“A Verilog Overview”
by
Orlando J. Hernandez, Ph.D.

Electrical & Computer Engineering
School of Engineering
THE COLLEGE OF NEW JERSEY
Fall Semester, 2004
Presentation Overview

- Introduction to Verilog – Part I
- Introduction to Verilog – Part II
  - AND, OR, HALF ADDER, FULL ADDER
- Introduction to Verilog – Part III
  - ALU Design
- Control and Data Path Organization
  - Finite State Machines, Digital Filter
- Q&A Sessions
INTRODUCTION TO Verilog

PART I
Design Automation

- Need To Keep With Rapid Changes, Electronic Products Have To Be Designed Extremely Quickly

- Electronic Design Automation (EDA)
  - Design Entry
  - Simulation
  - Synthesis
  - Design Validation & Test
Design Automation. Cont…

- Design Entry
  - Schematic Capture
Design Automation. Cont...

- Design Entry - Textual Form:
  - Verilog
  - VHDL (VHSIC Hardware Description Language)
  - VHSIC (Very High Speed Integrated Circuits)
Design Automation. Cont...

Design Entry - Textual Form:

```verbatim
module and_2 (X, Y, Z);
    input X, Y;
    output Z;
    assign Z = X & Y;
endmodule
```
Introduction To Verilog

Verilog Is an Industry Standard Language to Describe Hardware From the Abstract to Concrete Level.
BRIEF HISTORY OF Verilog

- Began as a proprietary HDL promoted by Cadence Design Systems.

- Cadence transferred control of Verilog to a consortium of companies and universities known as Open Verilog International (OVI).


- Verilog continues to be extended and upgraded (IEEE Standard 1364-2000, System Verilog).
MOTIVATION

- Need a Method to Quickly Design, Implement, Test and Document Increasingly Complex Digital Systems.

- Schematic and Boolean Equations Inadequate for Million-Gate ICs.

- Design Portability
What is Verilog?

- A Design entry language
- A Simulation modeling language.
- A Verification language.
- A Standard language.
- As simple or complex as required.
How is Verilog Used?

- For Design Specification ("Specify")
- For Design Entry ("Capture")
- For Design Simulation ("Verify")
- For Design Documentation ("Formalize")
- As an Alternate to Schematics
Design Process (e.g. for FPGAs)

- Verilog Can Be Used for Both Design and Test Development

Diagram:
- Design Entry
  - Synthesis
  - Device Mapping
  - Device
- Test Development
  - Functional Simulation
  - Timing Simulation
  - Device Mapping

When Should Verilog Be Used?

- Verilog is highly beneficial to use as a structured, top down approach to design.
- Verilog makes it easy to build, use, and reuse libraries of circuit elements.
- Verilog can greatly improve your chances of moving into more advanced tools and design flows.
Advantages of Verilog

- The Ability to Code the Behavior and to Synthesize an Actual Circuit.
- Power and Flexibility
- Device (specific FPGA) Independent Design
- Technology (specific silicon process) Independent Design
Advantages of Verilog Cont...

- Portability Among Tools and Devices
- Fast Switch Level Simulations
- Quick Time to Market and Low Cost
- Industry Standard
Getting Started with Verilog

- It's easy to get started with Verilog, but it can be difficult to master it.
- To begin with, a subset of the language can be learned to write useful models.
- Later, more complex features can be learned to implement complex circuits, libraries, and APIs.
A First look at Verilog

- Let's start with a simple Combinational circuit: an 8-bit Comparator.
An 8 Bit Comparator

- Comparator Specifications:
  - Two 8-bit inputs
  - 1-bit Output
  - Output is 1 if the inputs match or 0 if they differ.
An 8 Bit Comparator

Comparator

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

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Comparator Verilog Source Code

// Eight-bit Comparator
module compare (A, B, EQ)
  input [7:0] A, B;
  output EQ;

  assign EQ = (A == B);
endmodule

- Define the inputs and outputs - the ports of the circuit
- Define the function of the circuit
What is a module

- Every Verilog design description has at least one module construct.

- A large design has many modules and are connected to form the complete circuit.

- The module port declarations describe the circuit as it appears from “outside”- from perspective of its input and output interfaces.
What is a module?

```
module compare (A, B, EQ)
    input [7:0] A, B;
    output EQ;

The module and port declarations includes a name, compare, and port direction statements defining all the inputs and outputs of the module.

The Rest of the module Describes the Actual Function.
```
What is a module?

```verilog
assign EQ = (A == B);
endmodule
```

- Before the keyword `endmodule` is found, the actual functional description of the comparator.
Data Types

- Verilog’s high level data types allow data to be represented in much the same way as in high-level programming languages.

- A data type is an abstract representation of stored data.
Data Types

These data types might represent individual wires in a circuit, or a collection of wires.
Data Types

- Basic Data Types
  - Nets
    - wire, wand, tri, wor
    - Continuously driven
    - Gets new value when driver changes
    - LHS of continuous assignment
      ```
      tri [15:0] data;
      // unconditional
      assign data[15:0] = data_in;
      // conditional
      assign data[15:0] = enable ? data_in : 16'bz;
      ```
  - Registers
    - Reg
    - Represents storage
    - Always stores last assigned value
    - LHS of an assignment in a procedural block
      ```
      reg signal;
      @(posedge clock) signal = 1'b1;
      // positive edge
      @(reset) signal = 1'b0; // event (both edges)
      ```
### Some Data Types

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Values</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit</td>
<td>'1', '0', 'x', 'z'</td>
<td>Q = 1'b1;</td>
</tr>
<tr>
<td>Array of bits</td>
<td>&quot;101001&quot;</td>
<td>Data[5:0] = 6'b101001;</td>
</tr>
<tr>
<td>Boolean</td>
<td>Use Bit</td>
<td>EQ = 1'b1; // True</td>
</tr>
<tr>
<td>Integer</td>
<td>-2, -1, 0, 1, 2, 3</td>
<td>C = c+2;</td>
</tr>
<tr>
<td>Real</td>
<td>1.0, -1.0E5</td>
<td>V1 = V2/5.3;</td>
</tr>
<tr>
<td>Time</td>
<td><code>timescale 1ns/1ps</code></td>
<td>#6 Q = 1'b1;</td>
</tr>
<tr>
<td>Register</td>
<td>Single or array of bits</td>
<td></td>
</tr>
<tr>
<td>Character</td>
<td>Use 8-bit register</td>
<td></td>
</tr>
<tr>
<td>String</td>
<td>Use register of length 8 x the # of characters</td>
<td></td>
</tr>
</tbody>
</table>
Design Units

- Design units are a concept that provide advanced configuration management capabilities.

- Design units are modules of Verilog that can be compiled separately and stored in a library.
Library Design unit

- A Library is a collection of commonly used modules to be used globally among different design units.

- Library is identified with compiler/simulator command line switches.
Levels of Abstraction (Styles)

- Verilog supports many possible styles of design description.

- These styles differ primarily in how closely they relate to the underlying hardware.
Levels of Abstraction (Styles)

- Levels of Abstraction refers to how far your design description is from an actual hardware realization.

- The three main levels of abstraction are:
  - Behavior
  - Dataflow
  - Structure
Levels of Abstraction (Styles)

- Behavior
  - Performance Specification
  - Test Benches
  - Sequential Description
  - State Machines
  - Register Transfers
  - Selected Assignments
  - Arithmetic Operation
  - Boolean Equations
  - Hierarchy
  - Physical Information

- Dataflow

- Structure
Behavioral Modeling

- The Highest Level of Abstraction Supported in Verilog.

- The Behavior Approach Describes the Actual Behavior of Signals Inside the Component.
Verilog Timing Issues

- The Concept of Time Is the Critical Distinction Between Behavioral Descriptions and Low Level Descriptions.

- The Concept to Time May Be Expressed Precisely, With Actual Delays Between Related Events.
An Example of Behavioral Modeling: A half adder

\[
\begin{array}{c}
\text{a} \\
\text{b}
\end{array}
\quad \text{sum} \\
\quad \text{carry}
\]
half_adder

- **Half Adder**
- **Inputs** $a, b : 1$ bit each.
- **Output** Sum, Carry : 1 bit each.

![Half adder circuit](image)

**Figure 1-1 Half adder circuit**
Verilog Code for half_adder

```verilog
module half_adder (a, b, sum, carry);
    input a, b;
    output sum, carry;

    reg sum, carry;

    always @ (a or b) begin
        sum = a ^ b;
        carry = a & b;
    end
endmodule
```
INTRODUCTION TO Verilog
PART II
The dataflow level of abstraction is often called **Register Transfer Language (RTL)**.

Some behavioral modeling can also be called **RTL**.

The dataflow level of abstraction describes how information is passed between registers in the circuit.
Concurrent and Sequential Verilog

- Verilog Allows Both Concurrent and Sequential Statements to Be Entered.

- The Difference Between Concurrent and Sequential Statements Must Be Known for Effective Use of the Language.
Concurrent Verilog

- All Statements in the Concurrent Area Are Executed at the Same Time.

- There Is No Significance to the Order in Which Concurrent Statements Occur.
Concurrent Verilog
Example of Concurrent Verilog

Full Adder

\[ \text{Full-Adder} \]

\[ a \]

\[ b \]

\[ C_{\text{in}} \]

\[ \text{Sum} \]

\[ C_{\text{out}} \]
Full Adder circuit
Verilog code for Full Adder

```verilog
// Full Adder Using Signal Assignment Instructions
module full_adder (a, b, c_in, sum, c_out);
    input a, b, c_in;
    output sum, c_out;

    wire s1, s2, s3;

    assign s1 = a ^ b;
    assign s2 = s1 & c_in;
    assign s3 = a & b;
    assign sum = s1 ^ c_in;
    assign c_out = s2 | s3;
endmodule
```
The `assign` expressions are all concurrent signal assignment statements. All the statements are executed at the same time.

```verilog
assign s1 = a ^ b;
assign s2 = s1 & c_in;
assign s3 = a & b;
assign sum = s1 ^ c_in;
assign c_out = s2 | s3;
```
The simulator evaluates all the assign expressions, and then applies the results to the signals.

Once the simulator has applied the results it waits for one of the signal to change and it reevaluates all the expressions again.
Verilog code for Full Adder

- This cycle will continue until the simulation is completed.

- This is called “event driven simulation”.

- It is more computationally efficient than time driven simulation.
Wires

- In the full_adder Verilog code we came across “wire”.
- So what are “wires”?
  - Wires Are Used to Carry Data From Place to Place in a Verilog Design Description.
  - Wires in Verilog Are Similar to Wires in a Schematic.
  - Wires are internal to a module.
Sequential Verilog

- Sequential Statements Are Executed One After the Other in the Order That They Appear.

- Example of Sequential Statement: Always.
Sequential Verilog

Begin

Statement

Statement

Statement

End

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Always Construct

- The Always construct is the primary means to describe sequential operations.

- Always starts with the keyword *always*, then *begin*, and ends with the keyword *end*.

- The whole *always* construct itself is treated as a concurrent statement.
Always Statement

- The *always* construct consists of three parts
  
  - Sensitivity List
  - Declaration Part
  - Statement Part
Syntax of Always Statement

```verbatim
module module_name ( ... ports ... );

always @ (sensitivity_list)
begin
  block_name
  local_declaration;
  .......
  sequential statement;
  sequential statement;
  .......
end
endmodule
```
module nand2 (a, b, c);
    input a, b;
    output c;

    reg c;

    always @(a or b)
        begin : nand2_always_block
            reg temp;
            temp = ~(a & b);
            if (temp == 1'b1) #5 c = temp;
            else if (temp == 1'b0) #6 c = temp;

            end
        endmodule
Example Description

The **always** sensitivity list enumerates exactly which signals causes the block to execute.

```always @ (a or b)```
Example Description

- The declarative part is used to declare local variables or constants that can be used in the block.

```plaintext
reg temp;
```
Example Description

- Variables are temporary storage areas similar to variables in software programming languages.

```
reg temp;
```
Use of Sequential Statements

- Sequential Statements Exist Inside the Always Statements As Well As in Sub Programs.

- The Sequential Statements Are:
  - if
  - case
  - forever
  - repeat
  - while
  - for
  - wait
  - fork/join
if Statements

- The IF statement starts with the keyword *if* and ends with the keyword *end*.

```plaintext
if (x < 10) begin
    a = b;
end
```
if Statements

- There are also two optional clauses
  - else if clause
  - else clause

```plaintext
if (day == Sunday) begin
  weekend = true;
end
else if (day == Saturday) begin
  weekend = true;
end
else begin
  weekday = true;
end
```
if Statements

- The if statement can have multiple else if statement parts but only one else statement part.
Case Statement

The Case statement is used whenever a single expression value can be used to select between a number of actions.

A Case statement consists of the keyword `case` followed by an operator expression, and ended with an `endcase` keyword.
Case Statement

The expression will either return a value that matches one of the *choices* in a statement part or match a *default* clause.
Case Statement Example

```vhdl
reg [1:0] bit_vec;

......
case bit_vec
  2'b00 :
    return = 0;
  2'b01 :
    return = 1;
  2'b10 :
    return = 2;
  2'b11 :
    return = 3;
endcase
```
Loop Statements

The loop statement is used whenever an operation needs to be repeated.

Loop statements are implemented in three ways

- **repeat** condition loop statement
- **while** condition loop statement
- **for** condition loop statement
Loop Statements (repeat)

The **repeat** condition Loop statement will loop as many times as the condition expression.

```plaintext
repeat (flag) begin
    day = get_next_day (day);
end
```
Loop Statements (while)

- The **while** condition Loop statement will loop as long as the condition expression is TRUE.

```plaintext
while (day == weekday) begin
    day = get_next_day (day);
end
```
Loop Statements (for loop)

```
for (i = 1; i <= 10; i = i + 1) begin
    i_squared[i] = i*i;
end
```

This loop will execute 10 times whenever execution begins and its function is to calculate squares from 1 to 10 and insert them into i_squared memory.
The `wait` statement allows to suspend the sequential execution based on a conditional expression.

- `wait until` an expression is true.
**Wait Statement**

- The *wait* conditional expression clause will suspend execution of the process until the expression returns a true value.

```plaintext
initial
begin
  wait (!oe)
  o = q;
end
```
Structural Verilog

- Structural-level design methods can be useful for managing the complexity of a large design description.

- Structure level of abstraction is used to combine multiple components to form a larger circuit.
Structural Verilog

- Structural Verilog Descriptions Are Quite Similar in Format to Schematic Netlists.

- Larger Circuits Can Be Constructed From Smaller Building Blocks.
Example of Structural Verilog

Let us consider an ALU with

- An OR gate
- An XOR gate
- A Half Adder
- A Full Adder
- A Multiplexer
Example of Structural Verilog

ALU

OR gate
XOR gate
Half Adder
Full Adder
Mux
ALU – Block Diagram

- Input: a, b
- Select: s1, s0
- Half Adder
- Full Adder
- MUX
- Output: Z, C_out
## ALU – Function Table

<table>
<thead>
<tr>
<th>S1</th>
<th>S0</th>
<th>( Z )</th>
<th>( C_{\text{out}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>( a \text{ or } b )</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>( a \text{ xor } b )</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>( ha _\text{sum} )</td>
<td>( ha _c_\text{out} )</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>( fa _\text{sum} )</td>
<td>( fa _c_\text{out} )</td>
</tr>
</tbody>
</table>

![ALU Circuit Diagram](attachment://alu_circuit_diagram.png)

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Verilog code for OR gate

```verilog
module t_or (a, b, ored);
    input a, b;
    output ored;

    assign ored = a | b;
endmodule
```
Verilog code for XOR

module t_xor (a, b, xored);

    input a, b;
    output xored;

    assign xored = a ^ b;

endmodule
Verilog Code for half_adder

// Half Adder
module half_adder (a, b, sum, c_out);
  input a, b;  // declaring I/O ports
  output sum, c_out;
  assign sum = a ^ b;
  assign c_out = a & b;
endmodule

Figure 1-1 Half adder circuit
Full Adder circuit
Verilog code for full_adder

// Full Adder
module full_adder (a, b, c_in, sum, c_out);
    input a, b, c_in;
    output sum, c_out;

    wire s1, s2, s3;

    assign s1 = a ^ b;
    assign s2 = c_in & s1;
    assign s3 = a & b;
    assign sum = a ^ b;
    assign c_out = s2 | s3;
endmodule

// Using Signal Assignment Instructions
Main Code for ALU

```verilog
module alu (a, b, c_in, s0, s1, z, c_out);
    input a, b, c_in, s0, s1;
    output z, c_out;

    reg z, c_out;

    wire ored, xored, ha_sum, ha_c_out, fa_sum, fa_c_out;

    t_or a1 (.a(a), .b(b), .ored(ored));
    t_xor x1 (.a(a), .b(b), .xored(xored));
    half_adder h1 (.a(a), .b(b), .sum(ha_sum),
                   .c_out(ha_c_out));
    full_adder f1 (.a(a), .b(b), .c_in(c_in), .sum(fa_sum),
                   .c_out(fa_c_out));
```
Main Code for ALU Cont....

```verilog
always @ (a or b or c_in or s0 or s1) begin
  if (s1 == 1'b0 && s0 == 1'b0) begin
    z = ored;
    c_out = 1'b0;
  end
  if (s1 == 1'b0 && s0 == 1'b1) begin
    if (s1 == 1'b0 && s0 == 1'b1) begin
      z = xored;
      c_out = 1'b0;
    end
    if (s1 == 1'b1 && s0 == 1'b0) begin
      z = ha_sum;
      c_out = ha_c_out;
    end
    if (s1 == 1'b1 && s0 == 1'b1) begin
      z = fa_sum;
      c_out = fa_c_out;
    end
  end
endmodule
```
CONTROL AND DATA PATH ORGANIZATION
Control and Data Path Organization

Most complex digital circuits can be broken up into two parts:

- Control
- Data Path
Control and Data Path Organization

![Diagram of control and data path organization]

- Control Inputs
- Control Processing Block
- Status
- Data Processing Block
- Data

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Finite State Machines

- Two Classes of Finite State Machines (FSMs):
  - Moore Machines
  - Mealy Machines
Moore Finite State Machines

- Outputs depend only on the state
- State and Outputs Processing are combinational elements
- State Vector is Sequential Elements

![Moore Finite State Machine Diagram]
Mealy Finite State Machines

- Outputs depend on the state and the inputs
Verilog IMPLEMENTATION EXAMPLES – A Decimation Filter for a Sigma-Delta Analog to Digital Converter
2-Ch Σ-Δ Analog to Digital Converter

Analog Design

Bandgap ~ 1.25V

2nd Order Σ-Δ Modulators

Integrators / Comparator

Digital Filter (Sinc^2)

Digital Design

Clock Generation

PGA

Integrators / Comparator

Digital Filter (Sinc^2)

Digital Design

Σ-Δ ADC

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This can be modeled in Behavioral Verilog
2\textsuperscript{nd} Order $\Sigma$-$\Delta$ Modulator (circuit)

- This can also be modeled in Behavioral Verilog

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Decimation Digital Filter

IN

$\frac{z^{-1}}{f_s}$

$\frac{z^{-1}}{f_s / OSR}$

$\frac{z^{-1}}{f_s / OSR}$

OUT
Decimation Digital Filter

- Cubic sinc
- Bits of noise free accuracy for delta-sigma ADC's:
  - BITS = 3 * LOG(OSR) / LOG(2) + 2
  - Assume OSR=32, then BITS=17, and set BITS=16
Decimation Digital Filter

- First Filter Equations
  - \( H_1(z) = \frac{Y_1(z)}{X(z)} = \frac{1}{1 - 3 \, z^1 + 3 \, z^2 - z^3} \)
  - \( y_1(n) = x(n) + 3 \, y_1(n-1) - 3 \, y_1(n-2) + y_1(n-3) \)

- Second Filter Equations
  - \( H_2(z) = \frac{Y(z)}{X_1(z)} = 1 - 3 \, z^1 + 3 \, z^2 - z^3 \)
  - \( y(n) = x_1(n) - 3 \, x_1(n-1) + 3 \, x_1(n-2) - x_1(n-3) \)

- Decimation (Retiming)
  - \( x_1(n) = y_1(n/OSR) \)
  - \( x_1(n) = y_1(n/32) \)
What do we need for our design?

- \[ y_1(n) = x(n) + 3y_1(n-1) - 3y_1(n-2) + y_1(n-3) \]
- \[ y(n) = x_1(n) - 3x_1(n-1) + 3x_1(n-2) - x_1(n-3) \]
- \[ x_1(n) = y_1(n/32) \]

Control

- On every \(x(n)\)
  - S02: Store \(x(n)\) in accumulator, count \(x(n)\) mod 32
  - S03: Accumulate 2 \(y_1(n-1)\)
  - S04: Accumulate \(y_1(n-1)\)
  - S05: Accumulate 1's complement of 2 \(y_1(n-2)\)
  - S06: Accumulate 1's complement of \(y_1(n-2)\)
  - S07: Accumulate 2
  - S08: Accumulate \(y_1(n-3)\)
  - S09: Update \(y\) registers

- On every \(x_1(n)\) (every 32\textsuperscript{nd} \(y_1(n)\))
  - S10: Accumulate 1's complement of 2 \(x_1(n-1)\)
  - S11: Accumulate 1's complement of \(x_1(n-1)\)
  - S12: Accumulate 2 \(x_1(n-2)\)
  - S13: Accumulate \(x_1(n-2)\)
  - S14: Accumulate 1's complement of \(x_1(n-3)\)
  - S15: Accumulate 3, output result
  - S16: Store \(y_1(n-1)\) in accumulator
  - S17: Update \(x\) registers

Data Path

- 16 bits
- Adder-Accumulator
- 1's complement
- Shift left by one (\(x \times 2\))
- Store \(y_1(n-1), y_1(n-2), y_1(n-3)\)
- Store \(x_1(n-1), x_1(n-2), x_1(n-3)\)
- Constants: 2 & 3

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Decimation Digital Filter Architecture

Data Path:
- Ry1_n_1
- Ry1_n_2
- Ry1_n_3
- Rx1_n_1
- Rx1_n_2
- Rx1_n_3

Controller:
- S1
- S2
- S3
- S4
- URy
- URx
- OSS
- ISS

Accumulator:
- xn

Outputs:
- OUT
Verilog code for Data Path

// Data_Path
module Data_Path (CLK, reset, xn, URy, URx, S2, S3, S4, S1, OUTPUT);

input CLK, reset, xn, URy, URx, S2;
input [1:0] S3, S4;
input [2:0] S1;
output [15:0] OUTPUT;
Verilog code for Data Path

```verilog
reg [15:0] Ry1_n_1, Ry1_n_2, Ry1_n_3;
reg [15:0] Rx1_n_1, Rx1_n_2, Rx1_n_3;
reg [15:0] ACCUMULATOR;

parameter my_zero = 16'b0000000000000000;

reg [15:0] T1, T2, T3, T4, T5;
reg my_msb;

assign OUTPUT = ACCUMULATOR;

always @ (posedge CLK or reset) begin
  if (reset == 1'b1) begin
    Ry1_n_1 = my_zero; Ry1_n_2 = my_zero; Ry1_n_3 = my_zero;
    Rx1_n_1 = my_zero; Rx1_n_2 = my_zero; Rx1_n_3 = my_zero;
    ACCUMULATOR = my_zero;
  endelse if (CLK == 1'b1)
    begin
      if (URy == 1'b1) begin
        Ry1_n_3 = Ry1_n_2; Ry1_n_2 = Ry1_n_1;
        Ry1_n_1 = ACCUMULATOR;
      end
      if (URx == 1'b1) begin
        Rx1_n_3 = Rx1_n_2; Rx1_n_2 = Rx1_n_1;
        Rx1_n_1 = ACCUMULATOR;
      end
      case (S1)
        3'b000 : T1 = Ry1_n_1;
        3'b001 : T1 = Ry1_n_2;
        endcase
      end
endmodule
```

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Verilog code for Controller

// Controller
module Controller (CLK, reset, ISS, URy, URx, S2, OSS, S3, S4, S1);

input CLK, reset, ISS;
output URy, URx, S2, OSS;
output [1:0] S3, S4;
output [2:0] S1;
Verilog code for Controller

```verilog
parameter S00 = 5'h00, S01 = 5'h01, S02 = 5'h02, S03 = 5'h03,
    S04 = 5'h04, S05 = 5'h05, S06 = 5'h06, S07 = 5'h07, S08 = 5'h08,
    S09 = 5'h09, S10 = 5'h0A, S11 = 5'h0B, S12 = 5'h0C, S13 = 5'h0D,
    S14 = 5'h0E, S15 = 5'h0F, S16 = 5'h10, S17 = 5'h11;

reg URy, URx, S2, OSS;
reg [1:0] S3, S4;
reg [2:0] S1;

reg [4:0] PRState, NXState;

reg [4:0] Counter;

always @ (PRState) begin
    if (PRState == S09) URy = 1'b1;
    else URy = 1'b0;
    if (PRState == S17) URx = 1'b1;
    else URx = 1'b0;
    if (PRState == S05 || PRState == S06) S1 = 3'b001;
    else if (PRState == S08) S1 = 3'b010;
    else if (PRState == S10 || PRState == S11) S1 = 3'b011;
    else if (PRState == S12 || PRState == S13) S1 = 3'b100;
    else if (PRState == S14) S1 = 3'b101;
    else S1 = 3'b000;

    if (PRState == S03 || PRState == S05 ||
        PRState == S10 || PRState == S12) S2 = 1'b0;
    else S2 = 1'b1;
    if (PRState == S05 || PRState == S06 ||
        PRState == S10 || PRState == S11 ||
        PRState == S14) S3 = 2'b00;
    else if (PRState == S07) S3 = 2'b10;
    else if (PRState == S15) S3 = 2'b11;
    else S3 = 2'b01;
    if (PRState == S02) S4 = 2'b00;
    else if (PRState == S16) S4 = 2'b01;
    else if (PRState == S15) OSS = 1'b1;
    else OSS = 1'b0;
end
```
Verilog code for Controller

```verilog
always @ (posedge CLK or reset) begin
  if (reset == 1'b1) begin
    PRState = S00;
    Counter = 5'b00000;
  end
  else begin
    PRState = NXState;
    if (Counter == 5'b00000) NXState = S10;
    else NXState = S01;
  end
end

always @ (PRState or ISS) begin
  case (PRState)
    S00: if (ISS == 1'b1) NXState = S02;
    S01: if (ISS == 1'b1) NXState = S02;
    S02: NXState = S03;
    S03: NXState = S04;
    S04: NXState = S05;
    S05: NXState = S06;
    S06: NXState = S07;
    S07: NXState = S08;
    S08: NXState = S09;
    S09: if (Counter == 5'b00000) NXState = S10;
         else NXState = S01;
    S10: NXState = S11;
    S11: NXState = S12;
    S12: NXState = S13;
    S13: NXState = S14;
    S14: NXState = S15;
    S15: NXState = S16;
    S16: NXState = S17
    S17: NXState = S01;
  endcase
endmodule
```

Fall Semester, 2004
Main Code for FILTER

```verilog
module FILTER (reset, CLK, ISS, xn, OSS, OUTPUT);

input reset, CLK, ISS, xn;
output OSS;
output [15:0] OUTPUT;
```
wire URy, URx, S2;
wire [1:0] S3, S4;
wire [2:0] S1;

Controller c (.CLK(CLK), .reset(reset),
.ISS(ISS), .URy(URy), .URx(URx), .S2(S2),
.OSS(OSS), .S3(S3), .S4(S4), .S1(S1));
Data_Path dp (.CLK(CLK), .reset(reset),
.xn(xn), .URy(URy), .URx(URx), .S2(S2),
.S3(S3), .S4(S4), .S1(S1), .OUTPUT(OUTPUT));
endmodule
Conclusions

From Gates to Large IP
Conclusions

System Silicon

IP Providers

Virtual Components

hard

firm

soft
Thanks......

hernande@tcnj.edu

http://www.tcnj.edu/~hernande/

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