

COMS31700 Design Verification Hardware Design Languages

Kerstin Eder

(Acknowledgement: Avi Ziv from the IBM Research Labs in Haifa has kindly permitted the re-use of some of his slides.)



Department of
COMPUTER SCIENCE

Hardware Design Languages

- Hardware Design Languages were built with simulation in mind
 - Synthesis and other back-end purposes were added at a later stage
- Most popular languages today (both are IEEE standards)
 - VHDL
 - Verilog/SystemVerilog
- VHDL:
 - Committee-designed language contracted by U.S. (DoD) (ADA-derived)
 - Functional/logic modeling and simulation language
 - Main differentiator from Verilog is types (e.g. records)
- Verilog:
 - Logic modeling and simulation language
 - Started in EDA industry in the 80's then owned by Cadence
 - Donated to IEEE as a general industry standard
 - SystemVerilog (the next generation of Verilog) is designed to improve abstraction of Verilog
 - Abstraction levels
 - Data types
 - Verification constructs
- Verilog vs. VHDL: personal preferences, EDA tool availability, commercial, business and marketing issues.

2

Modeling Levels – Major Dimensions

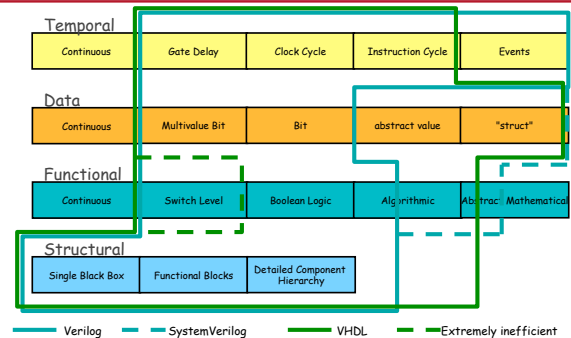
- Temporal Dimension:**
 - continuous (analog)
 - gate delay
 - clock cycle
 - instruction cycle
 - events

discrete time
- Data Abstraction:**
 - continuous (analog)
 - bit : multiple values
 - bit : binary
 - abstract value
 - composite value ("struct")

discrete value
- Functional Dimension:**
 - continuous functions (e.g. differential equations)
 - Switch-level (transistors as switches)
 - Boolean Logic
 - Algorithmic (e.g. sort procedure)
 - Abstract mathematical formula (e.g. matrix multiplication)
- Structural Dimension:**
 - Single black box
 - Functional blocks
 - Detailed hierarchy with primitive library elements

3

Modeling Levels – Major Dimensions



4

Verilog for Design Verification

- Assignment calc1 design in Verilog
 - Testbench for calc1 design in Verilog
- Interactive Evita Verilog tutorial** (Ch1-4,5-7):
 - Structure of Verilog modules
 - Verilog signal values: 0, 1, x and z (4-valued logic)
 - Verilog signals:
 - nets (used for "connections", no storage capacity)
 - registers (storage capacity, similar to variables in pgr languages)
 - Verilog external signals:
 - ports (input, output or inout, port connecting rules)
 - Coding styles:
 - Structural
 - Dataflow
 - Behavioural (best for verification)

5

Continuous Assignment

- Used in Dataflow coding style.**
- Keyword **assign** followed by optional delay declaration
- LHS** (target) can be net (scalar or vector) or concatenation of nets
 - NO registers allowed as target for assignment!
- Assignment symbol: **=**
- RHS** is an expression.
 - assign #4 Out = In1 & In2;**
- Implicit continuous assignment:** **wire x = ...;**
- Conditional assignment:**
 - assign Out = Sel ? In1 : In0;**
 - If Sel is 1 then In1 is assigned to Out; if Sel is 0 then Out is In0.
 - If Sel is x/z, evaluate both In1 and In0, if they are the same then Out is assigned this value, otherwise x/z.

6

Continuous Assignment: Execution

- Continuous assignments are **always active**.
- Concurrency:**
 - When any of the operands on RHS changes, assignment is evaluated.
 - Several assignments can be executed concurrently.
 - Race conditions can occur!**
 - Two or more assignments, which operate on the same data, read and write the data concurrently.
 - Result, which might be erroneous, depends on which assignment does what when.
- Delays** specify time between change of operand on RHS and assignment of resulting value to LHS target.
 - `assign #4 Out = In1 & In2;`

7

Behavioural Coding Style

- Most advanced coding style: flexible and high-level
 - closest to programming languages
 - allows use of conditional statements, case statements, loops, etc.
- Best for verification, but by no means ideal...**
- Behaviour:**
 - Actions a circuit is supposed to perform when it is active.
- Algorithmic description:** Need "variables" similar to PLs!
 - Abstraction of data storage elements - register objects:
 - `reg R`; one bit register - default value x before first assignment
 - `time T`; can store/manipulate simulation time
 - `integer N`; by default at least 32 bit - stores values signed
 - `real R`; default value is 0
 - [Other data types, e.g. arrays exist, but are out of the scope of this introduction.]

8

Behavioural Constructs for Coding

- Conditionals:**

```
if (expression true) true branch;
else false branch;
```
- Case:**

```
case ({_,...,_})
    pattern : ...;
    ...
    default : ...;
endcase
```
- Loops:** `forever`, `repeat`, `while`, `for`
- See Verilog reference card for syntax!

9

Mux421: Behavioural Coding Example

```
module mux421_behavioural (Out, In0, In1, In2, In3, Sel0, Sel1);
    output Out;
    input In0, In1, In2, In3, Sel0, Sel1;
    reg Out;
    always @ (Sel1 or Sel0 or In0 or In1 or In2 or In3)
    begin
        case ({Sel1,Sel0})
            2'b00 : Out = In0;
            2'b01 : Out = In1;
            2'b10 : Out = In2;
            2'b11 : Out = In3;
            default : Out = 1'bx;
        endcase
    end
endmodule // mux421_behavioural
```

10

Mux421: Behavioural Coding Example

```
module mux421_behavioural (Out, In0, In1, In2, In3, Sel0, Sel1);
    output Out;
    input In0, In1, In2, In3, Sel0, Sel1;
    reg Out;
    always @ (Sel1,Sel0,In0,In1,In2,In3) // Verilog 2001 style
    begin
        case ({Sel1,Sel0})
            2'b00 : Out = In0;
            2'b01 : Out = In1;
            2'b10 : Out = In2;
            2'b11 : Out = In3;
            default : Out = 1'bx;
        endcase
    end
endmodule // mux421_behavioural
```

11

Behavioural Blocks

- initial and always**
 - Can't be nested.
 - Block containing several statements must be grouped using:
 - `begin ... end (sequential)` or
 - `fork ... join (concurrent)`
- initial block:**
 - Used to initialise variables (registers).
 - Executed at (simulation) time 0. Only once!
- always block:**
 - Starts executing at time 0.
 - Contents is executed in infinite loop.
 - Means: Executing repeats as long as simulation is running.
 - Multiple blocks are all executed **concurrently** from time 0.

12

Assignment in Behavioural Coding

Assignment in behavioural coding style is **procedural**:

- LHS (target) must be a register (reg, integer, real or time) - not a net, a bit or part of a vector of registers.
- **NO assign keyword!**
- Must be contained within a behavioural (i.e. `initial` or `always`) block.
- **NOT always active!**
 - Target register value is only changed when procedural assignment is executed according to **sequence** contained in block.
- **Delays:** indicate time that simulator waits from "finding" the assignment to executing it.

13

Blocking Assignment

(... as opposed to continuous assignment from dataflow coding style.)

```
reg A;
reg [7:0] Vector;
integer Count;
initial
begin
    A = 1'b0;
    Vector = 8'b0;
    Count = 0;
end
```

- Sequential initialisation assignment.

14

Timing Control Evaluation

`#5 C = #10 A+B;`

Assignment delay Intra-assignment delay

1. Find procedural assignment
2. Wait 5 time units
3. Perform A+B
4. Wait 10 time units
5. Assign result to C

- So, what is the difference between:
 - `#10 C = A+B` and
 - `C = #10 A+B`?

15

Events and Wait

- **Events** mark changes in nets and registers, e.g. raising/falling edge of clock.
 - @ **negedge** means from any value to 0
 - @ **posedge** means from any value to 1
 - @ **clk** always activates when clock changes
- **Wait statement:**
 - `wait (condition) stmt;`
 - `wait (EN) #5 C = A + B;`
 - waits for EN to be 1 before `#5 C = A + B;`
- Use **wait** to block execution by not specifying a statement!
 - `wait (EN); ...`

16

Sensitivity List

```
always @(sensitivity list) <begin> <procedural stments> <end>
always @ (posedge Clk or EN)
begin ... end
always @ (Sel1,Sel2) // Verilog 2001 style
begin ... end
```

- Allows to **suspend always blocks**.
- Block executes and suspends until signal (one or more) in **sensitivity list** changes.
- NOTE: **or** is used to make statement **sensitive to multiple signals or events**.
- (Don't use sensitivity list to express a logical condition!)
- Common mistake:
 - Forgetting to add relevant signals to sensitivity list!

17

Non-blocking Assignments

- **Concurrency** can be introduced into sequential statements.
 - Delay is counted down before assignment,
 - BUT **control is passed to next statement immediately**.
- **Non-blocking Assignments** allow to model multiple concurrent data transfers after common event.
- A blocking assignment would force sequential execution.

`A <= #1 1; B <= #2 0; (non-blocking)`

```
A x 1 1 1
B x x 0 0
Time: 0 1 2 3
```

`A = #1 1; B = #2 0; (blocking)`

```
A x 1 1 1
B x x x 0
Time: 0 1 2 3
```

18

Approaches to Assignment - I

```
reg [7:0] MyReg;
initial
  fork
    #50 MyReg = 8'hFF;
    #100 MyReg = 8'h01;
    #150 MyReg = 8'h2F;
    #200 MyReg = 8'h00;
    #250 $finish;
  join
```

- **Concurrent blocking (=)**

```
Time:      0   50  100 150 200 250
MyReg[7:0] XX FF 01 2F 00 00
```

Important when driving input into a DUV in a testbench!

19

Approaches to Assignment - II

```
reg [7:0] MyReg;
initial
  begin
    MyReg <= #50 8'hFF; // pass control, wait, assign
    MyReg <= #50 8'h01;
    MyReg <= #50 8'h2F;
    MyReg <= #50 8'h00;
    #250 $finish;
  end
```

Race Condition!

- **Sequential non-blocking (<=)**

```
Time:      0   50  100 150 200 250
MyReg[7:0] XX ??
```

Important when driving input into a DUV in a testbench!

20

Approaches to Assignment - III

```
reg [7:0] MyReg;
initial
  begin
    MyReg <= #50 8'hFF; // pass control, wait, assign
    MyReg <= #100 8'h01;
    MyReg <= #150 8'h2F;
    MyReg <= #200 8'h00;
    #250 $finish;
  end
```

- **Sequential non-blocking (<=)**

```
Time:      0   50  100 150 200 250
MyReg[7:0] XX FF 01 2F 00 00
```

Important when driving input into a DUV in a testbench!

21

Approaches to Assignment - IV

```
reg [7:0] MyReg;
initial
  begin
    #50 MyReg = 8'hFF; // wait, assign, pass control
    #50 MyReg = 8'h01;
    #50 MyReg = 8'h2F;
    #50 MyReg = 8'h00;
    #250 $finish;
  end
```

- **Sequential blocking (=)**

```
Time:      0   50  100 150 200 250
MyReg[7:0] XX FF 01 2F 00 00
```

Important when driving input into a DUV in a testbench!

22

HDL vs. Programming Languages

3 major new concepts of HDLs compared to PLs:

- **Connectivity:**
 - Ability to describe a design using simpler blocks and then connecting them together.
- **Time:**
 - Can specify a delay (in time units of simulator): (WHY?)
 - and #2 (Y3, In3, Sel1, Sel0);
- **Concurrency is always assumed!** (for structural style this is)
 - No matter in which order primitives/components are specified, a change in value of any input signal **activates** the component.
 - If 2 or more components are activated **concurrently**, they perform their actions **concurrently**.
 - Order of specification does not influence order of activation!
 - (NOTE: Statements inside behavioural blocks may be sequential -more later.)

23

Tasks and Functions

Tasks and Functions

- Both are **purely behavioural**.
 - Can't define nets inside them.
 - Can use logical variables, registers, integers and reals.
- Must be declared within a module.**
 - Are local to this module.
 - To share tasks/functions in several modules, specify declaration in separate module and use **'include** directive.
- Timing (simulation time)**
 - Tasks:**
 - No restriction on use of timing; engineer specifies execution.
 - Functions:**
 - Execute in ZERO sim time units; no timing/event control allowed.

25

Comparing Tasks with Functions

	Tasks	Functions
Timing	can be non-zero sim time	execute in 0 sim time
Calling other tasks or functions	no limit; may enable functions	may not call tasks but may call another function No recursion!
Arguments	any number; any type; can't return result	at least one input; no output/inout; always results in single return value
Purpose	modularize code	react to some input with single response; only combinatorial code; use as operands in expressions

26

Example Task

```
task factorial;
  output [31:0] f;
  input [3:0] n;
  integer count; // local variable
  begin
    f = 1;
    for (count=n; count>0; count=count-1)
      f = f * count;
  end
endtask
```

- Invoke task:** < task name > (list of arguments);
 - Declaration order determines order of arguments when task is called!

27

Example Function

```
function ParityCheck;
  input [3:0] Data;
  begin
    ParityCheck = ^Data; // bit-wise xor reduction
  end
endfunction
```

- Result** is by default a 1 bit register assigned to implicitly declared local variable that has same name as function.
- Function calls:**
 - Are either assigned to a variable, or
 - occur in an expression that is assigned to a variable, or
 - occur as an argument of another function call.

28

System Tasks and Functions

- More than 100 Verilog system tasks/functions.
 - (See Evita Verilog Reference Guide for more information.)
- Can be used in any module without explicit include directive.
- Syntax:** \$< keyword >
- Most important tasks for verification:**
 - \$display, \$monitor
 - \$time, \$stop, \$finish
 - (Also with files: \$fopen, \$fdisplay)

29

Summary

- Evita Verilog Tutorial [Ch1-7]
- Verilog HDL IEEE Standard 1364-2001**
 - Signals: internal and external (ports)
 - Different coding styles:
 - structural
 - dataflow
 - behavioural
- SystemVerilog builds on IEEE 1364-2005
- HDLs: Connectivity, Time and Concurrency**
- BOOK: Verilog HDL by Samir Palnitkar [in QB Library]
- Next:** Specification of Assignment 1!

30