

# 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.)

# 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.

# Modeling Levels – Major Dimensions

---

- **Temporal Dimension:**

- continuous (analog)
- gate delay
- clock cycle
- instruction cycle
- events



- **Data Abstraction:**

- continuous (analog)
- bit : multiple values
- bit : binary
- abstract value
- composite value ("struct")



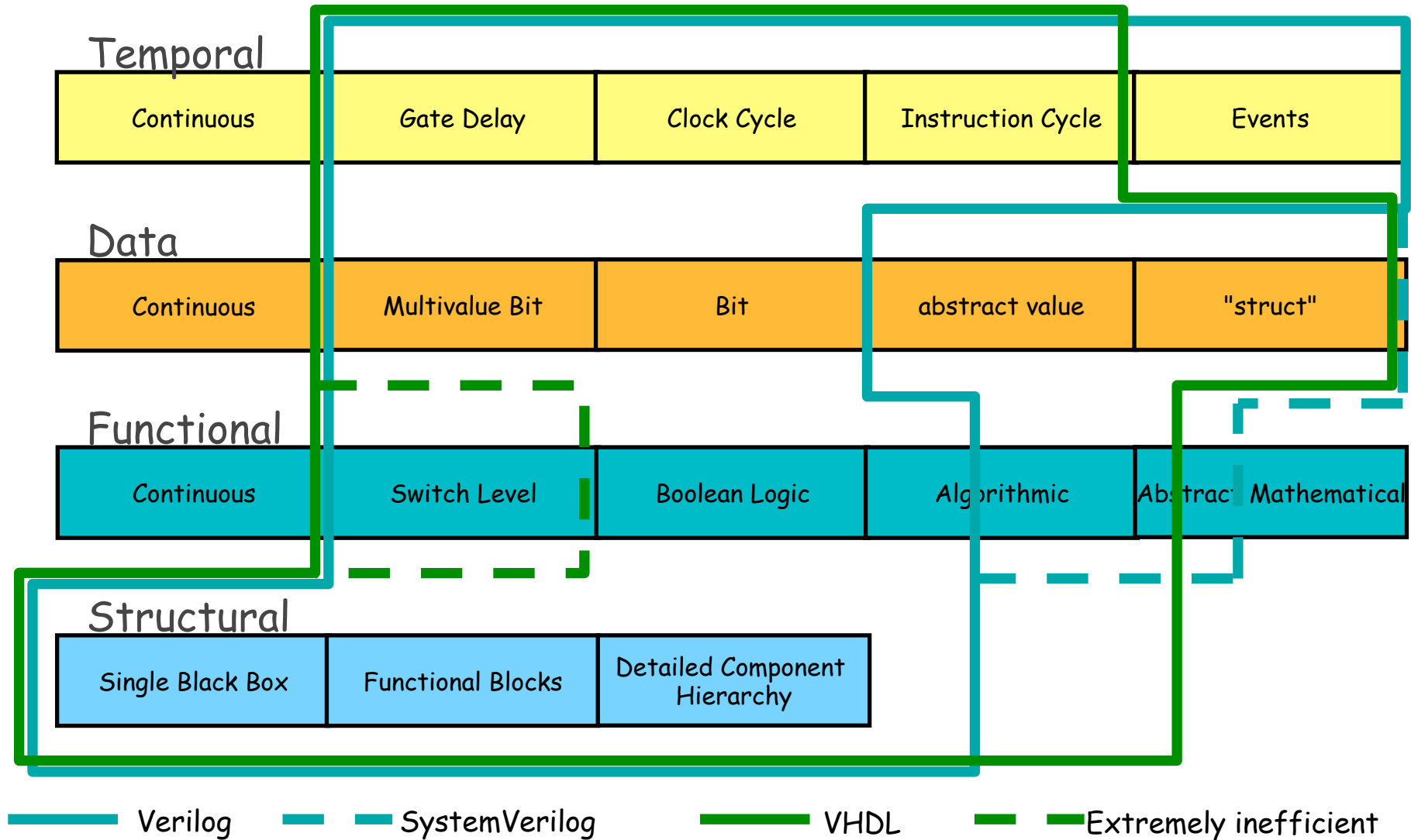
- **Functional Dimension:**

- 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

# Modeling Levels – Major Dimensions



# 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)

# 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`.

# 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;

# 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.]



# 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
```

# 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
```

# 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.

# 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.

# Blocking Assignment

---

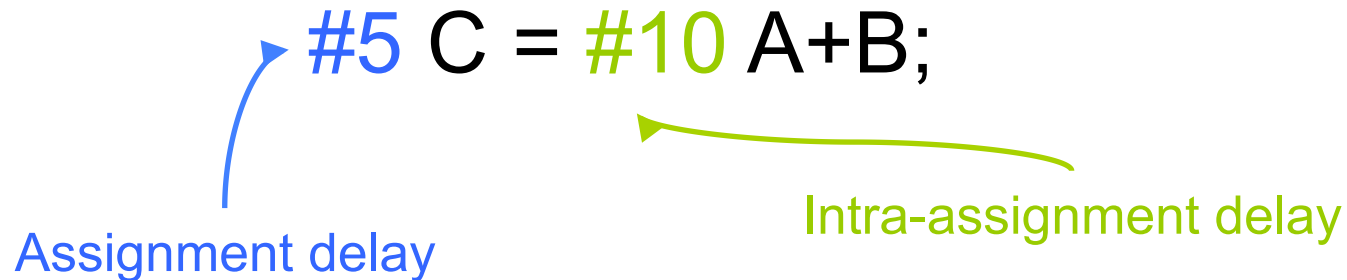
(... as opposed to continuous assignment from dataflow coding style.)

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

- Sequential initialisation assignment.

# Timing Control Evaluation

---



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`?

# 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) ; ...

# 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!



# 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

# 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!**

# 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!**

# 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!**

# 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!**

# 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.)

# 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.



# 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 <b>No recursion!</b>
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

# 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!

# 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.

# 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`)

# 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!