). If the range includes negative numbers, the synthesis tool uses a two's-complement bit vector of minimum width to represent it (four bits in this example). Using integers limits you to a 32-bit range of values, and is typically only used to represent small buses. Integers are most commonly used for indexes.

- Use the signed data type from the numeric_std or numeric_bit packages.

For unsigned arithmetic, you have the following choices:

- Use the std_logic_vector data type defined in the std_logic_1164 package and the package std_logic_unsigned.

- Use the unsigned data type and unsigned arithmetic defined in the package std_logic_arith.

- Use an integer subrange (for example: signal mysig: integer range 0 to 15). If the integers are restricted to positive values, the synthesis tool uses an unsigned bit vector of minimum width to represent it (four bits in this example). Using integers limits you to a 32-bit range of values, and is typically only used to represent small buses (integers are most commonly used for indexes).

- Use the unsigned data type from the numeric_std or numeric_bit packages.

Declaring and Assigning Objects in VHDL

VHDL objects (object classes) include signals (and ports), variables, and constants. The synthesis tool does not support the file object class.

Naming Objects

VHDL is case insensitive. A VHDL name (identifier) must start with a letter and can be followed by any number of letters, numbers, or underscores ('_'). Underscores cannot be the first or last character in a name and cannot be used twice in a row. No special characters such as '$', '?', '*', '-', or '!', can be used as part of a VHDL identifier.

Syntax

> *object_class object_name* **:** *data_type* [**:=** *initial_value*] **;**

- object_class is a signal, variable, or constant.

- object_name is the name (the identifier) of the object.

- data_type can be any predefined data type (such as bit or std_logic_vector) or user-defined data type.

Assignment Operators

> <= Signal assignment operator.

> := Variable assignment and initial value operator.

VHDL Dynamic Range Assignments

The tools support VHDL assignments with dynamic ranges, which are defined as follows:

> A(b downto c) <= D(e downto f);

A and D are constrained variables or signals, and b, c, e, and f are constants (generics) or variables. Dynamic range assignments can be used for RHS, LHS, or both.

```
library ieee;
use ieee.std_logic_1164.all;
use ieee.std_logic_arith.all;
```

```
entity test is
   port (data_out: out  std_logic_vector(63 downto 0);
         data_in: in std_logic_vector(63 downto 0);
         selector: in NATURAL range 0 to 7 );
end test;

architecture rtl of test is
begin
   data_out( (selector*8)+7 downto (selector*8))
      <= data_in((selector*8)+7 downto (selector*8));
end rtl;
```

Currently, the following limitations apply to dynamic range assignments:

- There is no support for procedures.

- There is no support for selected signal assignment; i.e., with *expression* Select.

- There is no support for use with concatenation operators.

Null Ranges

A null range is a range that specifies an empty subset of values. A range specified as *m* to *n* is a null range when *m* is greater than *n*, and a range specified as *n* downto *m* is a null range when *n* is less than *m*.

Support for null ranges allows ports with negative ranges to be compiled successfully. During compilation, any port declared with a null range and its related logic are removed by the compiler.

In the following example, port a_in1 (-1 to 0) is a null range and is subsequently removed by the compiler.

```
-- top.vhd
library ieee;
use ieee.std_logic_1164.all;

entity top is
generic (width : integer := 0);
   port (a_in1 : in std_logic_vector(width -1 downto 0);
         b_in1 : in std_logic_vector(3 downto 0);
         c_out1 : out std_logic_vector(3 downto 0) );
end top;
```

```
architecture struct of top is
component sub is
   port (a_in1 : in std_logic_vector(width -1 downto 0);
         b_in1 : in std_logic_vector(3 downto 0);
         c_out1 : out std_logic_vector(3 downto 0) );
end component;

begin
   UUT : sub port map ( a_in1 => a_in1, b_in1 => b_in1,
      c_out1 => c_out1);
end struct;

-- sub.vhd
library ieee;
use ieee.std_logic_1164.all;

entity sub is
generic (width : integer := 0);
   port (a_in1 : in std_logic_vector(width -1 downto 0);
         b_in1 : in std_logic_vector(3 downto 0);
         c_out1 : out std_logic_vector(3 downto 0) );
end sub;

architecture rtl of sub is
begin
   c_out1 <= not (b_in1 & a_in1);
end rtl;
```

Signals and Ports

In VHDL, the port list of the entity lists the I/O signals for the design. Ports of mode in can be read from, but not assigned (written) to. Ports of mode out can be assigned to, but not read from. Ports of mode inout are bidirectional and can read from and assigned to. Ports of mode buffer are like inout ports but can have only one internal driver on them.

Internal signals are declared in the architecture declarative area and can be read from or assigned to anywhere within the architecture.

Examples

```
signal my_sig1 : std_logic; -- Holds a single std_logic bit
begin     -- An architecture statement area
my_sig1 <= '1';  -- Assign a constant value '1'

-- My_sig2 is a 4-bit integer
   signal my_sig2 : integer range 0 to 15;
begin      -- An architecture statement area
my_sig2 <= 12;

-- My_sig_vec1 holds 8 bits of std_logic, indexed from 0 to 7
   signal my_sig_vec1 : std_logic_vector (0 to 7) ;
begin     -- An architecture statement area

-- Simple signal assignment with a literal value
my_sig_vec1 <= "01001000";

-- 16 bits of std_logic, indexed from 15 down to 0
   signal my_sig_vec2 : std_logic_vector (15 downto 0) ;
begin      -- An architecture statement area

-- Simple signal assignment with a vector value
my_sig_vec2 <= "0111110010000101";

-- Assigning with a hex value FFFF
my_sig_vec2 <= X"FFFF";

-- Use package Std_Logic_Signed
   signal my_sig_vec3 : signed (3 downto 0);
begin      -- An architecture statement area

-- Assigning a signed value, negative 7
my_sig_vec3 <= "1111";

-- Use package Std_Logic_Unsigned
   signal my_sig_vec4 : unsigned (3 downto 0);
begin     -- An architecture statement area

-- Assigning an unsigned value of 15
my_sig_vec4 <= "1111";

-- Declare an enumerated type, a signal of that type, and
-- then make an valid assignment to the signal
   type states is ( state0, state1, state2, state3);
   signal current_state : states;
begin      -- An architecture statement area
current_state <= state2;
```

```
-- Declare an array type, a signal of that type, and
-- then make a valid assignment to the signal

   type array_type is array (1 downto 0) of
      std_logic_vector (7 downto 0);
   signal my_sig: array_type;
begin -- An architecture statement area
my_sig <= ("10101010","01010101");
```

Variables

VHDL variables are declared within a process or subprogram and then used internally. Generally, variables are not visible outside the process or subprogram they are declared unless passed as a parameter to another subprogram.

Example

```
process (clk) -- What follows is the process declaration area
   variable my_var1 : std_logic := '0'; -- Initial value '0'

begin -- What follows is the process statement area
   my_var1 := '1';
end process;
```

Example

```
process (clk, reset)
-- Set the initial value of the variable to hex FF
   variable my_var2 : std_logic_vector (1 to 8) := X"FF";

begin
-- my_var2 is assigned the octal value 44
   my_var2 := O"44";
end process;
```

VHDL Constants

VHDL constants are declared in any declarative region and can be used within that region. The value of a constant cannot be changed.

Example

```
package my_constants is
    constant num_bits : integer := 8;

-- Other package declarations

end my_constants;
```

Libraries and Packages

When you want to synthesize a design in VHDL, include the HDL files in the source files list of your synthesis tool project. Often your VHDL design will have more than one source file. List all the source files in the order you want them compiled; the files at the top of the list are compiled first.

Compiling Design Units into Libraries

All design units in VHDL, including your entities and packages are compiled into libraries. A library is a special directory of entities, architectures and/or packages. You compile source files into libraries by adding them to the source file list. In VHDL, the library you are compiling has the default name work. All entities and packages in your source files are automatically compiled into work. You can keep source files anywhere on your disk, even though you add them to libraries. You can have as many libraries as are needed.

1. To add a file to a library, select the file in the Project view.

   The library structure is maintained in the Project view. The name of the library where a file belongs appears on the same line as the filename, and directly in front of it.

2. Choose Project -> Set Library from the menu bar, then type the library name. You can add any number of files to a library.

3. If you want to use a design unit that you compiled into a library (one that is no longer in the default work library), you must use a library clause in the VHDL source code to reference it.

For example, if you add a source file for the entity ram16x8 to library my_rams, and instantiate the 16x8 RAM in the design called top_level, you must add library my_rams; just before defining top_level.

Predefined Packages

The synthesis tool supports the two standard libraries, std and ieee, that contain packages containing commonly used definitions of data types, functions, and procedures. These libraries and their packages are built in to the synthesis tool, so you do not compile them. The predefined packages are described in the following table.

Library	Package	Description
std	standard	Defines the basic VHDL types including bit and bit_vector
ieee	std_logic_1164	Defines the 9-value std_logic and std_logic_vector types
ieee	numeric_bit	Defines numeric types and arithmetic functions. The base type is BIT.
ieee	numeric_std	Defines arithmetic operations on types defined in std_logic_1164
ieee	std_logic_arith	Defines the signed and unsigned types, and arithmetic operations for the signed and unsigned types
ieee	std_logic_signed	Defines signed arithmetic for std_logic and std_logic_vector
ieee	std_logic_unsigned	Defines unsigned arithmetic for std_logic and std_logic_vector

The synthesis tools also have vendor-specific built-in macro libraries for components like gates, counters, flip-flops, and I/Os. The libraries are located in *installDirectory*/lib/*vendorName*. Use the built-in macro libraries to instantiate vendor macros directly into the VHDL designs and forward-annotate them to the output netlist. Refer to the appropriate vendor support chapter for more information.

Additionally, the synthesis tool library contains an attributes package of built-in attributes and timing constraints (*installDirectory*/lib/vhd/synattr.vhd) that you can use with VHDL designs. The package includes declarations for timing constraints (including black-box timing constraints), vendor-specific attributes and synthesis attributes. To access these built-in attributes, add the following two lines to the beginning of each of the VHDL design units that uses them:

```
library synplify;
use synplify.attributes.all;
```

If you want the addition operator (+) to take two std_ulogic or std_ulogic_vector as inputs, you need the function defined in the std_logic_arith package (the cdn_arith.vhd file in *installDirectory*/lib/vhd/). Add this file to the project. To successfully compile, the VHDL file that uses the addition operator on these input types must have include the following statement:

```
use work.std_logic_arith.all;
```

Accessing Packages

To gain access to a package include a library clause in your VHDL source code to specify the library the package is contained in, and a use clause to specify the name of the package. The library and use clauses must be included immediately before the design unit (entity or architecture) that uses the package definitions.

Syntax

l**ibrary** *library_name* **;**
use *library_name***.***package_name***.all ;**

To access the data types, functions and procedures declared in std_logic_1164, std_logic_arith, std_logic_signed, or std_logic_unsigned, you need a library ieee clause and a use clause for each of the packages you want to use.

Example

```
library ieee;
use ieee.std_logic_1164.all ;
use ieee.std_logic_signed.all ;

-- Other code
```

Library and Package Rules

To access the standard package, no library or use clause is required. The standard package is predefined (built-in) in VHDL, and contains the basic data types of bit, bit_vector, Boolean, integer, real, character, string, and others along with the operators and functions that work on them.

If you create your own package and compile it into the work library to access its definitions, you still need a use clause before the entity using them, but not a library clause (because work is the default library.)

To access packages other than those in work and std, you must provide a library and use clause for each package as shown in the following example of creating a resource library.

```
-- Compile this in library mylib
library ieee;
use ieee.std_logic_1164.all;

package my_constants is
constant max: std_logic_vector(3 downto 0):="1111";
   .
   .
   .
end package;

-- Compile this in library work
library ieee, mylib;
use ieee.std_logic_1164.all;
use mylib.my_constants.all;

entity compare is
   port (a: in std_logic_vector(3 downto 0);
         z: out std_logic );
end compare;
```

```
architecture rtl of compare is
begin
    z <= '1' when (a = max) else '0';
end rtl;
```

The rising_edge and falling_edge functions are defined in the std_logic_1164 package. If you use these functions, your clock signal must be declared as type std_logic.

Instantiating Components in a Design

No library or use clause is required to instantiate components (entities and their associated architectures) compiled in the default work library. The files containing the components must be listed in the source files list before the file(s) that instantiates them.

To instantiate components from the built-in technology-vendor macro libraries, you must include the appropriate use and library clauses in your source code. Refer to the section for your vendor for more information.

To create a separate resource library to hold your components, put all the entities and architectures in one source file, and assign that source file the library components in the synthesis tool Project view. To access the components from your source code, put the clause library components; before the designs that instantiate them. There is no need for a use clause. The project file (prj) must include both the files that create the package components and the source file that accesses them.

Operators

The synthesis tool supports creating expressions using all predefined VHDL operators:

Arithmetic Operator	Description
-	addition
-	subtraction
*	multiplication
/	division

Arithmetic Operator	Description
**	exponentiation (supported for compile-time constants and when left operand is 2; right operand can be a variable)
mod	modulus
rem	remainder

Relational Operator	Description
=	equal (if either operand has a bit with an 'X' or 'Z' value, the result is 'X')
/=	not equal (if either operand has a bit with an 'X' or 'Z' value, the result is 'X')
<	less than (if, because of unknown bits in the operands, the relation is ambiguous, then the result is the unknown value 'X')
<=	less than or equal to (if, because of unknown bits in the operands, the relation is ambiguous, then the result is the unknown value 'X')
>	greater than (if, because of unknown bits in the operands, the relation is ambiguous, then the result is the unknown value 'X')
>=	greater than or equal to (if, because of unknown bits in the operands, the relation is ambiguous, then the result is the unknown value 'X')

Logical Operator	Description
and	and
or	or
nand	nand
nor	nor
xor	xor
xnor	xnor
not	not (takes only one operand)

Shift Operator	Description
sll	shift left logical – logically shifted left by R index positions
srl	shift right logical – logically shifted right by R index positions
sla	shift left arithmetic – arithmetically shifted left by R index positions
sra	shift right arithmetic – arithmetically shifted right by R index positions
rol	rotate left logical – rotated left by R index positions
ror	rotate right logical – rotated right by R index positions

Misc. Operator	Description
-	identity
-	negation
&	concatenation

Note: Initially, X's are treated as "don't-cares", but they are eventually converted to 0's or 1's in a way that minimizes hardware.

Large Time Resolution

The support of predefined physical time types includes the expanded range from –2147483647 to +2147483647 with units ranging from femtoseconds, and secondary units ranging up to an hour. Predefined physical time types allow selection of a wide number range representative of time type.

Example 1 – Using Large Time Values in Comparisons

```
library ieee;
use ieee.std_logic_1164.all;
use ieee.numeric_std.all;
use ieee.std_logic_unsigned.all;

entity test is
   generic (INTERVAL1 : time := 1000 fs ;
            INTERVAL2 : time := 1 ps;
            INTERVAL3 : time := 1000 ps;
            INTERVAL4 : time := 1 ns
   );

   port (a : in std_logic_vector(3 downto 0);
         b : in std_logic_vector(3 downto 0);
         c : out std_logic_vector(3 downto 0);
         d : out std_logic_vector(3 downto 0)
   );
end test;

architecture RTL of test is
begin
   c <= (a and b) when (INTERVAL1 = INTERVAL2) else
      (a or b);
   d <= (a xor b) when (INTERVAL3 /= INTERVAL4) else
      (a nand b);
end RTL;
```

Example 2 – Using Large Time Values in Constant Calculations

```
library ieee;
use ieee.std_logic_1164.all;

entity test is
   generic (Interval : time := 20 ns;
            CLK_PERIOD : time := 8 ns );
   port (en : in std_logic;
         a : in std_logic_vector(10 downto 0);
         b : in std_logic_vector(10 downto 0);
         a_in : in std_logic_vector(7 downto 0);
         b_in : in std_logic_vector(7 downto 0);
         dummyOut : out std_logic_vector(7 downto 0);
         out1 : out std_logic_vector(10 downto 0) );
end entity;
```

```
architecture behv of test is
    constant my_time : positive := (Interval / 2 ns);
    constant CLK_PERIOD_PS : real := real(CLK_PERIOD / 1 ns);
    constant RESULT : positive := integer(CLK_PERIOD_PS);
    signal dummy : std_logic_vector (RESULT-1 downto 0);
    signal temp : std_logic_vector (my_time downto 0);
begin
    process (a, b)
    begin
       temp <= a and b;
       out1 <= temp;
    end process;
dummy <= (others => '0') when en = '1' else
    (a_in or b_in);
dummyOut <= dummy;
end behv;
```

Example 3 – Using Large Time Values in Generic Calculations

```
library IEEE;
use IEEE.std_logic_1164.all;
library unisim;
use unisim.vcomponents.all;

entity test is
    generic (clk_period : time := 6 ns);
    port (rst_in : in std_logic;
          in1 : in std_logic;
          CLK_PAD : in std_logic;
          RST_DLL : in std_logic;
          dout : out std_logic;
          CLK_out : out std_logic;
          LOCKED : out std_logic );
end test;

architecture STRUCT of test is
    signal CLK, CLK_int, CLK_dcm : std_logic;
    signal clk_dv : std_logic;
    constant clk_prd : real := real(clk_period / 2.0 ns);
begin
U1 : IBUFG port map (I => CLK_PAD, O => CLK_int);
U2 : DCM generic map
(CLKDV_DIVIDE  => clk_prd)
    port map (CLKFB => CLK,
              CLKIN => CLK_int,
              CLKDV => clk_dv,
              DSSEN => '0',
              PSCLK => '0',
```

```
                    PSEN => '0',
                    PSINCDEC => '0',
                    RST => RST_DLL,
                    CLK0 => CLK_dcm,
                    LOCKED => LOCKED );
      U3 : BUFG port map (I => CLK_dcm, O => CLK);
      CLK_out <= CLK;
         process (clk_dv , rst_in, in1)
         begin
            if (rst_in = '1') then
               dout <= '0';
            elsif (clk_dv'event and clk_dv = '1') then
               dout <= in1;
            end if;
         end process;
      end architecture STRUCT;
```

VHDL Process

The VHDL keyword process introduces a block of logic that is triggered to execute when one or more signals change value. Use processes to model combinational and sequential logic.

process Template to Model Combinational Logic

```
      <optional_label> : process (<sensitivity_list>)

      -- Declare local variables, data types,
      -- and other local declarations here

      begin
         -- Sequential statements go here, including:
         --    signal and variable assignments
         --    if and case statements
         --    while and for loops
         --    function and procedure calls
      end process  <optional_label>;
```

Sensitivity List

The sensitivity list specifies the signal transitions that trigger the process to execute. This is analogous to specifying the inputs to logic on a schematic by drawing wires to gate inputs. If there is more than one signal, separate the names with commas.

A warning is issued when a signal is not in the sensitivity list but is used in the process, or when the signal is in the sensitivity list but not used by the process.

Syntax

process (*signal1***,** *signal2***, ...) ;**

A process can have only one sensitivity list, located immediately after the keyword process, or one or more wait statements. If there are one or more wait statements, one of these wait statements must be either the first or last statement in the process.

List all signals feeding into the combinational logic (all signals that affect signals assigned inside the process) in the sensitivity list. If you forget to list all signals, the synthesis tool generates the desired hardware, and reports a warning message that you are not triggering the process every time the hardware is changing its outputs, and therefore your pre- and post-synthesis simulation results might not match.

Any signals assigned in the process must either be outputs specified in the port list of the entity or declared as signals in the architecture declarative area.

Any variables assigned in the process are local and must be declared in the process declarative area.

Note: Make sure all signals assigned in a combinational process are explicitly assigned values each time the process executes. Otherwise, the synthesis tool must insert level-sensitive latches in your design, in order to hold the last value for the paths that don't assign values (if, for example, you have combinational loops in your design). This usually represents coding error, so the synthesis tool issues a warning message that level-sensitive latches are being inserted into the design because of combinational loops. You will get an error message if you have combinational loops in your design that are not recognized as level-sensitive latches.

Common Sequential Statements

This section describes the if-then-else and case statements.

if-then-else Statement

Syntax

if *condition1* **then**
    sequential_statement(s)
[**elsif** *condition2* **then**
    sequential_statement(s)]
[**else**
    sequential_statement(s)]
end if ;

The else and elsif clauses are optional.

Example

```
library ieee;
use ieee.std_logic_1164.all;

entity mux is
    port (output_signal : out std_logic;
          a, b, sel : in std_logic );
end mux;
```

```
architecture if_mux of mux is
begin
   process (sel, a, b)
   begin
      if sel = '1' then
         output_signal <= a;
      elsif sel = '0' then
         output_signal <= b;
      else
         output_signal <= 'X';
      end if;
   end process ;
end if_mux;
```

case Statement

Syntax

case *expression* **is**
   when *choice1* **=>** *sequential_statement(s)*
   when *choice2* **=>** *sequential _statement(s)*

  -- Other case choices

   when *choiceN* **=>** *sequential_statement(s)*
end case ;

Note: VHDL requires that the expression match one of the given
choices. To create a default, have the final choice be when others =>
sequential_statement(s) or null. (Null means not to do anything.)

Example

```
library ieee;
use ieee.std_logic_1164.all;

entity mux is
   port (output_signal : out std_logic;
         a, b, sel : in std_logic );
end mux;
```

```
architecture case_mux of mux is
begin
   process (sel, a, b)
   begin
      case sel is
         when '1' =>
            output_signal <= a;
         when '0' =>
            output_signal <= b;
         when others =>
            output_signal <= 'X';
      end case;
   end process;
end case_mux;
```

Note: To test the condition of matching a bit vector, such as `"0-11"`, that contains one or more don't-care bits, do *not* use the equality relational operator (=). Instead, use the std_match function (in the ieee.numeric_std package), which succeeds (evaluates to true) whenever all of the explicit constant bits (0 or 1) of the vector are matched, regardless of the values of the bits in the don't-care (-) positions. For example, use the condition `std_match(a, "0-11")` to test for a vector with the first bit unset (0) and the third and fourth bits set (1).

Concurrent Signal Assignments

There are three types of concurrent signal assignments in VHDL.

- Simple

- Selected (with-select-when)

- Conditional (when-else)

Use the concurrent signal assignment to model combinational logic. Put the concurrent signal assignment in the architecture body. You can any number of statements to describe your hardware implementation. Because all statements are concurrently active, the order you place them in the architecture body is not significant.

Re-evaluation of Signal Assignments

Every time any signal on the right side of the assignment operator (<=)
changes value (including signals used in the expressions, values, choices, or
conditions), the assignment statement is re-evaluated, and the result is
assigned to the signal on the left side of the assignment operator. You can use
any of the predefined operators to create the assigned value.

Simple Signal Assignments

Syntax

signal **<=** *expression* ;

Example

```
architecture simple_example of simple is
begin
   c <= a nand b ;
end simple_example;
```

Selected Signal Assignments

Syntax

with *expression* **select**
signal **<=** *value1* **when** *choice1* ,
   value2 **when** *choice2* ,

   .
   .
   .

   valueN **when** *choiceN* ;

Example

```
library ieee;
use ieee.std_logic_1164.all;
entity mux is
   port (output_signal : out std_logic;
         a, b, sel : in std_logic );
end mux;
```

```
architecture with_select_when of mux is
begin
   with_sel_select
   output_signal <= a when '1',
      b when '0',
      'X' when others;
end with_select_when;
```

Conditional Signal Assignments

Syntax

signal **<=** *value1* **when** *condition1* **else**
   value2 **when** *condition2* **else**
   valueN-1 **when** *conditionN-1* **else**
   valueN **;**

Example

```
library ieee;
use ieee.std_logic_1164.all;

entity mux is
   port (output_signal: out std_logic;
         a, b, sel: in std_logic );
end mux;

architecture when_else_mux of mux is
begin
output_signal <= a when sel = '1' else
   b when sel = '0' else
   'X';
end when_else_mux;
```

Note: To test the condition of matching a bit vector, such as `"0-11"`, that contains one or more don't-care bits, do *not* use the equality relational operator (=). Instead, use the std_match function (in the ieee.numeric_std package), which succeeds (evaluates to true) whenever all of the explicit constant bits (0 or 1) of the vector are matched, regardless of the values of the bits in the don't-care (-) positions. For example, use the condition `std_match(a, "0-11")` to test for a vector with the first bit unset (0) and the third and fourth bits set (1).

Resource Sharing

When you have mutually exclusive operators in a case statement, the synthesis tool shares resources for the operators in the case statements. For example, automatic sharing of operator resources includes adders, subtractors, incrementors, decrementors, and multipliers.

Combinational Logic

Combinational logic is hardware with output values based on some function of the current input values. There is no clock and no saved states. Most hardware is a mixture of combinational and sequential logic.

Create combinational logic with concurrent signal assignments and/or processes.

Sequential Logic

Sequential logic is hardware that has an internal state or memory. The state elements are either flip-flops that update on the active edge of a clock signal, or level-sensitive latches, that update during the active level of a clock signal.

Because of the internal state, the output values might depend not only on the current input values, but also on input values at previous times. State machines are made of sequential logic where the updated state values depend on the previous state values. There are standard ways of modeling state machines in VHDL. Most hardware is a mixture of combinational and sequential logic.

Create sequential logic with processes and/or concurrent signal assignments.

Component Instantiation in VHDL

A structural description of a design is made up of component instantiations that describe the subsystems of the design and their signal interconnects. The synthesis tool supports four major methods of component instantiation:

- Simple component instantiation (described below)

- Selected component instantiation

- Direct entity instantiation

- Configurations described in

Simple Component Instantiation

In this method, a component is first declared either in the declaration region of the architecture, or in a package of (typically) component declarations, and then instantiated in the statement region of the architecture. By default, the synthesis process binds a named entity (and architecture) in the working library to all component instances that specify a component declaration with the same name.

Syntax

label **:** [**component**] *declaration_name*
    [**generic map (***actual_generic1***,** *actual_generic2***,** ... **)**]
    [**port map (** *port1***,** *port2***,** ... **)**] **;**

The use of the reserved word component is optional in component instantiations.

Example: VHDL 1987

```
architecture struct of hier_add is
component add
   generic (size : natural);
   port (a : in bit_vector(3 downto 0);
         b : in bit_vector(3 downto 0);
         result : out bit_vector(3 downto 0) );
end component;

begin
-- Simple component instantiation
add1: add
   generic map(size => 4)
   port map(a => ain,
      b => bin,
      result => q);

-- Other code
```

Example: VHDL 1993

```
architecture struct of hier_add is
component add
   generic (size : natural);
   port (a : in bit_vector(3 downto 0);
         b : in bit_vector(3 downto 0);
         result : out bit_vector(3 downto 0) );
end component;

begin
-- Simple component instantiation
add1: component add -- Component keyword new in 1993
   generic map(size => 4)
   port map(a => ain,
      b => bin,
      result => q);

-- Other code
```

Note: If no entity is found in the working library named the same as the declared component, all instances of the declared component are

mapped to a black box and the error message "Unbound compo-
nent mapped to black box" is issued.

VHDL Selected Name Support

Selected Name Support (SNS) is provided in VHDL for constants, operators,
and functions in library packages. SNS eliminates ambiguity in a design
referencing elements with the same names, but that have unique function-
ality when the design uses the elements with the same name defined in
multiple packages. By specifying the library, package, and specific element
(constant, operator, or function), SNS designates the specific constant,
operator, or function used. This section discusses all facets of SNS. Complete
VHDL examples are included to assist you in understanding how to use SNS
effectively.

Constants

SNS lets you designate the constant to use from multiple library packages. To
incorporate a constant into a design, specify the library, package, and
constant. Using this feature eliminates ambiguity when multiple library
packages have identical names for constants and are used in an entity-archi-
tecture pair.

The following example has two library packages available to the design
constants. Each library package has a constant defined by the name C1 and
each has a different value. SNS is used to specify the constant (see
work.PACKAGE.C1 in the constants example below).

```
-- CONSTANTS PACKAGE1
library IEEE;
use IEEE.std_logic_1164.all;
package PACKAGE1 is
   constant Cl: std_logic_vector := "10001010";
end PACKAGE1;

-- CONSTANTS PACKAGE2
library IEEE;
use IEEE.std_logic_1164.all;
package PACKAGE2 is
   constant Cl: std_logic_vector := "10110110";
end PACKAGE2;
```

```
-- CONSTANTS EXAMPLE
library IEEE;
use IEEE.std_logic_1164.all;
use IEEE.std_logic_arith.all;
use IEEE.std_logic_unsigned.all;

entity CONSTANTS is
   generic (num_bits : integer := 8) ;
      port (a,b: in std_logic_vector (num_bits -1 downto 0);
             out1, out2: out std_logic_vector (num_bits -1 downto 0)
             );
end CONSTANTS;

architecture RTL of CONSTANTS is
begin
   out1 <= a - work.PACKAGE1.Cl; -Example of specifying SNS
   out2 <= b - work.PACKAGE2.Cl; -Example of specifying SNS
end RTL;
```

In the above design, outputs out1 and out2 use two C1 constants from two different packages. Although each output uses a constant named C1, the constants are not equivalent. For out1, the constant C1 is from PACKAGE1. For out2, the constant C1 is from PACKAGE2. For example:

```
out1 <= a - work.PACKAGE1.Cl; is equivalent to out1 <= a - "10001010";
```

whereas:

```
out2 <= b - work.PACKAGE2.Cl; is equivalent to out2 <= b - "10110110";
```

The constants have different values in different packages. SNS specifies the package and eliminates ambiguity within the design.

Functions and Operators

Functions and operators in VHDL library packages customarily have overlapping naming conventions. For example, the add operator in the IEEE standard library exists in both the std_logic_signed and std_logic_unsigned packages. Depending upon the add operator used, different values result. Defining only one of the IEEE library packages is a straightforward solution to eliminate ambiguity, but applying this solution is not always possible. A design requiring both std_logic_signed and std_logic_unsigned package elements must use SNS to eliminate ambiguity.

Functions

In the following example, multiple IEEE packages are declared in a 256x8 RAM design. Both std_logic_signed and std_logic_unsigned packages are included. In the RAM definition, the signal address_in is converted from type std_logic_vector to type integer using the CONV_INTEGER function, but which CONV_INTEGER function will be called? SNS determines the function to use. The RAM definition clearly declares the std_logic_unsigned package as the source for the CONV_INTEGER function.

```
library IEEE;
use IEEE.std_logic_1164.all;
use IEEE.std_logic_unsigned.all;
use IEEE.std_logic_arith.all;
use IEEE.std_logic_signed.all;
use IEEE.numeric_std.all;

entity FUNCTIONS is
   port (address : in std_logic_vector(7 downto 0);
         data_in : in std_logic_vector(7 downto 0);
         data_out : out std_logic_vector(7 downto 0);
         we : in std_logic;
         clk : in std_logic );

end FUNCTIONS;

architecture RTL of FUNCTIONS is
type mem_type is array (255 downto 0) of
   std_logic_vector (7 downto 0);
signal mem: mem_type;
signal address_in: std_logic_vector(7 downto 0);
begin
data_out <= mem(IEEE.std_logic_unsigned.CONV_INTEGER(address_in));
   process (clk)
   begin
      if rising_edge(clk) then
         if (we = '1') then
            mem(IEEE.std_logic_unsigned.CONV_INTEGER(address_in))
               <= data_in;
         end if;
      address_in <= address;
      end if;
   end process;
end RTL;
```

Operators

In this example, comparator functions from the IEEE std_logic_signed and std_logic_unsigned library packages are used. Depending upon the comparator called, a signed or an unsigned comparison results. In the assigned outputs below, the op1 and op2 functions show the valid SNS syntax for operator implementation.

```
library IEEE;
use IEEE.std_logic_1164.std_logic_vector;
use IEEE.std_logic_signed.">";
use IEEE.std_logic_unsigned.">";

entity OPERATORS is
   port (in1 :std_logic_vector(1 to 4);
         in2 :std_logic_vector(1 to 4);
         in3 :std_logic_vector(1 to 4);
         in4 :std_logic_vector(1 to 4);
         op1,op2 :out boolean );
end OPERATORS;

architecture RTL of OPERATORS is
begin
   process(in1,in2,in3,in4)
   begin

      --Example of specifying SNS
      op1 <= IEEE.std_logic_signed.">"(in1,in2);

      --Example of specifying SNS
      op2 <= IEEE.std_logic_unsigned.">"(in3,in4);
   end process;
end RTL;
```

User-defined Function Support

SNS is not limited to predefined standard IEEE packages and packages supported by the synthesis tool; SNS also supports user-defined packages. You can create library packages that access constants, operators, and functions in the same manner as the packages supported by IEEE or the synthesis tool.

The following example incorporates two user-defined packages in the design. Each package includes a function named func. In PACKAGE1, func is an XOR gate, whereas in PACKAGE2, func is an AND gate. Depending on the package called, func results in either an XOR or an AND gate. The function call uses SNS to distinguish the function that is called.

```vhdl
-- USER DEFINED PACKAGE1
library IEEE;
use IEEE.std_logic_1164.all;
package PACKAGE1 is
    function func(a,b: in std_logic) return std_logic;
end PACKAGE1;

package body PACKAGE1 is
    function func(a,b: in std_logic) return std_logic is
begin
    return(a xor b);
end func;
end PACKAGE1;

-- USER DEFINED PACKAGE2
library IEEE;
use IEEE.std_logic_1164.all;

package PACKAGE2 is
    function func(a,b: in std_logic) return std_logic;
end PACKAGE2;

package body PACKAGE2 is
    function func(a,b: in std_logic) return std_logic is
begin
    return(a and b);
end func;
end PACKAGE2;

-- USER DEFINED FUNCTION EXAMPLE
library IEEE;
use IEEE.std_logic_1164.all;

entity USER_DEFINED_FUNCTION is
    port (in0: in std_logic;
          in1: in std_logic;
          out0: out std_logic;
          out1: out std_logic );
end USER_DEFINED_FUNCTION;
```

```
architecture RTL of USER_DEFINED_FUNCTION is
begin
   out0 <= work.PACKAGE1.func(in0, in1);
   out1 <= work.PACKAGE2.func(in0, in1);
end RTL;
```

Demand Loading

In the previous section, the user-defined function example successfully uses
SNS to determine the func function to implement. However, neither PACKAGE1
nor PACKAGE2 was declared as a use package clause (for example,
work.PACKAGE1.all;). How could func have been executed without a use package
declaration? A feature of SNS is demand loading: this loads the necessary
package without explicit use declarations. Demand loading lets you create
designs using SNS without use package declarations, which supports all
necessary constants, operators, and functions.

VHDL Implicit Data-type Defaults

Type default propagation avoids potential simulation mismatches that are the result of differences in behavior with how initial values for registers are treated in the synthesis tools and how they are treated in the simulation tools.

With implicit data-type defaults, when there is no explicit initial-value declaration for a signal being registered, the VHDL compiler passes an init value through a syn_init property to the mapper, and the mapper then propagates the value to the respective register. Compiler requirements are based on specific data types. These requirements can be broadly grouped based on the different data types available in the VHDL language.

Implicit data-type defaults are enabled on the VHDL panel of the Implementation Options dialog box or through a -supporttypedflt argument to a set_option command.

Top Level Entity:

```
[                                        ]
```

☑ Push Tristates
☐ Synthesis On/Off Implemented as Translate On/Off
☐ VHDL 2008
☑ Implicit Initial Value Support
☐ Beta Features for VHDL
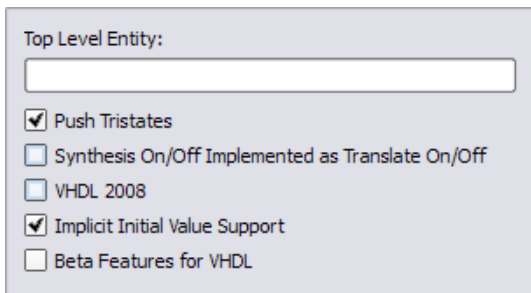
To illustrate the use of implicit data-type defaults, consider the following example.

```
library ieee;
use ieee.std_logic_1164.all;

entity top is
   port (clk:in std_logic;
         a : in integer range 1 to 8;
         b : out integer range 1 to 8;
         d : out positive range 1 to 7 );
end entity top;
```

```
architecture rtl of top is
signal a1,a2 : integer range 1 to 8 ;
signal a3,a4 : positive range 1 to 7;
begin
a1 <= a ;
a3 <= a ;
b <= a2 ;
d <= a4 ;
   process(clk)
   begin
      if (rising_edge(clk))then
         a2 <= a1 ;
         a4 <= a3 ;
      end if;
   end process;
end rtl;
```

In the above example, two signals (a2 and a4) with different type default values are registered. Without implicit data-type defaults, if the values of the signals being registered are not the same, the compiler merges the redundant logic into a single register as shown in the figure below.
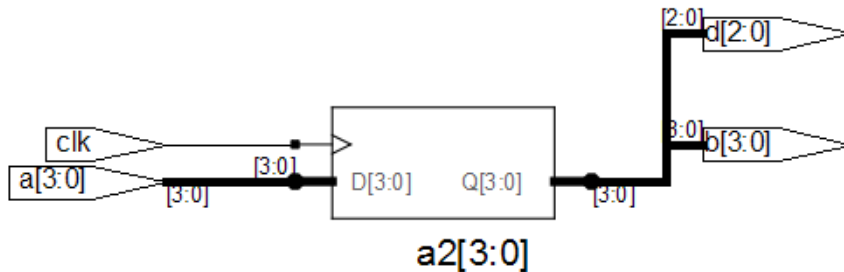
Enabling implicit data-type defaults prevents certain compiler and mapper optimizations to preserve both registers as shown in the following figure.
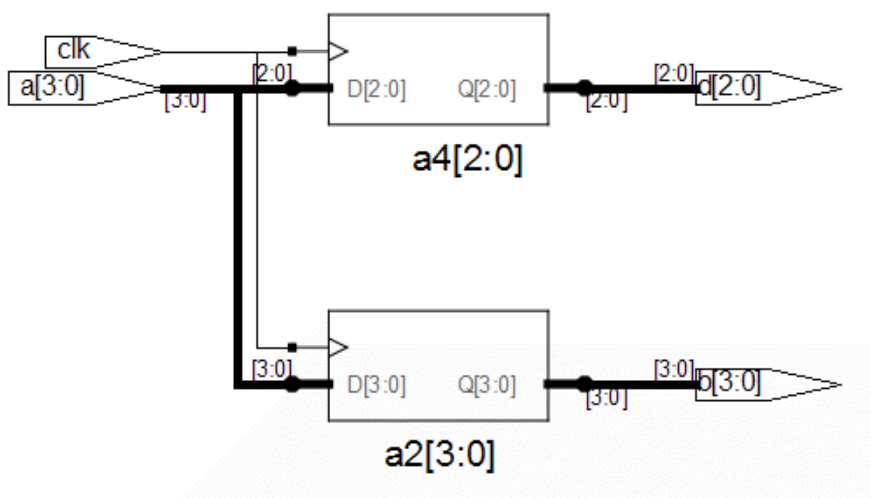
Example – Impact on Integer Ranges

The default value for the integer type when a range is specified is the minimum value of the range specified, and size is the upper limit of that range. With implicit data-type defaults, the compiler is required to propagate the minimum value of the range as the init value to the mapper. Consider the following example:

```
library ieee;
use ieee.std_logic_1164.all;

entity top is
   port (clk,set:in std_logic;
         a : in integer range -6 to 8;
         b : out integer range -6 to 8 );
end entity top;

architecture rtl of top is
signal a1,a2: integer range -6 to 8;
begin
a1 <= a ;
   process(clk,set)
   begin
      if (rising_edge(clk))then
```

```
                    if set = '1' then
                       a2 <= a;
                    else
                       a2 <= a1 ;
                    end if;
                 end if;
              end process;
          b <= a2;
          end rtl;
```

In the example,

```
     signal a1, a2: integer range -6 to 8;
```

the default value is -6 (FA in 2's complement) and the range is -6 to 8. With a total of 15 values, the size of the range can be represented in four bits.

Example – Impact on RAM Inferencing

When inferencing a RAM with implicit data-type defaults, the compiler propagates the type default values as init values for each RAM location. The mapper must check if the block RAMs of the selected technology support initial values and then determine if the compiler-propagated init values are to be considered. If the mapper chooses to ignore the init values, a warning is issued stating that the init values are being ignored. Consider the following VHDL design:

```
library ieee;
use ieee.std_logic_1164.all;
use ieee.std_logic_arith.all;
use ieee.std_logic_unsigned.all;

entity top is
   port (clk : in std_logic;
         addr : in std_logic_vector (6 downto 0);
         din : in positive;
         wen : in std_logic;
         dout : out positive );
end top;

architecture behavioral of top is
-- RAM
type tram is array(0 to 127) of  positive ;
signal ram : tram ;
begin
-- Contents of RAM has initial value = 1
   process (clk)
```

```
      begin
         if clk'event and clk = '1' then
            if wen = '1' then
               ram(conv_integer(addr)) <= din_sig;
            end if;
         dout <= ram(conv_integer(addr));
         end if;
      end process;
   end behavioral;
```

In the above example:

- The type of signal a1 is bit_vector

- The default value for type integer is 1 when no range is specified

Accordingly, a value of x00000001 is propagated by the compiler to the mapper with a syn_init property.

VHDL Synthesis Guidelines

This section provides guidelines for synthesis using VHDL. The following topics are covered:

General Synthesis Guidelines

Some general guidelines are presented here to help you synthesize your VHDL design.

- Top-level entity and architecture. The synthesis tool chooses the top-level entity and architecture – the last architecture for the last entity in the last file compiled. Entity selection can be overridden from the VHDL panel of the Implementation Options dialog box. Files are compiled in the order they appear – from top to bottom in the Project view source files list.

- Simulate your design before synthesis because it exposes logic errors. Logic errors that are not caught are passed through the synthesis tool, and the synthesized results will contain the same logic errors.

- Simulate your design after placement and routing. Have the place-and-route tool generate a post placement and routing (timing-accurate) simulation netlist, and do a final simulation before programming your devices.

- Avoid asynchronous state machines. To use the synthesis tool for asynchronous state machines, make a netlist of technology primitives from your target library.

- For modeling level-sensitive latches, it is simplest to use concurrent signal assignments.

VHDL Language Guidelines

This section discusses VHDL language guidelines.

Processes

- A process must have either a sensitivity list or one wait statement.

- Each sequential process can be triggered from exactly one clock and only one edge of clock (and optional sets and resets).

- Avoid combinational loops in processes. Make sure all signals assigned in a combinational process are explicitly assigned values every time the process executes; otherwise, the synthesis tool needs to insert level-sensitive latches in your design to hold the last value for the paths that do not assign values. This might represent a mistake on your part, so the synthesis tool issues a warning message that level-sensitive latches are being inserted into your design. You will get an warning message if you have combinational loops in your design that are not recognized as level-sensitive latches (for example, if you have an asynchronous state machine).

Assignments

- Assigning an 'X' or '-' to a signal is interpreted as a "don't care", so the synthesis tool creates the hardware that is the most efficient design.

Data Types

- Integers are 32-bit quantities. If you declare a port as an integer data type, specify a range (for example, my_input: in integer range 0 to 7). Otherwise, your synthesis result file will contain a 32-bit port.

- Enumeration types are represented as a vector of bits. The encoding can be sequential, gray, or one hot. You can manually choose the encoding for ports with an enumeration type.

Model Template

You can place any number of concurrent statements (signal assignments, processes, component instantiations, and generate statements) in your architecture body as shown in the following example. The order of these statements within the architecture is not significant, as all can execute concurrently.

- The statements between the begin and the end in a process execute sequentially, in the order you type them from top to bottom.

- You can add comments in VHDL by proceeding your comment text with two dashes "--". Any text from the dashes to the end of the line is treated as a comment, and ignored by the synthesis tool.

```
-- List libraries/packages that contain definitions you use
library <library_name> ;
use <library_name>.<package_name>.all ;

-- The entity describes the interface for your design.
entity <entity_name> is
    generic ( <define_interface_constants_here> ) ;
       port ( <port_list_information_goes_here> ) ;
end <entity_name> ;

-- The architecture describes the functionality (implementation)
-- of your design
architecture <architecture_name> of <entity_name> is

-- Architecture declaration region.
-- Declare internal signals, data types, and subprograms here
```

```
-- If you will create hierarchy by instantiating a
-- component (which is just another architecture), then
-- declare its interface here with a component declaration;
component <entity_name_instantiated_below>
   port (<port_list_information_as_defined_in_the_entity>) ;
end component ;

begin    -- Architecture body, describes functionality

-- Use concurrent statements here to describe the functionality
-- of your design. The most common concurrent statements are the
-- concurrent signal assignment, process, and component
-- instantiation.

-- Concurrent signal assignment (simple form):
<result_signal_name> <= <expression> ;

-- Process:
process <sensitivity list>)
-- Declare local variables, data types,
-- and other local declarations here
begin
-- Sequential statements go here, including:
   --    signal and variable assignments
   --    if and case statements
   --    while and for loops
   --    function and procedure calls
end process;

-- Component instantiation
<instance_name> : <entity_name>
   generic map (<override values here >)
   port map (<port list>) ;
end <architecture_name> ;
```

Constraint Files for VHDL Designs

In previous versions of the software, all object names output by the compiler were converted to lower case. This means that any constraints files created by dragging from the RTL view or through the SCOPE UI contained object names using only lower case. Case is preserved on design object names. If you use mixed-case names in your VHDL source, for constraints to be applied correctly, you must manually update any older constraint files or re-create constraints in the SCOPE editor.

Creating Flip-flops and Registers Using VHDL Processes

It is easy to create flip-flops and registers using a process in your
VHDL design.

process Template

```
process (<sensitivity list>)
begin
   <sequential statement(s)>
end;
```

To create a flip-flop:

1. List your clock signal in the sensitivity list. Recall that if the value of any
   signal listed in the sensitivity list changes, the process is triggered, and
   executes. For example,

   ```
   process (clk)
   ```

2. Check for rising_edge or falling_edge as the first statement inside the
   process. For example,

   ```
   process (clk)
   begin
      if rising_edge(clk) then
         <sequential statement(s)>
   ```

   or

   ```
   process (clk)
   begin
      if falling_edge(clk) then
         <sequential statement(s)>
   ```

   Alternatively, you could use an if clk'event and clk = '1' then statement to test
   for a rising edge (or if clk'event and clk = '0' then for a falling edge). Although
   these statements work, for clarity and consistency, use the rising_edge
   and falling_edge functions from the VHDL 1993 standard.

3. Set your flip-flop output to a value, with no delay, if the clock edge
   occurred. For example, q <= d ;.

Complete Example

```
library ieee;
use ieee.std_logic_1164.all;

entity dff_or is
   port (a, b, clk: in std_logic;
         q: out std_logic );
end dff_or;

architecture sensitivity_list of dff_or is
begin
   process (clk) -- Clock name is in sensitivity list
   begin
      if rising_edge(clk) then
         q <= a or b;
      end if;
   end process;
end sensitivity_list ;
```

In this example, if clk has an event on it, the process is triggered and starts executing. The first statement (the if statement) then checks to see if a rising edge has occurred for clk. If the if statement evaluates to true, there was a rising edge on clk and the q output is set to the value of a or b. If the clk changes from 1 to 0, the process is triggered and the if statement executes, but it evaluates to false and the q output is not updated. This is the functionality of a flip-flop, and synthesis correctly recognizes it as such and connects the result of the a or b expression to the data input of a D-type flip-flop and the q signal to the q output of the flip-flop.

Note: The signals you set inside the process will drive the data inputs of D-type flip-flops.

Synplify Pro for Microsemi Edition Language Support Reference

Clock Edges

There are many ways to correctly represent clock edges within a process including those shown here.

The typical rising clock edge representation is:

```
rising_edge(clk)
```

Other supported rising clock edge representations are:

```
clk = '1' and clk'event
clk'last_value = '0' and clk'event
clk'event and clk /= '0'
```

The typical falling clock edge representation is:

```
falling_edge(clk)
```

Other supported falling clock edge representations are:

```
clk = '0' and clk'event
clk'last_value = '1' and clk'event
clk'event and clk /= '1'
```

Incorrect or Unsupported Representations for Clock Edges

Rising clock edge:

```
clk = '1'
clk and clk'event -- Because clk is not a Boolean
```

Falling clock edge:

```
clk = '0'
not clk and clk'event -- Because clk is not a Boolean
```

Defining an Event Outside a Process

The 'event attribute can be used outside of a process block. For example, the process block

```
process (clk,d)
begin
   if (clk='1' and clk'event) then
      q <= d;
   end if;
end process;
```

can be replaced by including the following line outside of the process statement:

```
q <= d when (clk='1' and clk'event);
```

Using a WAIT Statement Inside a Process

The synthesis tool supports a wait statement inside a process to create flip-flops, instead of using a sensitivity list.

Example

```
library ieee;
use ieee.std_logic_1164.all;

entity dff_or is
   port (a, b, clk: in std_logic;
         q: out std_logic );
end dff_or;

architecture wait_statement of dff_or is
begin
   process -- Notice the absence of a sensitivity list.
   begin
-- The process waits here until the condition becomes true
      wait until rising_edge(clk);
         q <= a or b;
   end process;
end wait_statement;
```

Rules for Using wait Statements Inside a Process

- It is illegal in VHDL to have a process with a wait statement and a sensitivity list.

- The wait statement must either be the first or the last statement of the process.

Clock Edge Representation in wait Statements

The typical rising clock edge representation is:

```
wait until rising_edge(clk);
```

Other supported rising clock edge representations are:

```
wait until clk = '1' and clk'event
wait until clk'last_value = '0' and clk'event
wait until clk'event and clk /= '0'
```

The typical falling clock edge representation is:

```
wait until falling_edge(clk)
```

Other supported falling clock edge representations are:

```
wait until clk = '0' and clk'event
wait until clk'last_value = '1' and clk'event
wait until clk'event and clk /= '1'
```

Level-sensitive Latches Using Concurrent Signal Assignments

To model level-sensitive latches in VHDL, use a concurrent signal assignment statement with the conditional signal assignment form (also known as when-else).

Syntax

signal **<=** *value1* **when** *condition1* **else**
value2 **when** *condition2* **else**
valueN-1 **when** *conditionN-1* **else**
valueN **;**

Example

In VHDL, you are not allowed to read the value of ports of mode out inside of an architecture that it was declared for. Ports of mode buffer can be read from and written to, but must have no more than one driver for the port in the architecture. In the following port statement example, q is defined as mode buffer.

```
library ieee;
use ieee.std_logic_1164.all;

entity latchor1 is
   port (a, b, clk : in std_logic;
-- q has mode buffer so it can be read inside architecture
        q: buffer std_logic );
end latchor1;

architecture behave of latchor1 is
begin
   q <= a or b when clk = '1' else q;
end behave;
```

Whenever clk, a, or b changes, the expression on the right side re-evaluates. If clk becomes true (active, logic 1), the value of a or b is assigned to the q output. When the clk changes and becomes false (deactivated), q is assigned to q (holds the last value of q). If a or b changes, and clk is already active, the new value of a or b is assigned to q.

Level-sensitive Latches Using VHDL Processes

Although it is simpler to specify level-sensitive latches using concurrent signal assignment statements, you can create level-sensitive latches with VHDL processes. Follow the guidelines given here for the sensitivity list and assignments.

process Template

```
process (<sensitivity list>)
begin
   <sequential statement(s)>
end process;
```

Sensitivity List

The sensitivity list specifies the clock signal, and the signals that feed into the data input of the level-sensitive latch. The sensitivity list must be located immediately after the process keyword.

Syntax

process (*clock_name***,** *signal1***,** *signal2***,** ...**)**

Example

```
process (clk, data)
```

process Template for a Level-sensitive Latch

```
process (<clock, data_signals ... > ...)
begin
   if (<clock> = <active_value>)
      <signals> <= <expression involving data signals> ;
   end if;
end process ;
```

All data signals assigned in this manner become logic into data inputs of level-sensitive latches.

Whenever level-sensitive latches are generated from a process, the synthesis tool issues a warning message so that you can verify if level-sensitive latches are really what you intended. Often a thorough simulation of your architecture will reveal mistakes in coding style that can cause the creation of level-sensitive latches during synthesis.

Example: Creating Level-sensitive Latches that You Want

```
library ieee;
use ieee.std_logic_1164.all;

entity latchor2 is
   port (a, b, clk : in std_logic ;
         q: out std_logic );
end latchor2;
```

```
architecture behave of latchor2 is
begin
   process (clk, a, b)
   begin
      if clk = '1' then
         q <= a or b;
      end if;
   end process ;
end behave;
```

If there is an event (change in value) on either clk, a or b, and clk is a logic 1, set q to a or b.

What to do when clk is a logic 0 is not specified (there is no else), so when clk is a logic zero, the last value assigned is maintained (there is an implicit q=q). The synthesis tool correctly recognizes this as a level-sensitive latch, and creates a level-sensitive latch in your design. It will issue a warning message when you compile this architecture, but after examination, this warning message can safely be ignored.

Example: Creating Unwanted Level-sensitive Latches

This design demonstrates the level-sensitive latch warning caused by a missed assignment in the when two => case. The message generated is:

> "Latch generated from process for signal odd, probably caused by a missing assignment in an if or case statement".

This information will help you find a functional error even before simulation.

```
library ieee;
use ieee.std_logic_1164.all;

entity mistake is
   port (inp: in std_logic_vector (1 downto 0);
         outp: out std_logic_vector (3 downto 0);
         even, odd: out std_logic );
end mistake;

architecture behave of mistake is
   constant zero: std_logic_vector (1 downto 0):= "00";
   constant one: std_logic_vector (1 downto 0):= "01";
   constant two: std_logic_vector (1 downto 0):= "10";
   constant three: std_logic_vector (1 downto 0):= "11";
begin
   process (inp)
   begin
```

```
        case inp is
           when zero =>
              outp <= "0001";
              even <= '1';
              odd <= '0';
           when one =>
              outp <= "0010";
              even <= '0';
              odd <= '1';
           when two =>
              outp <= "0100";
              even <= '1';
-- Notice that assignment to odd is mistakenly commented out next.

              -- odd <= '0';
           when three =>
              outp <= "1000";
              even <= '0';
              odd <= '1';
        end case;
     end process;
  end behave;
```

Signed mod Support for Constant Operands

The synthesis tool supports signed mod for constant operands. Additionally, division operators (/, rem, mod), where the operands are compile-time constants and greater than 32 bits, are supported.

Example of using signed mod operator with constant operands

```
LIBRARY ieee; USE ieee.std_logic_1164.ALL;
LIBRARY ieee; USE ieee.numeric_std.all;

ENTITY divmod IS
   PORT (tstvec: out  signed(7 DOWNTO 0) );
END divmod;

ARCHITECTURE structure OF divmod IS
   CONSTANT NOMINATOR   : signed(7 DOWNTO 0) := "10000001";
   CONSTANT DENOMINATOR : signed(7 DOWNTO 0) := "00000011";
   CONSTANT RESULT      : signed(7 DOWNTO 0) := NOMINATOR mod
      DENOMINATOR;
BEGIN
   tstvec <= result;
```

```
END ARCHITECTURE structure;
```

Example of a signed division with a constant right operand.

```
LIBRARY ieee ; USE ieee.std_logic_1164.ALL;
LIBRARY ieee ; USE ieee.numeric_std.all;

ENTITY divmod IS
    PORT (tstvec: out  signed(7 DOWNTO 0) );
END divmod;

ARCHITECTURE structure OF divmod IS
    CONSTANT NOMINATOR   : signed(7 DOWNTO 0) := "11111001";
    CONSTANT DENOMINATOR : signed(7 DOWNTO 0) := "00000011";
    CONSTANT RESULT      : signed(7 DOWNTO 0) := NOMINATOR /
        DENOMINATOR;
BEGIN
    tstvec <= result;

END ARCHITECTURE structure;
```

An example where the operands are greater than 32 bits

```
LIBRARY ieee; USE ieee.std_logic_1164.ALL;
LIBRARY ieee; USE ieee.numeric_std.all;

ENTITY divmod IS
    PORT (tstvec: out  unsigned(33 DOWNTO 0) );
END divmod;

ARCHITECTURE structure OF divmod IS
    CONSTANT NOMINATOR   : unsigned(33 DOWNTO 0) :=
    "10000000000000000000000000000000000";
    CONSTANT DENOMINATOR : unsigned(32 DOWNTO 0) :=
    "000000000000000000000000000000011";
    CONSTANT RESULT      : unsigned(33 DOWNTO 0) := NOMINATOR /
        DENOMINATOR;
BEGIN
    tstvec <= result;
END ARCHITECTURE structure;
```

Sets and Resets

This section describes VHDL sets and resets, both asynchronous and synchronous. A set signal is an input to a flip-flop that, when activated, sets the state of the flip-flop to a logic one. A reset signal is an input to a flip-flop that, when activated, sets the state of the flip-flop to a logic zero.

The topics include:

- Asynchronous Sets and Resets, on page 313
- Synchronous Sets and Resets, on page 314

Asynchronous Sets and Resets

By definition, asynchronous sets and resets are independent of the clock and do not require an active clock edge. Therefore, you must include the set and reset signals in the sensitivity list of your process so they trigger the process to execute.

Sensitivity List

The sensitivity list is a list of signals (including ports) that, when there is an event (change in value), triggers the process to execute.

Syntax

process (clk_name**,** set_signal_name**,** reset_signal_name **)**

The signals are listed in any order, separated by commas.

Example: process Template with Asynchronous, Active-high reset, set

```
process (clk, reset, set)
begin
   if reset = '1' then
-- Reset the outputs to zero.
   elsif set = '1' then
-- Set the outputs to one.
   elsif rising_edge(clk) then -- Rising clock edge clock
-- Clocked logic goes here.
   end if;
end process;
```

Example: D Flip-flop with Asynchronous, Active-high reset, set

```
library ieee;
use ieee.std_logic_1164.all;

entity dff1 is
   port (data, clk, reset, set : in std_logic;
         qrs: out std_logic );
end dff1;

architecture async_set_reset of dff1 is
begin
   setreset: process(clk, reset, set)
   begin
      if reset = '1' then
         qrs <= '0';
      elsif set = '1' then
         qrs <= '1';
      elsif rising_edge(clk) then
         qrs <= data;
      end if;
   end process setreset;
end async_set_reset;
```

Synchronous Sets and Resets

Synchronous sets and resets set flip-flop outputs to logic '1' or '0' respectively on an active clock edge.

Do not list the set and reset signal names in the sensitivity list of a process so they will not trigger the process to execute upon changing. Instead, trigger the process when the clock signal changes, and check the reset and set as the first statements.

RTL View Primitives

The VHDL compiler can detect and extract the following flip-flops with synchronous sets and resets and display them in the RTL schematic view:

- sdffr – f lip-flop with synchronous reset

- sdffs – flip-flop with synchronous set

- sdffrs – flip-flop with both synchronous set and reset

- sdffpat – vectored flip-flop with synchronous set/reset pattern

- sdffre – enabled flip-flop with synchronous reset

- sdffse – enabled flip-flop with synchronous set

- sdffpate – enabled, vectored flip-flop with synchronous set/reset pattern

You can check the name (type) of any primitive by placing the mouse pointer over it in the RTL view: a tooltip displays the name.

Sensitivity List

The sensitivity list is a list of signals (including ports) that, when there is an event (change in value), triggers the process to execute.

Syntax

process (clk_signal_name **)**

Example: process Template with Synchronous, Active-high reset, set

```
process(clk)
begin
   if rising_edge(clk) then
      if reset = '1' then
         -- Set the outputs to '0'.
      elsif set = '1' then
         -- Set the outputs to '1'.
      else
         -- Clocked logic goes here.
      end if ;
   end if ;
end process;
```

Example: D Flip-flop with Synchronous, Active-high reset, set

```
library ieee;
use ieee.std_logic_1164.all;

entity dff2 is
   port (data, clk, reset, set : in std_logic;
         qrs: out std_logic );
end dff2;

architecture sync_set_reset of dff2 is
begin
   setreset: process (clk)
   begin
      if rising_edge(clk) then
         if reset = '1' then
            qrs <= '0';
         elsif set = '1' then
            qrs <= '1';
         else
            qrs <= data;
         end if;
      end if;
   end process setreset;
end sync_set_reset;
```

VHDL State Machines

This section describes VHDL state machines: guidelines for using them, defining state values with enumerated types, and dealing with asynchrony. The topics include:

- State Machine Guidelines, on page 317

- Using Enumerated Types for State Values, on page 321

- Simulation Tips When Using Enumerated Types, on page 322

- Asynchronous State Machines in VHDL, on page 323

State Machine Guidelines

A finite state machine (FSM) is hardware that advances from state to state at a clock edge.

The synthesis tool works best with synchronous state machines. You typically write a fully synchronous design, avoiding asynchronous paths such as paths through the asynchronous reset of a register. See Asynchronous State Machines in VHDL, on page 323 for information about asynchronous state machines.

The following are guidelines for coding FSMs:

- The state machine must have a synchronous or asynchronous reset, to be inferred. State machines must have an asynchronous or synchronous reset to set the hardware to a valid state after power-up, and to reset your hardware during operation (asynchronous resets are available freely in most FPGA architectures).

- The synthesis tool does not infer implicit state machines that are created using multiple wait statements in a process.

- Separate the sequential process statements from the combinational ones. Besides making it easier to read, it makes what is being registered very obvious. It also gives better control over the type of register element used.

- Represent states with defined labels or enumerated types.

- Use a case statement in a process to check the current state at the clock edge, advance to the next state, and set the output values. You can also use if-then-else statements.

- Assign default values to outputs derived from the FSM before the case statement. This helps prevent the generation of unwanted latches and makes it easier to read because there is less clutter from rarely used signals.

- If you do not have case statements for all possible combinations of the selector, use a when others assignment as the last assignment in your case statement and set the state vector to some valid state. If your state vector is not an enumerated type, set the value to X. Assign the state to X in the default clause of the case statement, to avoid mismatches between pre- and post-synthesis simulations. See Example: Default Assignment, on page 321.

- Override the default encoding style with the syn_encoding attribute. The default encoding is determined by the number of states, where a non-default encoding is implemented if it produces better results. See Values for syn_encoding, on page 37 for a list of default and other encodings. When you specify a particular encoding style with syn_encoding, that value is used during the mapping stage to determine encoding style.

```
attribute syn_encoding : string;
attribute syn_encoding of <typename> : type is "sequential";
```

One-hot implementations are not always the best choice for state machines, even in FPGAs and CPLDs. For example, one-hot state machines might result in higher speeds in CPLDs, but could cause fitting problems because of the larger number of global signals. An example in an FPGA with ineffective one-hot implementation is a state machine that drives a large decoder, generating many output signals. In a 16-state state machine, for example, the output decoder logic might reference sixteen signals in a one-hot implementation, but only four signals in an encoded representation.

In general, do not use the directive syn_enum_encoding to set the encoding style. Use syn_encoding instead. The value of syn_enum_encoding is used by the compiler to interpret the enumerated data types but is ignored by the mapper when the state machine is actually implemented.

The directive syn_enum_encoding affects the final circuit only when you have turned off the FSM Compiler. Therefore, if you are not using FSM Compiler or the syn_state_machine attribute, which use syn_encoding, you can use syn_enum_encoding to set the encoding style.

• Implement user-defined enumeration encoding, beyond the one-hot, gray, and sequential styles. Use the directive syn_enum_encoding to set the state encoding. See Example: FSM User-Defined Encoding, on page 320.

Example: FSM Coding Style

```
architecture behave of test is
   type state_value is (deflt, idle, read, write);
   signal state, next_state: state_value;
begin
-- Figure out the next state
   process (clk, rst)
   begin
      if rst = '0' then
         state <= idle;
      elsif rising_edge(clk) then
         state <= next_state;
      end if;
   end process;

   process (state, enable, data_in)
   begin
      data_out <= '0';
      -- Catch missing assignments to next_state
      next_state <= idle;
      state0 <= '0';
      state1 <= '0';
      state2 <= '0';
      case state is
         when idle =>
            if enable = '1' then
               state0 <= '1' ;data_out <= data_in(0);
               next_state <= read;
            else next_state <= idle;
            end if;
         when read =>
            if enable = '1' then
               state1 <= '1'; data_out <= data_in(1);
               next_state <= write;
            else next_state <= read;
            end if;
```

```
         when deflt =>
            if enable = '1' then
               state2 <= '1' ;data_out <= data_in(2);
               next_state <= idle;
            else next_state <= write;
            end if;
         when others => next_state <= deflt;
      end case;
   end process;
end behave;
```

Example: FSM User-Defined Encoding

```
library ieee;
use ieee.std_logic_1164.all;

entity shift_enum is
   port (clk, rst : bit;
         O : out std_logic_vector(2 downto 0) );
end shift_enum;

architecture behave of shift_enum is
type state_type is (S0, S1, S2);
attribute syn_enum_encoding: string;
attribute syn_enum_encoding of state_type : type is "001 010 101";
signal machine : state_type;
begin
   process (clk, rst)
   begin
      if rst = '1' then
         machine <= S0;
      elsif clk = '1' and clk'event then
         case machine is
            when S0 => machine <= S1;
            when S1 => machine <= S2;
            when S2 => machine <= S0;
         end case;
      end if;
   end process;

   with machine select
      O <= "001" when S0,
      "010" when S1,
      "101" when S2;
end behave;
```

Example: Default Assignment

The second others keyword in the following example pads (covers) all the bits. In this way, you need not remember the exact number of X's needed for the state variable or output signal.

```
when others =>
    state := (others => 'X') ;
```

Assigning X to the state variable (a "don't care" for synthesis) tells the synthesis tool that you have specified all the used states in your case statement, and any unnecessary decoding and gates related to other cases can therefore be removed. You do not have to add any special, non-VHDL directives.

If you set the state to a used state for the when others case (for example: when others => state <= delft), the synthesis tool generates the same logic as if you assign X, but there will be pre- and post-synthesis simulation mismatches until you reset the state machine. These mismatches occur because all inputs are unknown at start up on the simulator. You therefore go immediately into the when others case, which sets the state variable to state1. When you power up the hardware, it can be in a used state, such as state2, and then advance to a state other than state1. Post-synthesis simulation behaves more like hardware with respect to initialization.

Using Enumerated Types for State Values

Generally, you represent states in VHDL with a user-defined enumerated type.

Syntax

type *type_name* **is (** *state1_name*, *state2_name*, ... , *stateN_name* **) ;**

Example

```
type states is (st1, st2, st3, st4, st5, st6, st7, st8);
begin
-- The statement region of a process or subprogram.
next_state := st2 ;
-- Setting the next state to st2
```

Simulation Tips When Using Enumerated Types

You want initialization in simulation to mimic the behavior of hardware when it powers up. Therefore, do not initialize your state machine to a known state during simulation, because the hardware will not be in a known state when it powers up.

Creating an Extra Initialization State

If you use an enumerated type for your state vector, create an extra initialization state in your type definition (for example, stateX), and place it first in the list, as shown in the example below.

```
type state is (stateX, state1, state2, state3, state4);
```

In VHDL, the default initial value for an enumerated type is the leftmost value in the type definition (in this example, stateX). When you begin the simulation, you will be in this initial (simulation only) state.

Detecting Reset Problems

In your state machine case statement, create an entry for staying in stateX when you get in stateX. For example:

```
when stateX => next_state := stateX;
```

Look for your design entering stateX. This means that your design is not resetting properly.

Note: The synthesis tool does not create hardware to represent this initialization state (stateX). It is removed during optimization.

Detecting Forgotten Assignment to the Next State

Assign your next state value to stateX right before your state machine case statement.

Example

```
next_state := stateX;
case (current_state) is
...
   when state3 =>
      if (foo = '1') then
         next_state := state2;
      end if;
...
end case;
```

Asynchronous State Machines in VHDL

Avoid defining asynchronous state machines in VHDL. An asynchronous state machine has states, but no clearly defined clock, and has combinational loops. However, if you must use asynchronous state machines, you can do one of the following:

- Create a netlist of the technology primitives from the target library for your technology vendor. Any instantiated primitives that are left in the netlist are not removed during optimization.

- Use a schematic editor for the asynchronous state machine part of your design.

Do not use the synthesis tool to design asynchronous state machines; the tool might remove your hazard-suppressing logic when it performs logic optimization, causing your asynchronous state machine to work incorrectly.

The synthesis tool displays a "found combinational loop" warning message for an asynchronous FSM when it detects combinational loops in continuous assignment statements, processes and built-in gate-primitive logic.

Asynchronous State Machines that Generate Error Messages

In this example, both async1 and async2 will generate combinational loop errors, because of the recursive definition for output.

```vhdl
library ieee;
use ieee.std_logic_1164.all;

entity async is
-- output is a buffer mode so that it can be read
   port (output : buffer std_logic ;
         g, d : in std_logic ) ;
end async ;

-- Asynchronous FSM from concurrent assignment statement
architecture async1 of async is
begin
   -- Combinational loop error, due to recursive output definition.
   output <= (((((g and d) or (not g)) and output) or d) and
      output);
end async1;

-- Asynchronous FSM created within a process
architecture async2 of async is
begin
   process(g, d, output)
   begin
-- Combinational loop error, due to recursive output definition.
      output <= (((((g and d) or (not g)) and output) or d) and
         output);
   end process;
end async2;
```

Hierarchical Design Creation in VHDL

Creating hierarchy is similar to creating a schematic. You place available parts from a library onto a schematic sheet and connect them.

To create a hierarchical design in VHDL, you instantiate one design unit inside of another. In VHDL, the design units you instantiate are called components. Before you can instantiate a component, you must declare it (step 2, below).

The basic steps for creating a hierarchical VHDL design are:

1. Write the design units (entities and architectures) for the parts you wish to instantiate.

2. Declare the components (entity interfaces) you will instantiate.

3. Instantiate the components, and connect (map) the signals (including top-level ports) to the formal ports of the components to wire them up.

Step 1 – Write Entities and Architectures

Write entities and architectures for the design units to instantiate.

```
library ieee;
use ieee.std_logic_1164.all;

entity muxhier is
   port (outvec: out std_logic_vector (7 downto 0);
         a_vec, b_vec: in std_logic_vector (7 downto 0);
         sel: in std_logic );
end muxhier;

architecture mux_design of muxhier is
begin
-- <mux functionality>
end mux_design;
```

```
library ieee;
use ieee.std_logic_1164.all;

entity reg8 is
   port (q: buffer std_logic_vector (7 downto 0);
         data: in std_logic_vector (7 downto 0);
         clk, rst: in std_logic );
end reg8;

architecture reg8_design of reg8 is -- 8-bit register
begin
-- <8-bit register functionality>
end reg8_design;

library ieee;
use ieee.std_logic_1164.all;

entity rotate is
   port (q: buffer std_logic_vector (7 downto 0);
         data: in std_logic_vector (7 downto 0);
         clk, rst, r_l: in std_logic );
end rotate;

architecture rotate_design of rotate is
begin
-- Rotates bits or loads
-- When r_l is high, it rotates; if low, it loads data
-- <Rotation functionality>
end rotate_design;
```

Step 2 – Declare the Components

Components are declared in the declarative region of the architecture with a component declaration statement.

The component declaration syntax is:

```
component entity_name
    port (port_list ) ;
end component ;
```

The entity_name and port_list of the component must match exactly that of the entity you will be instantiating.

Example

```
architecture structural of top_level_design is
-- Component declarations are placed here in the
-- declarative region of the architecture.

component muxhier -- Component declaration for mux
   port (outvec: out std_logic_vector (7 downto 0);
         a_vec, b_vec: in std_logic_vector (7 downto 0);
         sel: in std_logic );
end component;

component reg8 -- Component declaration for reg8
   port (q: out std_logic_vector (7 downto 0);
         data: in std_logic_vector (7 downto 0);
         clk, rst: in std_logic );
end component;

component rotate  -- Component declaration for rotate
   port (q: buffer std_logic_vector (7 downto 0);
         data: in std_logic_vector (7 downto 0);
         clk, rst, r_l: in std_logic );
end component;
begin
-- The structural description goes here.
end structural;
```

Step 3 – Instantiate the Components

Use the following syntax to instantiate your components:

> *unique_instance_name* **:** *component_name*
>   [**generic map (***override_generic_values* **)]**
>   **port map (***port_connections* **) ;**

You can connect signals either with positional mapping (the same order declared in the entity) or with named mapping (where you specify the names of the lower-level signals to connect). Connecting by name minimizes errors, and especially advantageous when the component has many ports. To use configuration specification and declaration, refer to Configuration Specification and Declaration, on page 329.

Example

```
library ieee;
use ieee.std_logic_1164.all;

entity top_level is
   port (q: buffer std_logic_vector (7 downto 0);
         a, b: in std_logic_vector (7 downto 0);
         sel, r_l, clk, rst: in std_logic );
end top_level;

architecture structural of top_level is
-- The component declarations shown in Step 2 go here.
-- Declare the internal signals here
signal mux_out, reg_out: std_logic_vector (7 downto 0);

begin
-- The structural description goes here.
-- Instantiate a mux, name it inst1, and wire it up.
-- Map (connect) the ports of the mux using positional association.
inst1: muxhier port map (mux_out, a, b, sel);

-- Instantiate a rotate, name it inst2, and map its ports.
inst2: rotate port map (q, reg_out, clk, r_l, rst);

-- Instantiate a reg8, name it inst3, and wire it up.
-- reg8 is connected with named association.
-- The port connections can be given in any order.
-- Notice that the actual (local) signal names are on
-- the right of the '=>' mapping operators, and the
-- formal signal names from the component
-- declaration are on the left.
inst3: reg8 port map (
   clk => clk,
   data => mux_out,
   q => reg_out,
   rst => rst );

end structural;
```

Configuration Specification and Declaration

A configuration declaration or specification can be used to define binding information of component instantiations to design entities (entity-architecture pairs) in a hierarchical design. After the structure of one level of a design has been fully described using components and component instantiations, a designer must describe the hierarchical implementation of each component.

A configuration declaration or specification can also be used to define binding information of design entities (entity-architecture pairs) that are compiled in different libraries.

This section discusses usage models of the configuration declaration statement supported by the synthesis tool. The following topics are covered:

Component declarations and component specifications are not required for a component instantiation where the component name is the same as the entity name. In this case, the entity and its last architecture denote the default binding. In direct-entity instantiations, the binding information is available as the entity is specified, and the architecture is optionally specified. Configuration declaration and/or configuration specification are required when the component name does not match the entity name. If configurations are not used in this case, VHDL simulators give error messages, and the synthesis tool creates a black box and continues synthesis.

Configuration Specification

A configuration specification associates binding information with component labels that represent instances of a given component declaration. A configuration specification is used to bind a component instance to a design entity, and to specify the mapping between the local generics and ports of the component instance and the formal generics and ports of the entity. Optionally, a configuration specification can bind an entity to one of its architectures. The synthesis tool supports a subset of configuration specification commonly used in RTL synthesis; this section discusses that support.

The following Backus-Naur Form (BNF) grammar is supported (VHDL-93 LRM pp.73-79):

configuration_specification ::=

   for component_specification   binding_indication **;**

component_specification ::=

   instantiation_list : component_name

instantiation_list ::=

   instantiation_label {, instantiation_label } | **others** | **all**

binding_indication ::= [**use** entity_aspect]
                                    [generic_map_aspect]
                                    [port_map_aspect]

entity_aspect ::=

   entity entity_name [(architecture_identifier)] |
   configuration configuration_name
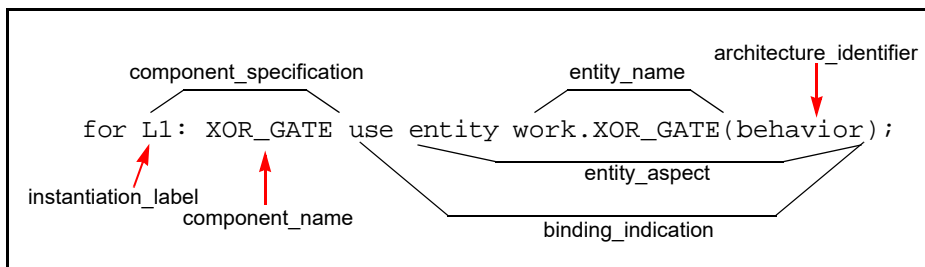

```
for others: AND_GATE use entity work.AND_GATE(structure);
for all: XOR_GATE use entity work.XOR_GATE;
```

Example: Configuration Specification

In the following example, two architectures (RTL and structural) are defined for an adder. There are two instantiations of an adder in design top. A configuration statement defines the adder architecture to use for each instantiation.

```
library IEEE;
use IEEE.std_logic_1164.all;

entity adder is
   port (a : in std_logic;
         b : in std_logic;
         cin : in std_logic;
         s : out std_logic;
         cout : out std_logic );
end adder;

library IEEE;
use IEEE.std_logic_unsigned.all;

architecture rtl of adder is
signal tmp : std_logic_vector(1 downto 0);
begin
   tmp <= ('0' & a) - b - cin;
   s <= tmp(0);
   cout <= tmp(1);
end rtl;

architecture structural of adder is
begin
   s <= a xor b xor cin;
   cout <= ((not a) and b and cin) or ( a and (not b) and cin)
      or (a and b and (not cin)) or ( a and b and cin);
end structural;

library IEEE;
use IEEE.std_logic_1164.all;

entity top is
   port (a : in std_logic_vector(1 downto 0);
         b : in std_logic_vector(1 downto 0);
         c : in std_logic;
         cout : out std_logic;
         sum : out std_logic_vector(1 downto 0));
end top;
```

```
architecture top_a of top is
component myadder
   port (a : in std_logic;
         b : in std_logic;
         cin : in std_logic;
         s : out std_logic;
         cout : out std_logic);
end component;

signal carry : std_logic;
for s1 : myadder use entity work.adder(structural);
for r1 : myadder use entity work.adder(rtl);
begin
   s1 : myadder port map ( a(0), b(0), c, sum(0), carry);
   r1 : myadder port map ( a(1), b(1), carry, sum(1), cout);
end top_a;
```

Results
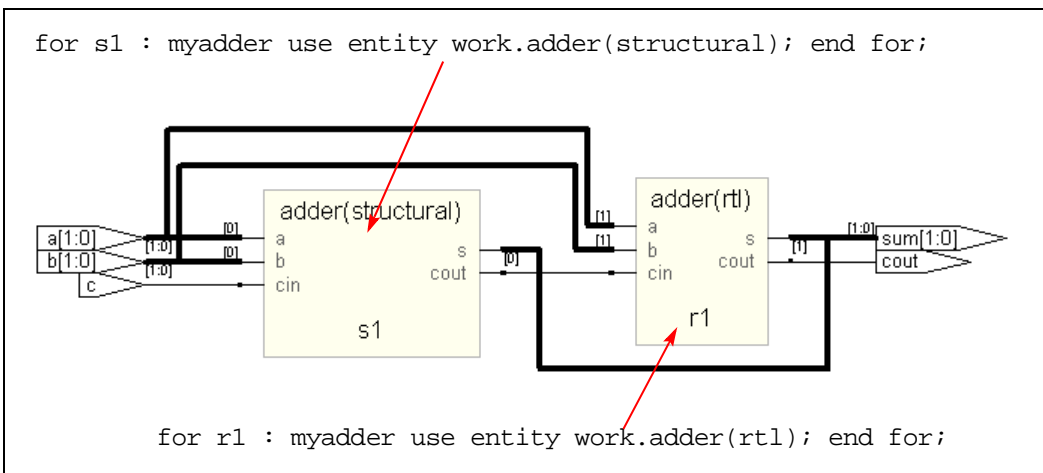
Unsupported Constructs for Configuration Specification

The following configuration specification construct is *not* supported by the synthesis tool. An appropriate message is issued in the log file when this construct is used.

- The VHDL-93 LRM defines entity_aspect in the binding indication as:

  entity_aspect ::=

  > **entity** entity_name [(architecture_identifier)] |
  > **configuration** configuration_name | **open**

  The synthesis tool supports entity_name and configuration_name in the entity_aspect of a binding indication. The tool does not yet support the open construct.

Configuration Declaration

Configuration declaration specifies binding information of component instantiations to design entities (entity-architecture pairs) in a hierarchical design. Configuration declaration can bind component instantiations in an architecture, in either a block statement, a for…generate statement, or an if…generate statement. It is also possible to bind different entity-architecture pairs to different indices of a for…generate statement.

The synthesis tool supports a subset of configuration declaration commonly used in RTL synthesis. The following Backus-Naur Form (BNF) grammar is supported (VHDL-93 LRM pp.11-17):

configuration_declaration ::=

> **configuration** identifier **of** entity_name **is**
>
> > block_configuration
>
> **end** [**configuration**] [configuration_simple_name] ;

block_configuration ::=

> **for** block_specification
>
> > { configuration_item }
>
> **end for** ;

block_specification ::=

      achitecture_name | block_statement_label |
      generate_statement_label [(index_specification)]

index_specification ::=

      discrete_range | static_expression

configuration_item ::=

      block_configuration | component_configuration

component_configuration ::=

      for component_specification
        [binding_indication **;**]
        [block_configuration]
      end for ;

The BNF grammar for component_specification and binding_indication is described in Configuration Specification, on page 329.

Configuration Declaration within a Hierarchy

The following example shows a configuration declaration describing the binding in a 3-level hierarchy, for…generate statement labeled label1, within block statement blk1 in architecture arch_gen3. Each architecture implementation of an instance of my_and1 is determined in the configuration declaration and depends on the index value of the instance in the for…generate statement.

```
entity and1 is
   port(a,b: in bit ; o: out bit);
end;

architecture and_arch1 of and1 is
begin
   o <= a and b;
end;

architecture and_arch2 of and1 is
begin
   o <= a and b;
end;

architecture and_arch3 of and1 is
begin
   o <= a and b;
end;

library WORK; use WORK.all;
entity gen3_config is
   port(a,b: in bit_vector(0 to 7);
        res: out bit_vector(0 to 7));
end;

library WORK; use WORK.all;
architecture arch_gen3 of gen3_config is
component my_and1 port(a,b: in bit ; o: out bit); end component;
begin
   label1: for i in 0 to 7 generate
      blk1: block
      begin
         a1: my_and1 port map(a(i),b(i),res(i));
      end block;
   end generate;
end;
```

```
library work;
configuration config_gen3_config of gen3_config is
    for arch_gen3 -- ARCHITECTURE block_configuration "for
          -- block_specification"
       for label1 (0 to 3) --GENERATE block_config "for
          -- block_specification"
          for blk1 -- BLOCK block_configuration "for
          -- block_specification"
          -- {configuration_item}
             for a1 : my_and1 -- component_configuration
             -- Component_specification "for idList : compName"
                use entity work.and1(and_arch1); --
binding_indication
             end for; -- a1 component_configuration
          end for; -- blk1 BLOCK block_configuration
       end for; -- label1 GENERATE block_configuration
       for label1 (4) -- GENERATE block_configuration "for
          -- block_specification"
          for blk1
             for a1 : my_and1
                use entity work.and1(and_arch3);
             end for;
          end for;
       end for;

       for label1 (5 to 7)
          for blk1
             for a1 : my_and1
                use entity work.and1(and_arch2);
             end for;
          end for;
       end for;
    end for; -- ARCHITECTURE block_configuration
end config_gen3_config;
```

Selection with Configuration Declaration

In the following example, two architectures (RTL and structural) are defined for an adder. There are two instantiations of an adder in design top. A configuration declaration defines the adder architecture to use for each instantiation. This example is similar to the configuration specification example.

```
library IEEE;
use IEEE.std_logic_1164.all;
```

```
entity adder is
   port (a : in std_logic;
         b : in std_logic;
         cin : in std_logic;
         s : out std_logic;
         cout : out std_logic );
end adder;

library IEEE;
use IEEE.std_logic_unsigned.all;

architecture rtl of adder is
signal tmp : std_logic_vector(1 downto 0);
begin
   tmp <= ('0' & a) - b - cin;
   s <= tmp(0);
   cout <= tmp(1);
end rtl;

architecture structural of adder is
begin
   s <= a xor b xor cin;
   cout <= ((not a) and b and cin) or ( a and (not b) and cin) or
      (a and b and (not cin)) or ( a and b and cin);
end structural;

library IEEE;
use IEEE.std_logic_1164.all;

entity top is
   port (a : in std_logic_vector(1 downto 0);
         b : in std_logic_vector(1 downto 0);
         c : in std_logic;
         cout : out std_logic;
         sum : out std_logic_vector(1 downto 0) );
end top;

architecture top_a of top is
component myadder
   port (a : in std_logic;
         b : in std_logic;
         cin : in std_logic;
         s : out std_logic;
         cout : out std_logic);
end component;
```

```
        signal carry : std_logic;
        begin
            s1 : myadder port map ( a(0), b(0), c, sum(0), carry);
            r1 : myadder port map ( a(1), b(1), carry, sum(1), cout);
        end top_a;

        library work;
        configuration config_top of top is -- configuration_declaration
            for top_a -- block_configuration "for block_specification"
            -- component_configuration
                for s1: myadder -- component_specification
                    use entity work.adder (structural); -- binding_indication
                end for; -- component_configuration
            -- component_configuration
                for r1: myadder -- component_specification
                    use entity work.adder (rtl); -- binding_indication
                end for; -- component_configuration
            end for; -- block_configuration
        end config_top;
```

Results
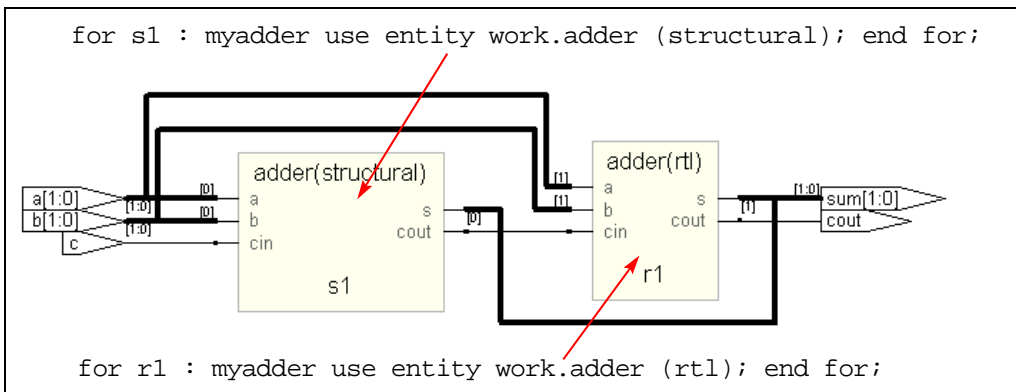
Direct Instantiation of Entities Using Configuration

In this method, a configured entity (i.e., an entity with a configuration declaration) is directly instantiated by writing a component instantiation statement that directly names the configuration.

Syntax

```
label : configuration configurationName
    [generic map (actualGeneric1, actualGeneric2, ... ) ]
    [port map ( port1, port2, ... ) ] ;
```

Example – Direct Instantiation Using Configuration Declaration

```
//TECHPUBS Example - Direct Instantiation Using Configuration
Declaration

--Entity to be instantiated using the configuration

library ieee;

use ieee.std_logic_1164.all;

entity module0 is

    generic (SIZE : integer := 10);

    port (l : in std_logic_vector(SIZE-1 downto 0);

        m : in std_logic_vector(SIZE-1 downto 0);

        out1 : out std_logic_vector(SIZE-1 downto 0) );

end entity module0;

architecture behv of module0 is

begin

    out1 <= l xor m;

end behv;

-- Configuration for the entity module0

configuration conf_sub of module0 is

    for behv

    end for;

end conf_sub;

-- Module in which the entity module0 is instantiated

-- using the configuration

library ieee;
```

```
use ieee.std_logic_1164.all;

entity top is

    port (in0 : in std_logic_vector(31 downto 0);

        in1 : in std_logic_vector(31 downto 0);

        out1 : out std_logic_vector(31 downto 0) );

end entity top;

architecture behv of top is

begin

U0: configuration conf_sub

    generic map (SIZE => 32)

    port map (l => in0,

        m => in1,

        out1 => out1 );

end behv;
```

Unsupported Constructs for Configuration Declaration

The following are the configuration declaration constructs that are *not* supported by the synthesis tool. Appropriate messages are displayed in the log file if these constructs are used.

1. The VHDL-93 LRM defines the configuration declaration as:

    configuration_declaration ::=

        configuration identifier **of** entity_name **is**
            configuration_declarative_part
            block_configuration
        end [**configuration**] [configuration_simple_name] **;**

    configuration_declarative_part ::= { configuration_declarative_item }

    configuration_declarative_item ::=

        use_clause | attribute_specification | group_declaration

The synthesis tool does not support the configuration_declarative_part. It parses the use_clause and attribute_specification without any warning message. The group_declaration is not supported and an error message is issued.

2. VHDL-93 LRM defines entity aspect in the binding indication as:

entity_aspect ::=

> **entity** entity_name [(architecture_identifier)] |
> **configuration** configuration_name | **open**

block_configuration ::=

> **for** block_specification
>   { use_clause }
>   { configuration_item }
> **end for ;**

The synthesis tool does not support use_clause in block_configuration. This construct is parsed and ignored.

VHDL Configuration Statement Enhancement

This section highlights the VHDL configuration statement support and handling component declarations with corresponding entity descriptions. Topics include:

- Generic mapping, on page 342

- Port Mapping, on page 343

- Mapping Multiple Entity Names to the Same Component, on page 344

- Generics Assigned to Configurations, on page 345

- Arithmetic Operators and Functions in Generic Maps, on page 349

- Ports in Component Declarations, on page 351

Generic mapping

Generics and ports can have different names and sizes at the entity and component levels. You use the configuration statement to bind them together with a configuration specification or a configuration declaration. The binding priority follows this order:

- Configuration specification

- Component specification

- Component declaration

```
library ieee;
use ieee.std_logic_1164.all;

entity test is
generic ( range1 : integer := 11);
   port (a, a1 : in std_logic_vector( range1 - 1 downto 0);
         b, b1 : in std_logic_vector( range1 - 1 downto 0);
         c, c1 : out std_logic_vector( range1 - 1 downto 0) );
end test;

architecture test_a of test is
component submodule1 is
generic ( size : integer := 6);
   port (a : in std_logic_vector(size -1 downto 0);
         b : in std_logic_vector(size -1 downto 0);
         c : out std_logic_vector(size -1 downto 0) );
end component;

for all : submodule1
use entity work.sub1(rtl)
generic map (size => range1);
begin
   UUT1 : submodule1 generic map (size => 4)
   port map (a => a,b => b,c => c);

end test_a;
```

If you define the following generic map for sub1, it takes priority:

```
entity sub1 is
generic(size: integer:=1);
   port (a: in std_logic_vector(size -1 downto 0);
         b : in std_logic_vector(size -1 downto 0);
         c : out std_logic_vector(size -1 downto 0 );
end sub1;
```

Port Mapping

See Generic mapping, on page 342 for information about using the configuration statement and binding priority.

```
library ieee;
use ieee.std_logic_1164.all;

entity test is
generic ( range1 : integer := 1);
   port (ta, ta1 : in std_logic_vector( range1 - 1 downto 0);
         tb, tb1 : in std_logic_vector( range1 - 1 downto 0);
         tc, tc1 : out std_logic_vector( range1 - 1 downto 0) );
end test;

architecture test_a of test is
component submodule1
generic ( my_size1 : integer := 6; my_size2 : integer := 6);
   port (d : in std_logic_vector(my_size1 -1 downto 0);
         e : in std_logic_vector(my_size1 -1 downto 0);
         f : out std_logic_vector(my_size2 -1 downto 0) );
end component;

for UUT1 : submodule1
use entity work1.sub1(rtl)
generic map (size1 => my_size1, size2 => my_size2)
port map ( a => d, b => e, c => f);

   begin
   UUT1 : submodule1 generic map (my_size1 => 1, my_size2 => 1)
   port map (d => ta, e => tb,f => tc);
   end test_a;
```

If you define the following port map for sub1, it overrides the previous definition:

```
entity sub1 is
generic(size1: integer:=6; size2:integer:=6);
port (a: in std_logic_vector (size1 -1 downto 0);
      b : in std_logic_vector (size1 -1 downto 0);
      c : out std_logic_vector (size2 -1 downto 0 );
end sub1:
```

Mapping Multiple Entity Names to the Same Component

When a single component has multiple entities, you can use the configuration statement and the for label clause to bind them. The following is an example:

```
entity test is
generic ( range1 : integer := 1);
   port (ta, ta1 : in std_logic_vector(range1 - 1 downto 0);
         tb, tb1 : in std_logic_vector(range1 - 1 downto 0);
         tc, tc1 : out std_logic_vector(range1 - 1 downto 0));
end test;

architecture test_a of test is
component submodule
generic (my_size1 : integer := 6; my_size2 : integer := 6);
   port (d,e : in std_logic_vector(my_size1 -1 downto 0);
         f : out std_logic_vector(my_size2 -1 downto 0));
end component;

begin
UUT1 : submodule generic map (1, 1)
   port map (d => ta, e => tb, f => tc);
UUT2 : submodule generic map (1, 1) port map
   (d => ta1, e => tb1, f => tc1)
end test_a;

configuration my_config of test is
for test_a
   for UUT1 : submodule
      use entity work.sub1(rtl)
      generic map (my_size1, my_size2)
      port map (d, e, f);
   end for;
   for others : submodule
      use entity work.sub2(rtl)
      generic map (my_size1, my_size2)
      port map ( d, e, f);
   end for;
end for;
end my_config;
```

You can map multiple entities to the same component, as shown here:

```
entity sub1 is
generic(size1: integer:=6; size2:integer:=6);
port (a: in std_logic_vector (size1 -1 downto 0);
      b : in std_logic_vector (size1 -1 downto 0);
      c : out std_logic_vector (size2 -1 downto 0 );
end sub1:

entity sub2 is
generic(width1: integer; width2:integer);
port (a1: in std_logic_vector(width1 -1 downto 0);
      b1 : in std_logic_vector (width1 -1 downto 0);
      c1 : out std_logic_vector (width2 -1 downto 0 );
end sub1:
```

Generics Assigned to Configurations

Generics can be assigned to configurations instead of entities.

Entities can contain more generics than their associated component declarations. Any additional generics on the entities must have default values to be able to synthesize.

Entities can also contain fewer generics than their associated component declarations. The extra generics on the component have no affect on the implementation of the entity.

Following are some examples.

Example1

Configuration conf_module1 contains a generic map on configuration conf_c. The component declaration for submodule1 does not have the generic use_extra-SYN_ff, however, the entity has it.

```
library ieee;
use IEEE.std_logic_1164.all;

entity submodule1 is
generic (width : integer := 16;
use_extraSYN_ff : boolean := false);
   port (clk : in std_logic;
         b : in std_logic_vector(width - 1 downto 0);
         c : out std_logic_vector(width - 1 downto 0) );
end submodule1;
```

```
architecture rtl of submodule1 is
signal d : std_logic_vector(width - 1 downto 0);
begin
no_resynch : if use_extraSYN_ff = false generate
   d <= b;
end generate no_resynch;

resynch : if use_extraSYN_ff = true generate
   process (clk)
   begin
      if falling_edge(clk) then
         d <= b;
      end if;
   end process;
end generate resynch;

   process (clk)
   begin
      if rising_edge(clk) then
         c <= d;
      end if;
   end process;
end rtl;

configuration conf_c of submodule1 is
   for rtl
   end for;
end configuration conf_c;

library ieee;
use ieee.std_logic_1164.all;

entity module1 is
generic ( width: integer := 16);
   port (clk : in std_logic;
         b : in std_logic_vector(width - 1 downto 0);
         c : out std_logic_vector(width - 1 downto 0) );
end module1;

architecture rtl of module1 is
component submodule1
generic (width: integer := 8);
   port (clk : in std_logic;
         b : in std_logic_vector(width - 1 downto 0);
         c : out std_logic_vector(width - 1 downto 0) );
end component;
```

```
      begin
      UUT2 : submodule1 port map (clk => clk,
         b => b,
         c => c);
      end rtl;

      library ieee;
      configuration conf_module1 of module1 is
         for rtl
            for UUT2 : submodule1
               use configuration conf_c generic map( width => 16,
               use_extraSYN_ff => true);
            end for;
         end for;
      end configuration conf_module1;
```

Example2

The component declaration for mod1 has the generic size, which is not in the
entity. A component declaration can have more generics than the entity,
however, extra component generics have no affect on the entity's implementa-
tion.

```
      library ieee;
      use ieee.std_logic_1164.all;

      entity module1 is
      generic (width: integer := 16;
      use_extraSYN_ff : boolean := false);
         port (clk : in std_logic;
               b : in std_logic_vector ( width - 1 downto 0);
               c : out std_logic_vector( width - 1 downto 0) );
      end module1;

      architecture rtl of module1 is
      signal d : std_logic_vector(width - 1 downto 0);
      begin
         no_resynch : if use_extraSYN_ff = false generate
            d <= b ;
      end generate no_resynch;
```

```
resynch : if use_extraSYN_ff = true generate -- insert pipeline
   -- registers
   process (clk)
   begin
      if falling_edge(clk) then
         d <= b;
      end if;
   end process;
end generate resynch;

   process (clk)
   begin
      if rising_edge(clk) then
         c <= d;
      end if;
   end process;
end rtl;

configuration module1_c of module1 is
   for rtl
   end for;
end module1_c;

library ieee;
use ieee.std_logic_1164.all;

entity test is
   port (clk : in std_logic;
         tb : in std_logic_vector( 7 downto 0);
         tc : out std_logic_vector( 7 downto 0) );
end test;

architecture test_a of test is
component mod1
generic (width: integer := 16;
use_extraSYN_ff: boolean := false;
size : integer := 8);
   port (clk : in std_logic;
         b : in std_logic_vector(width - 1 downto 0);
         c : out std_logic_vector(width - 1 downto 0) );
end component;

begin
UUT1 : mod1 generic map (width => 18)
   port map (clk => clk,
      b => tb,
      c => tc);
end test_a;
```

```
Configuration test_c of test is
for test_a
   for UUT1 : mod1
      use configuration module1_c
      generic map (width => 8, use_extraSYN_ff => true);
   end for;
end for;
end test_c;
```

Arithmetic Operators and Functions in Generic Maps

Arithmetic operators and functions can be used in generic maps. Following is
an example.

Example

```
library ieee;
use ieee.std_logic_1164.all;
use ieee.std_logic_arith.all;

entity sub is
generic (width : integer:= 16);
   port (clk : in std_logic;
         a : in std_logic_vector (width - 1 downto 0);
         y : out std_logic_vector (width - 1 downto 0) );
end sub;

architecture rtl1 of sub is
begin
   process (clk, a)
   begin
      if (clk = '1' and clk'event) then
         y <= a;
      end if;
   end process;
end rtl1;

architecture rtl2 of sub is
begin y <= a;
end rtl2;

configuration sub_c of sub is
for rtl1 end for;
end sub_c;
```

```
library ieee;
use ieee.std_logic_1164.all;
use ieee.std_logic_arith.all;

entity test is
generic (mcu_depth : integer:=1;
mcu_width : integer:=16 );
   port (clk : in std_logic;
         a : in std_logic_vector
            ((mcu_depth*mcu_width)-1 downto 0);
         y : out std_logic_vector
            ((mcu_depth*mcu_width)-1downto 0));
end test;

architecture RTL of test is
constant CWIDTH : integer := 2;
constant size : unsigned := "100";
component sub generic ( width : integer );
   port (clk : in std_logic;
         a : in std_logic_vector (CWIDTH - 1 downto 0);
         y : out std_logic_vector (CWIDTH - 1 downto 0) );
end component;

begin i_sub : sub
generic map (width => CWIDTH ) port map (clk => clk,
   a => a,
   y => y );
end RTL;

library ieee;
use ieee.std_logic_arith.all;

configuration test_c of test is
   for RTL
      for i_sub : sub use
         configuration sub_c
         generic map(width => (CWIDTH ** (conv_integer (size)))));
      end for;
   end for;
end test_c;
```

Ports in Component Declarations

Entities can contain more or fewer ports than their associated component declarations. Following are some examples.

Example1

```
library ieee;
use ieee.std_logic_1164.all;

entity module1 is
generic ( width: integer := 16; use_extraSYN_ff : boolean :=
false);
   port (clk : in std_logic;
         b : in std_logic_vector ( width - 1 downto 0);
         a : out integer range 0 to 15; --extra output port
            on entity
         e : out integer range 0 to 15; -- extra output port
            on entity
         c : out std_logic_vector( width - 1 downto 0));
end module1;

architecture rtl of module1 is
signal d : std_logic_vector(width - 1 downto 0);
begin
e <= width;
a <= width;
no_resynch : if use_extraSYN_ff = false generate
   d <= b ;
end generate no_resynch;

resynch : if use_extraSYN_ff = true generate
   process (clk)
   begin
     if falling_edge(clk) then
        d <= b;
     end if;
   end process;
end generate resynch;

   process (clk)
   begin
     if rising_edge(clk) then
        c <= d;
     end if;
   end process;
end rtl;
```

```
configuration module1_c of module1 is
for rtl
end for;
end module1_c;

library ieee;
use ieee.std_logic_1164.all;

entity test is
   port (clk : in std_logic;
         tb : in std_logic_vector( 7 downto 0);
         tc : out std_logic_vector( 7 downto 0) );
end test;

architecture test_a of test is
component mod1
generic (width: integer := 16);
   port (clk : in std_logic;
         b : in std_logic_vector(width - 1 downto 0);
         c : out std_logic_vector(width - 1 downto 0) );
end component;

begin
UUT1 : mod1 generic map (width => 18)
port map (clk => clk,
   b => tb,
   c => tc);
end test_a;

Configuration test_c of test is
for test_a
   for UUT1 : mod1
      use configuration module1_c
      generic map (width => 8, use_extraSYN_ff => true);
   end for;
end for;
end test_c;
```

In the figure above, the entity module1 has extra ports a and e that are not defined in the corresponding component declaration mod1. The additional ports are not connected during synthesis.

Example2

```
LIBRARY ieee;
USE ieee.std_logic_1164.ALL;

ENTITY sub1 IS
GENERIC(
size1 : integer := 11;
size2 : integer := 12);
    PORT (r : IN std_logic_vector(size1 -1 DOWNTO 0);
          s : IN std_logic_vector(size1 -1 DOWNTO 0);
          t : OUT std_logic_vector(size2 -1 DOWNTO 0) );
END sub1;

ARCHITECTURE rtl OF sub1 IS
BEGIN
    t <= r AND s;
END ARCHITECTURE rtl;

LIBRARY ieee;
USE ieee.std_logic_1164.ALL;

ENTITY test IS
GENERIC (range1 : integer := 12);
    PORT (ta0 : IN std_logic_vector(range1 - 1 DOWNTO 0);
          tb0 : IN std_logic_vector(range1 - 1 DOWNTO 0);
          tc0 : OUT std_logic_vector(range1 - 1 DOWNTO 0) );
END test;
```

```
ARCHITECTURE test_a OF test IS
COMPONENT submodule
GENERIC (
my_size1 : integer := 4;
my_size2 : integer := 5);
    PORT (d : IN std_logic_vector(my_size1 -1 DOWNTO 0);
          e : IN std_logic_vector(my_size1 -1 DOWNTO 0);
          ext_1 : OUT std_logic_vector(my_size1 -1 DOWNTO 0);
          ext_2 : OUT std_logic_vector(my_size1 -1 DOWNTO 0);
          f : OUT std_logic_vector(my_size2 -1 DOWNTO 0) );
END COMPONENT;

BEGIN
UUT1 : submodule
GENERIC MAP (
my_size1 => range1,
my_size2 => range1)
    PORT MAP (ext_1 => open,
        ext_2 => open,
        d => ta0,
        e => tb0,
        f => tc0 );
END test_a;

CONFIGURATION my_config OF test IS
    FOR test_a
        FOR UUT1 : submodule
        USE ENTITY work.sub1(rtl)
        GENERIC MAP (
            size1 => my_size1,
            size2 => my_size2)
        PORT MAP (r => d,
            s => e,
            t => f );
        END FOR;
    END FOR; -- test_a
END my_config;
```
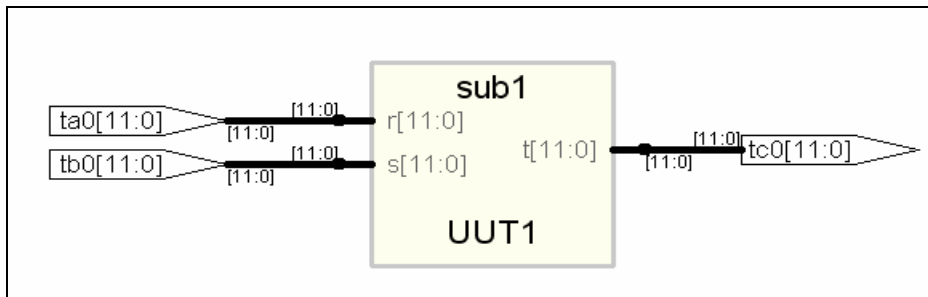
In the figure above, the component declaration has more ports (ext_1 ext_2) than entity sub1. The component is synthesized based on the number of ports on the entity.

Scalable Designs

This section describes creating and using scalable VHDL designs. You can create a VHDL design that is scalable, meaning that it can handle a user-specified number of bits or components.

- Creating a Scalable Design Using Unconstrained Vector Ports, on page 356
- Creating a Scalable Design Using VHDL Generics, on page 357
- Using a Scalable Architecture with VHDL Generics, on page 358
- Creating a Scalable Design Using Generate Statements, on page 360

Creating a Scalable Design Using Unconstrained Vector Ports

Do not size (constrain) the ports until you need them. This first example is coding the adder using the – operator, and gives much better synthesized results than the second and third scalable design examples, which code the adders as random logic.

Example

```
library ieee;
use ieee.std_logic_1164.all;
use ieee.std_logic_unsigned.all;
entity addn is
-- Notice that a, b, and result ports are not constrained.
-- In VHDL, they automatically size to whatever is connected
-- to them.
   port (result : out std_logic_vector;
         cout : out std_logic;
         a, b : in std_logic_vector;
         cin : in std_logic );
end addn;

architecture stretch of addn is
   signal tmp : std_logic_vector (a'length downto 0);
begin
-- The next line works because "-" sizes to the largest operand
-- (also, you need only pad one argument).
tmp <= ('0' & a) - b - cin;
```

```
      result <= tmp(a'length - 1 downto 0);
      cout <= tmp(a'length);
      assert result'length = a'length;
      assert result'length = b'length;
      end stretch;

      -- Top level design
      -- Here is where you specify the size for a, b,
      -- and result. It is illegal to leave your top
      -- level design ports unconstrained.

      library ieee;
      use ieee.std_logic_1164.all;

      entity addntest is
         port (result : out std_logic_vector (7 downto 0);
               cout : out std_logic;
               a, b : in std_logic_vector (7 downto 0);
               cin : in std_logic );
      end addntest;

      architecture top of addntest is
      component addn
         port (result : std_logic_vector;
               cout : std_logic;
               a, b : std_logic_vector;
               cin : std_logic );
      end component;

      begin
      test : addn port map (result => result,
         cout => cout,
         a => a,
         b => b,
         cin => cin );
      end;
```

Creating a Scalable Design Using VHDL Generics

Create a VHDL generic with default value. The generic is used to represent bus
sizes inside a architecture, or a number of components. You can define more
than one generic per declaration by separating the generic definitions with
semicolons (;).

Syntax

generic (*generic_1_name* **:** *type* [**:=** *default_value*]**) ;**

Examples

```
generic (num : integer := 8) ;
generic (top : integer := 16; num_bits : integer := 32);
```

Using a Scalable Architecture with VHDL Generics

Instantiate the scalable architecture, and override the default generic value with the generic map statement.

Syntax

generic map (*list_of_overriding_values***)**

Examples

Generic map construct

```
generic map (16)
-- These values will get mapped in order given.
generic map (8, 16)
```

Creating a scalable adder

```
library ieee;
use ieee.std_logic_1164.all;
entity adder is
    generic(num_bits : integer := 4); -- Default adder
        -- size is 4 bits
    port (a : in std_logic_vector (num_bits downto 1);
          b : in std_logic_vector (num_bits downto 1);
          cin : in std_logic;
          sum : out std_logic_vector (num_bits downto 1);
          cout : out std_logic );
end adder;
```

```
architecture behave of adder is
begin
   process (a, b, cin)
   variable vsum : std_logic_vector (num_bits downto 1);
   variable carry : std_logic;
   begin
   carry := cin;
      for i in 1 to num_bits loop
         vsum(i) := (a(i) xor b(i)) xor carry;
         carry := (a(i) and b(i)) or (carry and (a(i) or b(i)));
      end loop;
   sum <= vsum;
   cout <= carry;
   end process;
end behave;
```

Scaling the Adder by Overriding the generic Statement

```
library ieee;
use ieee.std_logic_1164.all;

entity adder16 is
   port (a : in std_logic_vector (16 downto 1);
         b : in std_logic_vector (16 downto 1);
         cin : in std_logic;
         sum : out std_logic_vector (16 downto 1);
         cout : out std_logic );
end adder16;

architecture behave of adder16 is
-- The component declaration goes here.
-- This allows you to instantiate the adder.
component adder
-- The default adder size is 4 bits.
generic(num_bits : integer := 4);
   port (a : in std_logic_vector ;
         b : in std_logic_vector;
         cin : in std_logic;
         sum : out std_logic_vector;
         cout : out std_logic );
end component;

begin
my_adder : adder
   generic map (16) -- Use a 16 bit adder
   port map(a, b, cin, sum, cout);
end behave;
```

Creating a Scalable Design Using Generate Statements

A VHDL generate statement allows you to repeat logic blocks in your design without having to write the code to instantiate each one individually.

Creating a 1-bit Adder

```
library ieee;
use ieee.std_logic_1164.all;

entity adder is
   port (a, b, cin : in std_logic;
         sum, cout : out std_logic );
end adder;

architecture behave of adder is
begin
   sum <= (a xor b) xor cin;
   cout <= (a and b) or (cin and a) or (cin and b);
end behave;
```

Instantiating the 1-bit Adder Many Times with a Generate Statement

```
library ieee;
use ieee.std_logic_1164.all;

entity addern is
generic(n : integer := 8);
   port (a, b : in std_logic_vector (n downto 1);
         cin : in std_logic;
         sum : out std_logic_vector (n downto 1);
         cout : out std_logic );
end addern;

architecture structural of addern is
-- The adder component declaration goes here.
component adder
   port (a, b, cin : in std_logic;
         sum, cout : out std_logic);
end component;
```

```vhdl
signal carry : std_logic_vector (0 to n);
begin
-- Generate instances of the single-bit adder n times.
-- You need not declare the index 'i' because
-- indices are implicitly declared for all FOR
-- generate statements.

gen: for i in 1 to n generate
   add: adder port map(
      a => a(i),
      b => b(i),
      cin => carry(i - 1),
      sum => sum(i),
      cout => carry(i));
end generate;

carry(0) <= cin;
cout <= carry(n);

end structural;
```

VHDL Guidelines for RAM Inference

This section provides guidelines for synthesis using RAMS and covers the following topics:

RAM Inference in VHDL Designs

The synthesis tool can automatically infer synchronous and synchronously resettable RAMs from your VHDL source code and, where appropriate, generate technology-specific single or dual-port RAMs. You do not need any special input, like attributes, in your source code for this inference. To override the automatic inference or specify implementations, use the syn_ramstyle attribute (syn_ramstyle, on page 108).

Automatic RAM inference and implementation is a two-step process:

- The compiler infers an RTL-level RAM component. This always has an asynchronous READ. The RAM component that is inferred can be one of the following:

RAM1	RAM component
RAM2	RAM component with reset
NRAM	RAM component with multiple ports

- During synthesis, the mappers convert the RTL-level RAM inferred by the compiler to the appropriate technology-specific RAM primitives. Depending on the technology used, the synthesized design can include RAM primitives with either synchronous or asynchronous READs. See Synchronous READ RAMs, on page 365, for information on coding your VHDL description to ensure that you get technology-specific RAM primitives with synchronous READs.

For certain technologies, the mappers implement single-port, dual-port, or multi-port RAMs. The following table lists the supported technology-specific RAMs that can be generated by the synthesis tool.

Technology vendor	Family	RAM Type
Microsemi	ProASIC3E	Single and dual port

Example

```
library ieee;
use ieee.std_logic_1164.all;
use ieee.std_logic_unsigned.all;

entity ram_test is
   port (d : in std_logic_vector(7 downto 0);
         a : in std_logic_vector(6 downto 0);
         we : in std_logic;
         clk : in std_logic;
         q : out std_logic_vector(7 downto 0) );
end ram_test;

architecture rtl of ram_test is
type mem_type is array (127 downto 0) of
   std_logic_vector (7 downto 0);
signal mem: mem_type;
begin
   process (clk)
   begin
      if rising_edge(clk) then
         if (we = '1') then
            mem(conv_integer (a)) <= d;
         end if;
      end if;
   end process;
q <= mem(conv_integer (a));

end rtl ;
```

Limited RAM Resources

If your RAM resources are limited, designate additional instances of inferred RAMs as flip-flops and logic using the syn_ramstyle attribute. This attribute takes the string argument of registers, placed on the RAM instance.

Additional Components

After inferring a RAM for some technologies, you might notice that the synthesis tool has generated a few additional components (glue logic) adjacent to the RAM. These components assure accuracy in your post placement and routing simulation results.

Multi-Port RAM Extraction

The compiler extracts multi-write port RAMs, creating an nram primitive which can have n write ports. The nrams are implemented differently depending on your technology. For information about the implementations, see the appropriate vendor chapter.

The following aspects of multi-port RAM extraction are described here:

Prerequisites for Multi-Port RAM Extraction

In order to infer the nram, you must do the following:

- The compiler will infer the nram even if you do not register the read address, as subsequent examples show. However, for many technology families, you must register the read address for the nram to be implemented as vendor RAMs.

- If the writes are in different processes, you no longer need to specify no_rw_check for the syn_ramstyle attribute in order to infer the RAM. Note that the simulator produces x's when the two writes occur at the same time while the synthesis tool assumes that one write gets priority over the other based on the code.

Write Processes and Multi-Port RAM Inference

The compiler infers the multi-port RAMs from the write processes as follows:

- When all the writes are made in one process, there are no address conflicts, and the compiler generates an nram.

- When writes are made in multiple processes, the software does not infer a multi-port RAM unless there is an explicit syn_ramstyle attribute. If there is no attribute, the software does not infer a RAM. If there is an attribute, the software infers a RAM with multiple write ports. You might get a warning about simulation mismatches when the two addresses are the same.

Multi-Port RAM Recommended Coding Style

Currently, you must use a registered read address when you code the RAM. If you do not, you could get error messages.

There are two situations which can result in the error message: "@E:MF216 : ram.v(29) | Found NRAM mem_1[7:0] with multiple processes":

- An nram with two clocks and two write addresses has syn_ramstyle set to a value of registers. The software cannot implement this, because there is a physical FPGA limitation that does not allow registers with multiple writes.

- You have a registered output for an nram with two clocks and two write addresses.

Synchronous READ RAMs

All RAM primitives that the synthesis tool generates for inferred RAMs have asynchronous READs.

Multi-port RAM Extraction

The compiler extracts multi-write port RAMs, creating an nram primitive which can have n write ports. The nrams are implemented differently depending on your technology. For more information about the implementations, see the appropriate vendor chapter.

In order for the compiler to infer an nram, you must do the following:

- Register the read address.

- Add the syn_ramstyle attribute.

The compiler then infers the multi-port RAMs from the write processes as follows:

- When all the writes are made in one process, there are no address conflicts, and the compiler generates an nram.

- When writes are made in multiple processes, the software does not infer a multi-port RAM unless there is an explicit syn_ramstyle attribute. If there is no attribute, the software does not infer a RAM. If there is an attribute, the software infers a RAM with multiple write ports. You might get a warning about simulation mismatches when the two addresses are the same.

- If the writes are in different processes, you no longer need to specify no_rw_check for the syn_ramstyle attribute in order to infer the RAM. Note that the simulator produces x's when the two writes occur at the same time while the synthesis tool assumes that one write gets priority over the other based on the code.

Multi-port RAM Recommended Coding Style

You must use a registered read address when you code the RAM or have writes to one process. If you have writes to multiple processes, you must use the syn_ramstyle attribute to infer the RAM.

There are two situations which can result in this error message: "@E:MF216 : ram.v(29) | Found NRAM mem_1[7:0] with multiple processes":

- An nram with two clocks and two write addresses has syn_ramstyle set to a value of registers. The software cannot implement this, because there is a physical FPGA limitation that does not allow registers with multiple writes.

- You have a registered output for an nram with two clocks and two write addresses.

Two-write Port RAM Example

```
library ieee;
use ieee.std_logic_1164.all;
use ieee.numeric_std.all;

entity one is
generic (data_width : integer := 4;
address_width :integer := 5 );
```

```
       port (data_a:in std_logic_vector(data_width-1 downto 0);
             data_b:in std_logic_vector(data_width-1 downto 0);
             addr_a:in std_logic_vector(address_width-1 downto 0);
             addr_b:in std_logic_vector(address_width-1 downto 0);
             wren_a:in std_logic;
             wren_b:in std_logic;
             clk:in std_logic;
             q_a:out std_logic_vector(data_width-1 downto 0);
             q_b:out std_logic_vector(data_width-1 downto 0) );
   end one;

   architecture rtl of one is
   type mem_array is array(0 to 2**(address_width) -1) of
   std_logic_vector(data_width-1 downto 0);
   signal mem : mem_array;
   attribute syn_ramstyle : string;
   attribute syn_ramstyle of mem : signal is "no_rw_check" ;
   signal addr_a_reg : std_logic_vector(address_width-1 downto 0);
   signal addr_b_reg : std_logic_vector(address_width-1 downto 0);
   begin
      WRITE_RAM : process (clk)
      begin
         if rising_edge(clk) then
            if (wren_a = '1') then
               mem(to_integer(unsigned(addr_a))) <= data_a;
            end if;
            if (wren_b='1') then
               mem(to_integer(unsigned(addr_b))) <= data_b;
            end if;
            addr_a_reg <= addr_a;
            addr_b_reg <= addr_b;
         end if;
      end process WRITE_RAM;
   q_a <= mem(to_integer(unsigned(addr_a_reg)));
   q_b <= mem(to_integer(unsigned(addr_b_reg)));
   end rtl;
```

Instantiating RAMs with SYNCORE

The SYNCORE Memory Compiler is available under the IP Wizard to help you
generate HDL code for your specific RAM implementation requirements. For
information on using the SYNCORE Memory Compiler, see *Specifying RAMs
with SYNCore,* on page 275 in the *User Guide.*

ROM Inference

As part of BEST (Behavioral Extraction Synthesis Technology) feature, the synthesis tool infers ROMs (read-only memories) from your HDL source code, and generates block components for them in the RTL view.

The data contents of the ROMs are stored in a text file named `rom.info`. To quickly view `rom.info` in read-only mode, synthesize your HDL source code, open an RTL view, then push down into the ROM component. For an example of the ROM data, refer to ROM Table Data (rom.info File), on page 103.

Generally, the synthesis tool infers ROMs from HDL source code that uses `case` statements, or equivalent `if` statements, to make 16 or more signal assignments using constant values (words). The constants must all be the same width.

Another requirement for ROM inference is that values must be specified for at least half of the address space. For example, if the ROM has 5 address bits, then the address space is 32 and at least 16 of the different addresses must be specified.

Example

```
library ieee;
use ieee.std_logic_1164.all;

entity rom4 is
   port (a : in std_logic_vector(4 downto 0);
         z : out std_logic_vector(3 downto 0) );
end rom4;

architecture behave of rom4 is
begin
   process(a)
   begin
      if a = "00000" then
         z <= "0001";
      elsif a = "00001" then
         z <= "0010";
      elsif a = "00010" then
         z <= "0110";
      elsif a = "00011" then
         z <= "1010";
      elsif a = "00100" then
         z <= "1000";
```

```
            elsif a = "00101" then
               z <= "1001";
            elsif a = "00110" then
               z <= "0000";
            elsif a = "00111" then
               z <= "1110";
            elsif a = "01000" then
               z <= "1111";
            elsif a = "01001" then
               z <= "1110";
            elsif a = "01010" then
               z <= "0001";
            elsif a = "01011" then
               z <= "1000";
            elsif a = "01100" then
               z <= "1110";
            elsif a = "01101" then
               z <= "0011";
            elsif a = "01110" then
               z <= "1111";
            elsif a = "01111" then
               z <= "1100";
            elsif a = "10000" then
               z <= "1000";
            elsif a = "10001" then
               z <= "0000";
            elsif a = "10010" then
               z <= "0011";
            else
               z <= "0111";
            end if;
      end process;
   end behave;
```

ROM Table Data (rom.info file)

```
Note: This data is for viewing only

ROM work.rom4(behave)-z_1[3:0]
address width: 5
data width: 4
inputs:
0: a[0]
1: a[1]
2: a[2]
3: a[3]
4: a[4]
outputs:
0: z_1[0]
1: z_1[1]
2: z_1[2]
3: z_1[3]

data:
00000 -> 0001
00001 -> 0010
00010 -> 0110
00011 -> 1010
00100 -> 1000
00101 -> 1001
00110 -> 0000
00111 -> 1110
01000 -> 1111
01001 -> 1110
01010 -> 0001
01011 -> 1000
01100 -> 1110
01101 -> 0011
01110 -> 0010
01111 -> 0010
10000 -> 0010
10001 -> 0010
10010 -> 0010
default -> 0111
```

Instantiating Black Boxes in VHDL

Black boxes are design units with just the interface specified; internal information is ignored by the synthesis tool. Black boxes can be used to directly instantiate:

- Technology-vendor primitives and macros (including I/Os).

- User-defined macros whose functionality was defined in a schematic editor, or another input source (when the place-and-route tool can merge design netlists from different sources).

Black boxes are specified with the syn_black_box synthesis directive, in conjunction with other directives. If the black box is a technology-vendor I/O pad, use the black_box_pad_pin directive instead.

Here is a list of the directives that you can use to specify modules as black boxes, and to define design objects on the black box for consideration during synthesis:

- syn_black_box

- black_box_pad_pin

- black_box_tri_pins

- syn_isclock

- syn_tco<*n*>

- syn_tpd<*n*>

- syn_tsu<*n*>

For information on how to instantiate black boxes and technology-vendor I/Os, see *Defining Black Boxes for Synthesis,* on page 378 of the *User Guide.*

Black-Box Timing Constraints

You can provide timing information for your individual black box instances. The following are the three predefined timing constraints available for black boxes.

- syn_tpd<*n*> – Timing propagation for combinational delay through the black box.

- syn_tsu<*n*> – Timing setup delay required for input pins (relative to the clock).

- syn_tco<*n*>– Timing clock to output delay through the black box.

Here, *n* is an integer from 1 through 10, inclusive. See Black-Box Timing Constraints, on page 372, for details about constraint syntax.

VHDL Attribute and Directive Syntax

Synthesis attributes and directives can be defined in the VHDL source code to control the way the design is analyzed, compiled, and mapped. *Attributes* direct the way your design is optimized and mapped during synthesis. *Directives* control the way your design is analyzed prior to compilation. Because of this distinction, directives must be included in your VHDL source code while attributes can be specified either in the source code or in a constraint file.

The synthesis tool directives and attributes are predefined in the attributes package in the synthesis tool library. This library package contains the built-in attributes, along with declarations for timing constraints (including black-box timing constraints) and vendor-specific attributes. The file is located here:

> *installDirectory*/lib/vhd/synattr.vhd

There are two ways to specify VHDL attributes and directives:

- Using the attributes Package, on page 373
- Declaring Attributes, on page 374

You can either use the attributes package or redeclare the types of directives and attributes each time you use them. You typically use the attributes package.

Using the attributes Package

This is the most typical way to specify the attributes, because you only need to specify the package once. You specify the attributes package, using the following code:

```
library synplify;
use synplify.attributes.all;
-- design_unit_declarations
attribute productname_attribute of object : object_type is value ;
```

The following is an example using syn_noclockbuf from the attributes package:

```
library synplify;
use synplify.attributes.all;

entity simpledff is
   port (q : out bit_vector(7 downto 0);
         d : in bit_vector(7 downto 0);
         clk : in bit );

// No explicit type declaration is necessary
attribute syn_noclockbuf of clk : signal is true;

-- Other code
```

Declaring Attributes

The alternative method is to declare the attributes to explicitly define them. You must do this each time you use an attribute. Here is the syntax for declaring directives and attributes in your code, without referencing the attributes package:

-- design_unit_declarations
attribute *attribute_name* **:** *data_type* **;**
attribute *attribute_name* **of** *object* **:** *object_type* **is** *value* **;**

Here is an example using the syn_noclockbuf attribute:

```
entity simpledff is
   port (q : out bit_vector(7 downto 0);
         d : in bit_vector(7 downto 0);
         clk : in bit);

// Explicit type declaration
attribute syn_noclockbuf : boolean;
attribute syn_noclockbuf of clk : signal is true;

-- Other code
```

Case Sensitivity

Although VHDL is case-insensitive, directives, attributes, and their values are case sensitive and must be declared in the code using the correct case. This rule applies especially for port names in directives.

For example, if a port in VHDL is defined as GIN, the following code does not work:

```
attribute black_box_tri_pin : string;
attribute black_box_tri_pin of BBDLHS : component is "gin";
```

The following code is correct because the case of the port name is correct:

```
attribute black_box_tri_pin : string;
attribute black_box_tri_pin of BBDLHS : component is "GIN";
```

VHDL Synthesis Examples

This section describes the VHDL examples that are provided with the synthesis tool. The topics include:

Combinational Logic Examples

The following combinational logic synthesis examples are included in the *installDirectory*/examples/vhdl/common_rtl/combinat directory:

- Adders

- ALU

- Bus Sorter (illustrates using procedures in VHDL)

- 3-to-8 Decoders

- 8-to-3 Priority Encoders

- Comparator

- Interrupt Handler (coded with an if-then-else statement for the desired priority encoding)

- Multiplexers (concurrent signal assignments, case statements, or if-then-else statements can be used to create multiplexers; the synthesis tool automatically creates parallel multiplexers when the conditions in the branches are mutually exclusive)

- Parity Generator

- Tristate Drivers

Sequential Logic Examples

The following sequential logic synthesis examples are included in the *installDirectory*/examples/vhdl/common_rtl/sequentl directory:

- Flip-flops and level-sensitive latches

- Counters (up, down, and up/down)

- Register file

- Shift register

- State machines

For additional information on synthesizing flip-flops and latches, see:

- Creating Flip-flops and Registers Using VHDL Processes, on page 303

- Level-sensitive Latches Using Concurrent Signal Assignments, on page 307

- Level-sensitive Latches Using VHDL Processes, on page 308

- Asynchronous Sets and Resets, on page 313

- Synchronous Sets and Resets, on page 314

PREP VHDL Benchmarks

PREP (Programmable Electronics Performance) Corporation distributes benchmark results that show how FPGA vendors compare with each other in terms of device performance and area.

The following PREP benchmarks are included in the *installDirectory*/examples/vhdl/common_rtl/prep directory:

- PREP Benchmark 1, Data Path (prep1.vhd)

- PREP Benchmark 2, Timer/Counter (prep2.vhd)

- PREP Benchmark 3, Small State Machine (prep3.vhd)

- PREP Benchmark 4, Large State Machine (prep4.vhd)

- PREP Benchmark 5, Arithmetic Circuit (prep5.vhd)

- PREP Benchmark 6, 16-Bit Accumulator (prep6.vhd)

- PREP Benchmark 7, 16-Bit Counter (prep7.vhd)

- PREP Benchmark 8, 16-Bit Pre-scaled Counter (prep8.vhd)

- PREP Benchmark 9, Memory Map (prep9.vhd)

The source code for the benchmarks can be used for design examples for synthesis or for doing your own FPGA vendor comparisons.

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CHAPTER 4

VHDL 2008 Language Support

This chapter describes support for the VHDL 2008 standard in the Synopsys FPGA synthesis tools. For information on the VHDL standard, see Chapter 3, *VHDL Language Support* and the IEEE 1076™-2008 standard. The following sections describe the current level of VHDL 2008 support.

Features

The support for VHDL 2008 includes:

Operators

VHDL 2008 includes support for the following operators:

- Logical Reduction operators – the logic operators: and, or, nand, nor, xor, and xnor can now be used as unary operators

- Condition operator (??) – converts a bit or std_ulogic value to a boolean value

- Matching Relational operators (?=, ?/=, ?<, ?<=, ?>, ?>=) – similar to the normal relational operators, but return bit or std_ulogic values in place of Boolean values

Bit-string Literals

Bit-string literal support in VHDL 2008 includes:

- Support for characters other than 0 and 1 in the bit string, such as X or Z.

  For example:

  X"Z45X" is equivalent to "ZZZZ01000101XXXX"

  B"0001-" is equivalent to "0001-"

  O"75X" is equivalent to "111101XXX"

- Optional support for a length specifier that determines the length of the string to be assigned.

  Syntax: [*length*] *baseSpecifier* **"***bitStringvalue***"**

  For example:

  12X"45" is equivalent to "000001000101"

  5O"17" is equivalent to "01111"

- Optional support for a signed (S) or unsigned (U) qualifier that determines how the bit-string value is expanded/truncated when a length specifier is used.

  Syntax: [*length*] **S**|**U** *baseSpecifier* **"***bitStringvalue***"**

  For example:

  12UB"101" is equivalent to "000000000101"

`12SB"101"` is equivalent to `"111111111101"`

`12UX"96"` is equivalent to `"000010010110"`

`12SX"96"` is equivalent to `"111110010110"`

- Additional support for a base specifier for decimal numbers (D). The number of characters in the bit string can be determined by using the expression $(\log_2 n)+1$; where n is the decimal integer.

  Syntax: [*length*] **D "***bitStringvalue***"**

  For example:

  `D"10"` is equivalent to `"1010"`

  `10D"35"` is equivalent to `"0000100011"`

For complete descriptions of bit-string literal requirements, see the VHDL 2008 LRM.

Logical Reduction Operators

The logical operators and, or, nand, nor, xor, and xnor can be used as unary operators.

Example – Logical Operators

```
--TECHPUBS Example 1: Logical Operators

entity reductionOpTest is

port (

invec: in bit_vector(2 downto 0);

nandout, xorout, xnorout, norout, orout, andout: out bit

);

end reductionOpTest;


architecture rtlArch of reductionOpTest is

begin

nandout <= nand invec;
```

```
xorout <= xor invec;

xnorout <= xnor invec;

norout <= nor invec;

orout <= or invec;

andout <= and invec;

end rtlArch;
```

Condition Operator

The condition operator (??) converts a bit or std_ulogic value to a boolean value. The operator is implicitly applied in a condition where the expression would normally be interpreted as a boolean value as shown in the if statement in the two examples below.

Example – VHDL 2008 Style Conditional Operator

```
--TECHPUBS Example 1: VHDL 2008 Style Conditional Operator

entity condOpTest is

port (

sel, in1, in2: in bit;

res: out bit

);

end condOpTest;

architecture rtlArch of condOpTest is

begin

process(in1,in2,sel)

begin

if sel then

res <= in2;

else
```

```
            res <= in1;

            end if;

            end process;

            end rtlArch;
```

Example – VHDL 1993 Style Conditional Operator

```
            --TECHPUBS Example 2: VHDL 1993 Style Conditional Operator

            entity condOpTest is

            port (

            sel, in1, in2: in bit;

            res: out bit

            );

            end condOpTest;

            architecture rtlArch of condOpTest is

            begin

            process(in1,in2,sel)

            begin

            if sel = '1' then

            res <= in2;

            else

            res <= in1;

            end if;

            end process;

            end rtlArch;
```

In the VHDL 2008 example, the statement

```
if sel then
```

is equivalent to:

```
if (?? sel) then
```

The implicit use of the ?? operator occurs in the following conditional expressions:

- after if or elsif in an if statement

- after if in an if-generate statement

- after until in a wait statement

- after while in a while loop

- after when in a conditional signal statement

- after assert in an assertion statement

- after when in a next statement or an exit statement

Matching Relational Operators

The matching relational operators return a bit or std_ulogic result in place of a Boolean.

Example – Relational Operators

```
--TECHPUBS Example: Relational Operator

entity relOpTest is

port (

in1, in2: in bit;

res_eq, res_lteq: out bit

);

end relOpTest;

architecture rtlArch of relOpTest is

begin
```

```
res_eq <= in1 ?= in2;

res_lteq <= in1 ?<= in2;

end rtlArch;
```

Unconstrained Data Types

VHDL 2008 allows the element types for arrays and the field types for records to be unconstrained. In addition, VHDL 2008 includes support for partially constrained subtypes in which some elements of the subtype are constrained, while others elements are unconstrained. Specifically, VHDL 2008:

- Supports unconstrained arrays of unconstrained arrays (i.e., element types of arrays can be unconstrained)

- Supports the VHDL 2008 syntax that allows a new subtype to be declared that constrains any element of an existing type that is not yet constrained

- Supports the 'element attribute that returns the element subtype of an array object

- Supports the new 'subtype attribute that returns the subtype of an object

Example – Unconstrained Element Types

```
-- TECHPUBS Example - Unconstrained element types

library ieee;

use ieee.std_logic_1164.all;

use ieee.std_logic_signed.all;

package myTypes is

    type memUnc is array (natural range <>) of std_logic_vector;

    function summation(varx: memUnc) return std_logic_vector;

end package myTypes;

package body myTypes is

    function summation(varx: memUnc) return std_logic_vector is

        variable sum: varx'element;

    begin

        sum := (others => '0');

            for I in 0 to varx'length - 1 loop
```

```
                  sum := sum + varx(I);

             end loop;

         return sum;

     end function summation;

end package body myTypes;

library ieee;

use ieee.std_logic_1164.all;

use ieee.std_logic_signed.all;

use work.myTypes.all;

entity sum is

   port (in1: memUnc(0 to 2)(3 downto 0);

         out1: out std_logic_vector(3 downto 0) );

end sum;

architecture uncbehv of sum is

begin

   out1 <= summation(in1);

end uncbehv;

library ieee;
use ieee.std_logic_1164.all;
use ieee.std_logic_signed.all;

package myTypes is
   type memUnc is array (natural range <>) of std_logic_vector;
   function summation(varx: memUnc) return std_logic_vector;
end package myTypes;

package body myTypes is
   function summation(varx: memUnc) return std_logic_vector is
      variable sum: varx'element;
   begin
      sum := (others => '0');
         for I in 0 to varx'length - 1 loop
```

```
            sum := sum + varx(I);
         end loop;
      return sum;
   end function summation;
end package body myTypes;

library ieee;
use ieee.std_logic_1164.all;
use ieee.std_logic_signed.all;
use work.myTypes.all;

entity sum is
   port (in1: memUnc(0 to 2)(3 downto 0);
         out1: out std_logic_vector(3 downto 0) );
end sum;

architecture uncbehv of sum is
begin
   out1 <= summation(in1);
end uncbehv;
```

Example – Unconstrained Elements within Nested Arrays

```
-- TECHPUBS Example - Unconstrained elements within nested arrays

library ieee;

use ieee.std_logic_1164.all;

use ieee.std_logic_signed.all;

package myTypes is

   type t1 is array (0 to 1) of std_logic_vector;

   type memUnc is array (natural range <>) of t1;

   function doSum(varx: memUnc) return std_logic_vector;

end package myTypes;

package body myTypes is

   function addVector(vec: t1) return std_logic_vector is

      variable vecres: vec'element := (others => '0');

   begin

      for I in vec'Range loop
```

```
                    vecres := vecres + vec(I);
            end loop;
            return vecres;
        end function addVector;
        function doSum(varx: memUnc) return std_logic_vector is
            variable sumres: varx'element'element;
        begin
            if (varx'length = 1) then
                return addVector(varx(varx'low));
            end if;
            if (varx'Ascending) then
                sumres := addVector(varx(varx'high)) +
                    doSum(varx(varx'low to varx'high-1));
            else
                sumres := addVector(varx(varx'low)) +
                    doSum(varx(varx'high downto varx'low+1));
            end if;
            return sumres;
        end function doSum;
    end package body myTypes;
    library ieee;
    use ieee.std_logic_1164.all;
    use ieee.std_logic_signed.all;
    use work.myTypes.all;
    entity uncfunc is
        port (in1: in memUnc(1 downto 0)(open)(0 to 3);
                in2: in memUnc(0 to 2)(open)(5 downto 0);
```

```
            in3: in memUnc(3 downto 0)(open)(2 downto 0);

            out1: out std_logic_vector(5 downto 0);

            out2: out std_logic_vector(0 to 3);

            out3: out std_logic_vector(2 downto 0) );

   end uncfunc;

   architecture uncbehv of uncfunc is

   begin

      out1 <= doSum(in2);

      out2 <= doSum(in1);

      out3 <= doSum(in3);

   end uncbehv;

   library ieee;
   use ieee.std_logic_1164.all;
   use ieee.std_logic_signed.all;

   package myTypes is
      type t1 is array (0 to 1) of std_logic_vector;
      type memUnc is array (natural range <>) of t1;
      function doSum(varx: memUnc) return std_logic_vector;
   end package myTypes;

   package body myTypes is
      function addVector(vec: t1) return std_logic_vector is
         variable vecres: vec'element := (others => '0');
      begin
         for I in vec'Range loop
            vecres := vecres + vec(I);
         end loop;
         return vecres;
      end function addVector;
      function doSum(varx: memUnc) return std_logic_vector is
         variable sumres: varx'element'element;
      begin
         if (varx'length = 1) then
            return addVector(varx(varx'low));
         end if;
         if (varx'Ascending) then
            sumres := addVector(varx(varx'high)) +
               doSum(varx(varx'low to varx'high-1));
```

```
            else
                sumres := addVector(varx(varx'low)) +
                    doSum(varx(varx'high downto varx'low+1));
            end if;
            return sumres;
        end function doSum;
    end package body myTypes;

    library ieee;
    use ieee.std_logic_1164.all;
    use ieee.std_logic_signed.all;
    use work.myTypes.all;

    entity uncfunc is
        port (in1: in memUnc(1 downto 0)(open)(0 to 3);
                in2: in memUnc(0 to 2)(open)(5 downto 0);
                in3: in memUnc(3 downto 0)(open)(2 downto 0);
                out1: out std_logic_vector(5 downto 0);
                out2: out std_logic_vector(0 to 3);
                out3: out std_logic_vector(2 downto 0) );
    end uncfunc;

    architecture uncbehv of uncfunc is
    begin
        out1 <= doSum(in2);
        out2 <= doSum(in1);
        out3 <= doSum(in3);
    end uncbehv;
```

Unconstrained Record Elements

VHDL 2008 allows element types for records to be unconstrained (earlier
versions of VHDL required that the element types for records be fully
constrained). In addition, VHDL 2008 supports the concept of partially
constrained subtypes in which some parts of the subtype are constrained,
while others remain unconstrained.

Example – Unconstrained Record Elements

```
    -- TECHPUBS Example - Unconstrained record elements

    library ieee;
```

```
use ieee.std_logic_1164.all;

entity unctest is

    port (in1: in std_logic_vector (2 downto 0);

            in2: in std_logic_vector (3 downto 0);

            out1: out std_logic_vector(2 downto 0) );

end unctest;

architecture uncbehv of unctest is

    type zRec is record

        f1: std_logic_vector;

        f2: std_logic_vector;

    end record zRec;

subtype zCnstrRec is zRec(f1(open), f2(3 downto 0));

subtype zCnstrRec2 is zCnstrRec(f1(2 downto 0), f2(open));

signal mem: zCnstrRec2;

begin

    mem.f1 <= in1;

    mem.f2 <= in2;

    out1 <= mem.f1 and mem.f2(2 downto 0);

end uncbehv;

library ieee;
use ieee.std_logic_1164.all;

entity unctest is
    port (in1: in std_logic_vector (2 downto 0);
            in2: in std_logic_vector (3 downto 0);
            out1: out std_logic_vector(2 downto 0) );
end unctest;

architecture uncbehv of unctest is
    type zRec is record
        f1: std_logic_vector;
        f2: std_logic_vector;
    end record zRec;
```

```
subtype zCnstrRec is zRec(f1(open), f2(3 downto 0));
subtype zCnstrRec2 is zCnstrRec(f1(2 downto 0), f2(open));
signal mem: zCnstrRec2;
begin
   mem.f1 <= in1;
   mem.f2 <= in2;
   out1 <= mem.f1 and mem.f2(2 downto 0);
end uncbehv;
```

Predefined Functions

VHDL 2008 adds the minimum and maximum predefined functions. The behavior of these functions is defined in terms of the **"<"** operator for the operand type. The functions can be binary to compare two elements, or unary when the operand is an array type.

Example – Minimum/Maximum Predefined Functions

```
--TECHPUBS Example: Minimum Maximum Predefined Functions

entity minmaxTest is

port (ary1, ary2: in bit_vector(3 downto 0);

minout, maxout: out bit_vector(3 downto 0);

unaryres: out bit

);

end minmaxTest;

architecture rtlArch of minmaxTest is

begin

maxout <= maximum(ary1, ary2);

minout <= minimum(ary1, ary2);

unaryres <= maximum(ary1);

end rtlArch;
```

```
entity minmaxTest is
   port (ary1, ary2: in bit_vector(3 downto 0);
           minout, maxout: out bit_vector(3 downto 0);
           unaryres: out bit );
end minmaxTest;

architecture rtlArch of minmaxTest is
begin
   maxout <= maximum(ary1, ary2);
   minout <= minimum(ary1, ary2);
   unaryres <= maximum(ary1);
end rtlArch;
```

Generic Types

VHDL 2008 introduces several types of generics that are not present in VHDL
IEEE Std 1076-1993. These types include generic types, generic packages,
and generic subprograms.

Generic Types

Generic types allow logic descriptions that are independent of type. These
descriptions can be declared as a generic parameter in both packages and
entities. The actual type must be provided when instantiating a component or
package.

Example of a generic type declaration:

```
entity mux is
   generic (type dataType);
   port (sel: in bit; za, zb: in dataType; res: out dataType);
end mux;
```

Example of instantiating an entity with a type generic:

```
inst1:  mux generic map (bit_vector(3 downto 0))
   port map (selval,in1,in2,out1);
```

Generic Packages

Generic packages allow descriptions based on a formal package. These
descriptions can be declared as a generic parameter in both packages and
entities. An actual package (an instance of the formal package) must be
provided when instantiating a component or package.

Example of a generic package declaration:

```
entity mux is generic (
   package argpkg is new dataPkg generic map (<>);
);
   port (sel: in bit; za, zb: in bit_vector(3 downto 0);
      res: out bit_vector(3 downto 0) );
end mux;
```

Example of instantiating a component with a package generic:

```
package memoryPkg is new dataPkg generic map (4, 16);

...

inst1: entity work.mux generic map (4, 16, argPkg => memoryPkg)
```

Generic Subprograms

Generic subprograms allow descriptions based on a formal subprogram that provides the function prototype. These descriptions can be declared as a generic parameter in both packages and entities. An actual function must be provided when instantiating a component or package.

Example of a generic subprogram declaration:

```
entity mux is
   generic (type dataType; function filter(datain: dataType)
      return dataType);
   port (sel: in bit; za, zb: in dataType; res: out dataType);
end mux;
```

Example of instantiating a component with a subprogram generic:

```
architecture myarch2 of myTopDesign is
   function intfilter(din: integer) return integer is
   begin
      return din + 1;
   end function intfilter;

...

begin
   inst1: mux generic map (integer, intfilter)
      port map (selval,intin1,intin2,intout);
```

Packages

VHDL 2008 includes several new packages and modifies some of the existing packages. The new and modified packages are located in the $LIB/vhd2008 folder instead of $LIB/vhd.

New Packages

The following packages are supported in VHDL 2008:

- fixed_pkg.vhd, float_pkg.vhd, fixed_generic_pkg.vhd, float_generic_pkg.vhd, fixed_-float_types.vhd – IEEE fixed and floating point packages

- numeric_bit_unsigned.vhd – Overloads for bit_vector to have all operators defined for ieee.numeric_bit.unsigned

- numeric_std_unsigned.vhd – Overloads for std_ulogic_vector to have all operators defined for ieee.numeric_std.unsigned

String and text I/O functions in the above packages are not supported. These functions include read(), write(), to_string().

Modified Packages

The following modified IEEE packages are supported with the exception of the new string and text I/O functions (the previously supported string and text I/O functions are unchanged):

- std.vhd – new overloads

- std_logic_1164.vhd – std_logic_vector is now a subtype of std_ulogic_vector; new overloads

- numeric_std.vhd – new overloads

- numeric_bit.vhd – new overloads

Unsupported Packages/Functions

The following packages and functions are not currently supported:

- string and text I/O functions in the new packages

- The fixed_pkg_params.vhd or float_pkg_params.vhd packages, which were temporarily supported to allow the default parameters to be changed for fixed_pkg.vhd and float_pkg.vhd packages, have been obsoleted by the inclusion of the fixed_generic_pkg.vhd or float_generic_pkg.vhd packages.

Using the Packages

A switch for VHDL 2008 is located in the GUI on the VHDL panel (Implementation Options dialog box) to enable use of these packages and the ?? operator.
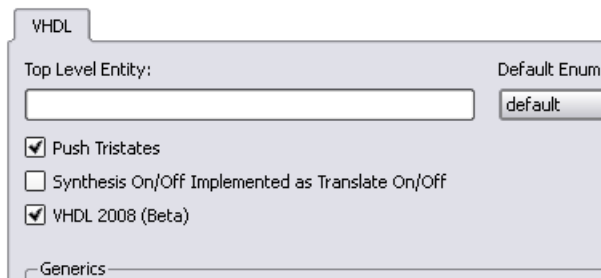
You can also enable the VHDL 2008 packages by including the following command in the compiler options section of your project file:

```
set_option -vhdl2008 1
```

Generics in Packages

In VHDL 2008, packages can include generic clauses. These generic packages can then be instantiated by providing values for the generics as shown in the following example.

Example – Including Generics in Packages

```
--TECHPUBS Example - Including generics in packages

-- Generic Package Declaration

package myTypesGeneric is

   generic

   (width: integer := 7; testVal: bit_vector(3 downto 0) := "0011";

    dfltVal: bit_vector(3 downto 0) := "1110"

   );

   subtype nvector is bit_vector(width-1 downto 0);

   constant resetVal: bit_vector(3 downto 0) := dfltVal;

   constant myVal: bit_vector(3 downto 0) := testVal;

end package myTypesGeneric;


-- Package instantiation

package myTypes is new work.myTypesGeneric

   generic map

   (width => 4, dfltVal => "0110"

   );


library IEEE;

package my_fixed_pkg is new IEEE.fixed_generic_pkg

   generic map

   (fixed_round_style    => IEEE.fixed_float_types.fixed_round,
```

```
        fixed_overflow_style => IEEE.fixed_float_types.fixed_saturate,

        fixed_guard_bits     => 3,

        no_warning           => false

        );


use work.myTypes.all;

use work.my_fixed_pkg.all;


entity myTopDesign is

    port  (in1: in nvector; out1: out nvector;

        insf: in sfixed(3 downto 0);

        outsf: out sfixed(3 downto 0);

        out2, out3, out4: out bit_vector(3 downto 0)

        );

end myTopDesign;


architecture myarch2 of myTopDesign is

begin

    out1 <= in1;

    out2 <= resetVal;

    out3 <= myVal;

    outsf <= insf;

end myarch2;
```

Context Declarations

VHDL 2008 provides a new type of design unit called a context declaration. A context is a collection of library and use clauses. Both context declarations and context references are supported as shown in the following example.

Example – Context Declaration

```
--TECHPUBS Example - Context declaration

context zcontext is

    library ieee;

    use ieee.std_logic_1164.all;

end context zcontext;


context work.zcontext;

use ieee.numeric_std.all;


entity myTopDesign is

    port (in1: in std_logic_vector(1 downto 0);

        out1: out std_logic_vector(1 downto 0) );

end myTopDesign;


architecture myarch2 of myTopDesign is

begin

    out1 <= in1;

end myarch2;
```

In VHDL 2008, a context clause cannot precede a context declaration. The following code segment results in a compiler error.

```
library ieee; -- Illegal context clause before a
              -- context declaration
context zcontext is
   use ieee.std_logic_1164.all;
   use ieee.numeric_std.all;
end context zcontext;
```

Similarly, VHDL 2008 does not allow reference to the library name work in a context declaration. The following code segment also results in a compiler error.

```
context zcontext is
   use work.zpkg.all; -- Illegal reference to library work
                  -- in a context declaration
   library ieee;
   use ieee.numeric_std.all;
end context zcontext;
```

VHDL 2008 supports the following two, standard context declarations in the IEEE package:

- IEEE_BIT_CONTEXT

- IEEE_STD_CONTEXT

Case-generate Statements

The case-generate statement is a new type of generate statement incorporated into VHDL 2008. Within the statement, alternatives are specified similar to a case statement. A static (computable at elaboration) select statement is compared against a set of choices as shown in the following syntax:

```
caseLabel:  case expression generate
              when choice1 =>
                     -- statement list
              when choice2 =>
                     -- statement list
              …
              end generate caseLabel;
```

To allow for configuration of alternatives in case-generate statements, each alternative can include a label preceding the choice value (e.g., labels L1 and L2 in the syntax below):

```
caseLabel:  case expression generate
               when L1: choice1 =>
                      -- statement list
               when L2: choice2 =>
                      -- statement list
               …
               end generate caseLabel;
```

Example – Case-generate Statement with Alternatives

```
--TECHPUBS Example - Case-generate statement with alternatives


entity myTopDesign is

    generic (instSel: bit_vector(1 downto 0) := "10");

    port (in1, in2, in3: in bit; out1: out bit);

end myTopDesign;

architecture myarch2 of myTopDesign is

component mycomp

    port (a: in bit; b: out bit);

end component;

begin

a1: case instSel generate

    when "00" =>

        inst1: component mycomp port map (in1,out1);

    when "01" =>

        inst1: component mycomp port map (in2,out1);

    when others =>

        inst1: component mycomp port map (in3,out1);
```

```
      end generate;

   end myarch2;



   entity myTopDesign is
      generic (instSel: bit_vector(1 downto 0) := "10");
      port (in1, in2, in3: in bit; out1: out bit);
   end myTopDesign;

   architecture myarch2 of myTopDesign is
   component mycomp
      port (a: in bit; b: out bit);
   end component;

   begin
   a1: case instSel generate
      when "00" =>
         inst1: component mycomp port map (in1,out1);
      when "01" =>
         inst1: component mycomp port map (in2,out1);
      when others =>
         inst1: component mycomp port map (in3,out1);
      end generate;
   end myarch2;
```

Example – Case-generate Statement with Labels for Configuration

```
   --TECHPUBS Example - Case-generate statement with labels for
   configuration

   entity myTopDesign is

   generic (selval: bit_vector(1 downto 0) := "10");

      port (in1, in2, in3: in bit; tstIn: in bit_vector(3 downto 0);

          out1: out bit);

   end myTopDesign;

   architecture myarch2 of myTopDesign is

      component mycomp

         port (a: in bit; b: out bit);

      end component;
```

```
begin

a1: case selval generate

   when spec1: "00" | "11"=> signal inRes: bit;

      begin

         inRes <= in1 and in3;

         inst1: component mycomp port map (inRes,out1);

      end;

   when spec2: "01" =>

      inst1: component mycomp port map (in1, out1);

   when spec3: others =>

      inst1: component mycomp port map (in3,out1);

   end generate;

end myarch2;

entity mycomp is

   port (a : in bit;

         b : out bit);

end mycomp;

architecture myarch of mycomp is

begin

   b <= not a;

end myarch;

architecture zarch of mycomp is

begin

   b <= '1';

end zarch;

configuration myconfig of myTopDesign is

for myarch2
```

```
      for a1 (spec1)

         for inst1: mycomp use entity mycomp(myarch);

         end for;

      end for;

      for a1 (spec2)

         for inst1: mycomp use entity mycomp(zarch);

         end for;

      end for;

      for a1 (spec3)

         for inst1: mycomp use entity mycomp(myarch);

         end for;

      end for;

   end for;

   end configuration myconfig;

   entity myTopDesign is
   generic (selval: bit_vector(1 downto 0) := "10");
      port (in1, in2, in3: in bit; tstIn: in bit_vector(3 downto 0);
            out1: out bit);
   end myTopDesign;

   architecture myarch2 of myTopDesign is
      component mycomp
         port (a: in bit; b: out bit);
      end component;
   begin
   a1: case selval generate
      when spec1: "00" | "11"=> signal inRes: bit;
         begin
            inRes <= in1 and in3;
            inst1: component mycomp port map (inRes,out1);
         end;
      when spec2: "01" =>
```

```
        inst1: component mycomp port map (in1, out1);
    when spec3: others =>
        inst1: component mycomp port map (in3,out1);
    end generate;
end myarch2;

entity mycomp is
    port (a : in bit;
          b : out bit);
end mycomp;

architecture myarch of mycomp is
begin
    b <= not a;
end myarch;

architecture zarch of mycomp is
begin
    b <= '1';
end zarch;

configuration myconfig of myTopDesign is
for myarch2
    for a1 (spec1)
        for inst1: mycomp use entity mycomp(myarch);
        end for;
    end for;
    for a1 (spec2)
        for inst1: mycomp use entity mycomp(zarch);
        end for;
    end for;
    for a1 (spec3)
        for inst1: mycomp use entity mycomp(myarch);
        end for;
    end for;
end for;
end configuration myconfig;
```

Matching case and select Statements

Matching case and matching select statements are supported – case? (matching case statement) and select? (matching select statement). The statements use the ?= operator to compare the case selector against the case options.

Example – Use of case? Statement

```
--TECHPUBS Example - Use of case? statement

library ieee;

use ieee.std_logic_1164.all;

entity myTopDesign is

   port (in1, in2: in bit;

         sel: in std_logic_vector(2 downto 0);

         out1: out bit );

end myTopDesign;

architecture myarch2 of myTopDesign is

begin

   process(all)

   begin

      a1: case? sel is

         when "1--" =>

            out1 <= in1;

         when "01-" =>

            out1 <= in2;

         when others =>

            out1 <= in1 xor in2;

      end case?;

   end process;

end myarch2;
```

Example – Use of select? Statement

```
--TECHPUBS Example - Use of select? Statement

library ieee;

use ieee.std_logic_1164.all;

entity myTopDesign is

   port (in1, in2: in bit;

         sel: in std_logic_vector(2 downto 0);

         out1: out bit );

end myTopDesign;

architecture myarch2 of myTopDesign is

begin

   with sel select?

      out1 <=

      in1 when "1--",

      in2 when "01-",

      in1 xor in2 when others;

end myarch2;
```

Else/elsif Clauses

In VHDL 2008, else and elsif clauses can be included in if-generate statements. You can configure specific if/else/elsif clauses using configurations by adding a label before each condition. In the code example below, the labels on the branches of the if-generate statement are spec1, spec2, and spec3. These labels are later referenced in the configuration myconfig to specify the appropriate entity/architecture pair. This form of labeling allows statements to be referenced in configurations.

Example – Else/elsif Clauses in If-Generate Statements

```
--TECHPUBS Example - Else/elsif clauses in if-generate statements


entity myTopDesign is

   generic (genval: bit_vector(1 downto 0) := "01");

   port (in1, in2, in3: in bit; out1: out bit);

end myTopDesign;


architecture myarch2 of myTopDesign is


component mycomp

   port (a: in bit;

      b: out bit );

end component;


begin

a1:

   if spec1: genval="10" generate

      inst1: mycomp port map (in1,out1);

   elsif spec2: genval="11" generate

      inst1: component mycomp port map (in2,out1);

   else spec3: generate

      inst1: component mycomp port map (in3,out1);

   end generate;

end myarch2;
```

```vhdl
library ieee;
use ieee.std_logic_1164.all;


entity mycomp is
   port ( a: in bit;
          b : out bit);
end entity mycomp;


architecture myarch1 of mycomp is
begin
   b <= '1' xor a;
end myarch1;


architecture myarch2 of mycomp is
begin
   b <= '1' xnor a;
end myarch2;


architecture myarch3 of mycomp is
signal temp : bit := '1';
begin
   b <= temp xor not(a);
end myarch3;


configuration myconfig of myTopDesign is
   for myarch2
      for a1 (spec1)
```

```
          for inst1: mycomp
              use entity mycomp(myarch1);
          end for;
       end for;
       for a1 (spec2)
          for inst1: mycomp
              use entity mycomp(myarch2);
          end for;
       end for;
       for a1 (spec3)
          for inst1: mycomp
              use entity mycomp(myarch3);
          end for;
       end for;
    end for;
end configuration myconfig;
```

Syntax Conventions

The following syntax conventions are supported in VHDL 2008:

- All keyword
- Comment delimiters
- Extended character set

All Keyword

VHDL 2008 supports the use of an all keyword in place of the list of input signals to a process in the sensitivity list.

Example – All Keyword in Sensitivity List

```
--TECHPUBS Example - all keyword

entity mycomp is

   port (a, c: in bit; b: out bit);

end mycomp;


architecture myarch of mycomp is

begin

   process (all)

   begin

      b <= not a or c;

   end process;

end myarch;
```

Comment Delimiters

VHDL 2008 supports the /* and */ comment-delimiter characters. All text enclosed between the beginning /* and the ending */ is treated as a comment, and the commented text can span multiple lines. The standard VHDL "--" comment-introduction character string is also supported.

Extended Character Set

The extended ASCII character literals (ASCII values from 128 to 255) are supported.

Example – Extended Character Set

```
--TECHPUBS Example - extended character set

library ieee;

use ieee.std_logic_1164.all;

entity get_version is

    port ( ver : out string(16 downto 1));

end get_version;

architecture behv of get_version is

constant version : string (16 downto 1) := "version ©«ãëïõü»";

-- Above string includes extended ASCII characters that

-- fall between 127-255

begin

    ver <= version;

end behv;
```

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