3. Verilog I
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Sub-Modules
1. Introduction HDL-based Design with Verilog
2. A complete example: count.v
   - Design → Verification
3. A complete example: count.v
   - Synthesis
4. Further examples
3.2 A complete example: count.v

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Outline
1. Design before coding
2. count.v example
3. How verilog works internally

References
1. Quick Reference Guides
2. Ciletti, Ch. 4, Appendix I.
3. Smith & Franzon, Chapter 2-6

Attachments Required: Standard Synthesis Script (count.dc)
See Course Outline for further list of references
Objectives and Motivation

Objectives:
- Understand how to execute the mantra “Always Design Before Coding”.
- Understand how Verilog models the intrinsic parallelism of hardware.

Motivation:
- “put it all together” in big picture
- Start understanding how HDL models intrinsic parallelism of hardware
  - UNLIKE C
    - Useful to understand basics of “what is under the hood”
References

- Sutherland quick reference guide: Summary of main statement types
- Tutorial 1: Goes through tool usage with this example
- Ciletti:
  - Section 4.1: Basic Verilog Structures
  - Appendices: A-I: Verilog features
- Smith and Franzon:
  - Section 6.5: Follows this example
Mantra #2

- The most important one for this course

**ALWAYS DESIGN BEFORE CODING**

- Why?
  - Must code at Register Transfer Level
  - Registers and “transfer” (combinational) logic must be worked out before coding can start
Design Before Coding

- Automatic synthesis does NOT relieve you of logic design
- It does relieve you of:
  - Logic optimization
  - Timing calculations and control
  - In many cases, detailed logic design
- If you don’t DESIGN BEFORE CODING, you are likely to end up with the following:
  - A very slow clock (long critical path)
  - Poor performance and large area
  - Non-synthesizable Verilog
  - Many HDL lint errors
Avoid Temptation!

- Temptation #1:
  - “Verilog looks like C, so I’ll write the algorithm in C and turn it into Verilog with a few always@ statements”

- Usual results:
  - Synthesis problems, unknown clock level timing, too many registers
Avoid Temptation! (cont’d)

● Temptation #2
  ● “I can’t work out how to design it, so I’ll code up something that looks right and let Synthesis fix it”

● Usual result
  ● Synthesis DOES NOT fix it
Avoid Temptation! (cont’d)

- Temptation #3
  - “Look at these neat coding structures available in Verilog, I’ll write more elegant code and get better results”

- Usual result of temptation #3
  - Neophytes: Synthesis problems
  - Experts: Works fine but does not usually give a smaller or faster design + makes code harder to read and maintain

- Better logic, not better code gives a better design
Design Before Coding

Steps in Design

1. Work out the hardware algorithm and overall strategy
2. Identify and name all the registers (flip-flops)
   - Determine system timing while doing this
3. Identify the behavior of each “cloud” of combinational logic
4. TRANSLATE design to RTL
5. Verify Design
6. Synthesize Design
Design Example: Count Down Timer

- Specification:
  - 4-bit counter
  - count value loaded from `in` on a positive clock edge when `latch` is high
  - count value decremented by 1 on a positive clock edge when `dec` is high
  - decrement stops at 0
  - `zero` flag active high whenever count value is 0
What NOT TO Do

- Coding before design:
  ```vhdl
  always@(posedge clock)
  for (value=in; value>=0; value--)
  if (value==0) zero = 1
  else zero = 0;
  ```

- OR:
  ```vhdl
  always@(posedge clock)
  for (value=in; value>=0; value--)
    @(posedge clock)
    if (value==0) zero = 1
    else zero = 0;
  ```
**Strategy**

1. Work out the hardware algorithm and overall strategy

- **Strategy:**
  - Load ‘in’ into a register
  - Decrement value of register while ‘dec’ high
  - Monitor register values to determine when zero
Design

2. Identify and name all the registers (flip-flops)
Design (cont’d)

3. Identify the behavior of each “cloud” of combinational logic
4. TRANSLATE design to RTL

```verilog
module counter (clock, in, latch, dec, zero);

input clock; /* clock */
input [3:0] in; /* starting count */
input latch; /* latch `in' when high */
input dec; /* decrement count when dec high */
output zero; /* high when count down to zero */

reg [3:0] value; /* current count value */
wire zero;

always@(posedge clock)
  begin
    if (latch) value <= in;
    else if (dec && !zero) value <= value - 1'b1;
  end

assign zero = (value == 4'b0);
endmodule /* counter */
```
Features in Verilog Code

Note that it follows the hardware design, not the `C’ specification

Multibit variables:

```verilog
reg [3:0] value;
```

Specifying constant values:

```verilog
1’b1; 4’b0;
size ‘base value; size = # bits, HERE: base = binary
NOTE: zero filled to left
```

Procedural Block:

```verilog
always@( ) Executes whenever variables in sensitivity list ( ) change value
begin change as indicated
Usually statements execute in sequence, i.e. procedurally
end ... end only needed if more than one statement in block
```
Design Example ... Verilog

- **Continuous Assignment:**
  
  assign is used to implement combinational logic directly

**Questions**

1. When is the procedural block following the `always@(posedge clock)` executed?

2. When is ‘zero’ evaluated?

3. How is a comment done?

4. What does `1'b1` mean?

5. What does `reg [3:0] value;` declare?
Behavior $\rightarrow$ Function

```verilog
always@ (posedge clock)
begin
  if (latch) value = in;
  else if (dec && !zero) value = value - 1'b1;
end

assign zero = ~|value;
```
Misc. Alternative Coding

```verilog
module counter (clock, in, latch, dec, zero);

// Simple down counter with zero flag
input clock;       /* clock */
input [3:0] in;   /* starting count */
input latch;      /* latch `in' when high */
input dec;        /* decrement count when dec high */
output zero;      /* high when count down to zero */

reg [3:0] value;  /* current count value */
wire zero;
wire [3:0] value_minus1;
reg [3:0] mux_out;

// Count Flip-flops with input multiplexor
always @(posedge clock) begin
    value <= mux_out;
end

always @(*) begin
    if(latch) begin
        mux_out <= in;
    end
    else if(dec && !zero) begin
        mux_out <= value_minus1;
    end
    else begin
        mux_out <= value;
    end
end

assign value_minus1 = value - 1'b1;
// combinational logic for zero flag
assign zero = ~|value;
endmodule /* counter */
```

"ECE 406" style
- Clearly separates comb. Logic from FFs
- Use if you get confused
Alternative Coding

module counter (clock, in, latch, dec, zero);
// Simple down counter with zero flag
input clock;  /* clock */
input [3:0] in;  /* starting count */
input latch;  /* latch `in' when high */
input dec;  /* decrement count when dec high */
output zero;  /* high when count down to zero */

reg [3:0] value;  /* current count value */
reg zero;
// register `value' and associated input logic
always@(posedge clock) begin
  if (latch) value <= in;
  else if (dec && !zero) value <= value - 1'b1;
end
// combinational logic to produce `zero' flag
always@(value) begin
  if(value == 4'b0)
    zero = 1'b1;
  else
    zero = 1'b0;
end
endmodule /* counter */
module counter (input clock,
          input [3:0] in,
          input latch,
          input dec,
          output reg zero);

/* current count value */
reg [3:0] value;

always@(posedge clock) begin
  if (latch)
    value <= in;
  else if (dec && !zero)
    value <= value - 1'b1;
end

always@(*) begin
  if (value == 4'b0)
    zero = 1'b0;
else
  zero = 0;
end
endmodule /* counter */
Intrinsic Parallelism

- How Verilog models the intrinsic parallelism of hardware

```verilog
always@(posedge clock)
    A <= C & D;
always@(A)
    G = |A;
assign F = E ^ A;
```

Clock triggers

triggers
Intrinsic Parallelism

- Algorithm for
  
  \[
  \text{always@}(A) \quad G = |A; \\
  \text{assign} \quad F = E \land A;
  \]

  when \( A \) changes:

  In same time “step” the following steps are performed internally and sequentially:

  \[
  \text{next}G = |A; \\
  \text{next}F = E \land A;
  \]

  At end of time step:

  \[
  G = \text{next}G; \quad F = \text{next}F;
  \]
Timing

- The RTL only specifies the clock level timing
- The internal logic delays are worked out (and optimized) during synthesis
- Pre-synthesis, many signals will look like they are changing right on each clock edge
  - Think of them changing just after the clock edge
Exercise

- Modify design so it is decremented by TWO and stops, setting zero flag high, when it reaches 0000 or 0001

```verilog
always@(posedge clock)
    begin
        if (latch) value <= in;
        else if (dec && !zero) value <= value - 2'b10;
    end

assign zero = ((value == 4'b0)
endmodule /* counter */
```
Review

- How do you build a flip-flop in Verilog?

- How does Verilog handle the intrinsic parallelism of hardware?

- What is a procedural block?

- What is continuous assignment?