

Computer-Aided VLSI System Design

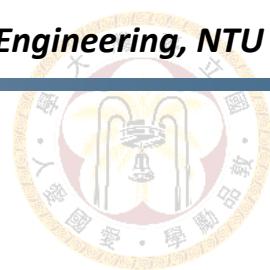
Chapter 5. Synopsys Synthesis Design Compiler & Post-sim Part1

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Graduate Institute of Electronics Engineering, National Taiwan University

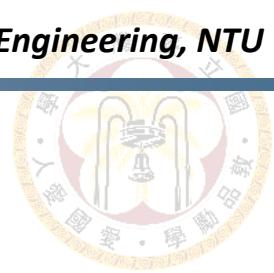


NTU GIEE



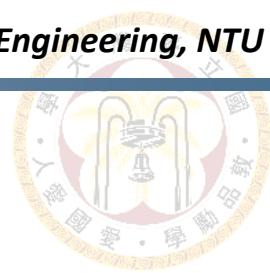
Outline

- **Introduction**
- **RTL Coding Related to Synthesis**
- **Synopsys Environment**
- **Synthesis Design Flow**
- **Gate-Level Simulation**
- **Files Demo**

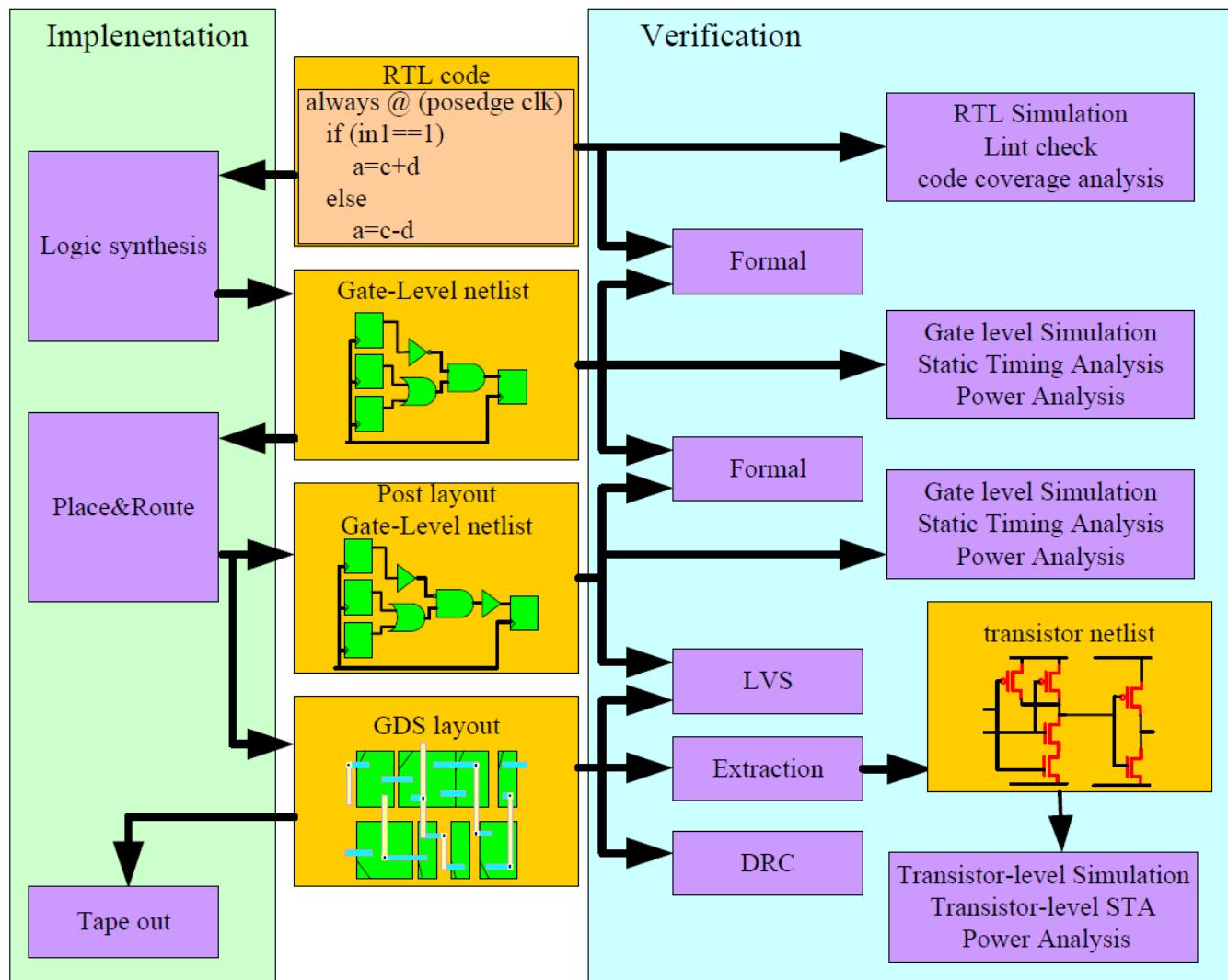


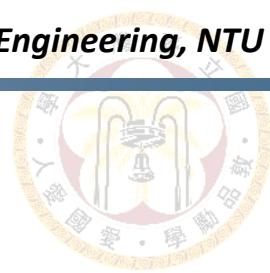
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Cell-based IC Design Flow





Logic Synthesis

- A process to convert RTL into a technology-specific gate-level netlist optimized with a set of design constraints
 - Library
 - Standard cell library
 - User data
 - RTL design
 - Design constraints

```
module counter (
    input i_clk, rstn, load,
    input [1:0] in,
    output reg [1:0] out);
    always@(posedge i_clk) begin
        if(!rstn) out <= 2'b0;
        else if (load) out <= in;
        else out <= out+1;
    end
endmodule
```

RTL Design
counter.v

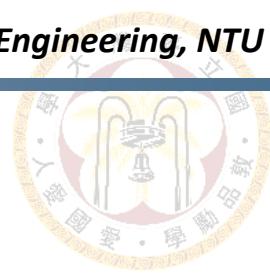
Synthesis Tool:
Design Compiler

Standard Cell Lib.
Design Constraints

```
module counter ( i_clk, rstn, load, in, out );
    input [1:0] in;
    output [1:0] out;
    input i_clk, rstn, load;
    wire n12, n13, N6, N7, n5, n8, n9, n10, n11;

    DFFQX1 out_reg_1_ ( .D(N7), .CK(i_clk), .Q(n12) );
    DFFQX1 out_reg_0_ ( .D(N6), .CK(i_clk), .Q(n13) );
    CLKINVX1 U9 ( .A(n13), .Y(n5) );
    INVX16 U10 ( .A(n5), .Y(out[0]) );
    BUFX16 U11 ( .A(n12), .Y(out[1]) );
    INVXL U12 ( .A(load), .Y(n9) );
    OAI21XL U13 ( .A0(in[0]), .A1(n9), .B0(rstn), .Y(n8) );
    AOI21XL U14 ( .A0(n9), .A1(out[0]), .B0(n8), .Y(N6) );
    AOI2BB2X1 U15 ( .B0(out[1]), .B1(out[0]), .A0N(out[1]),
                      .A1N(out[0]), .Y(n11) );
    OAI21XL U16 ( .A0(in[1]), .A1(n9), .B0(rstn), .Y(n10) );
    AOI2BB1X1 U17 ( .A0N(n11), .A1N(load), .B0(n10), .Y(N7) );
endmodule
```

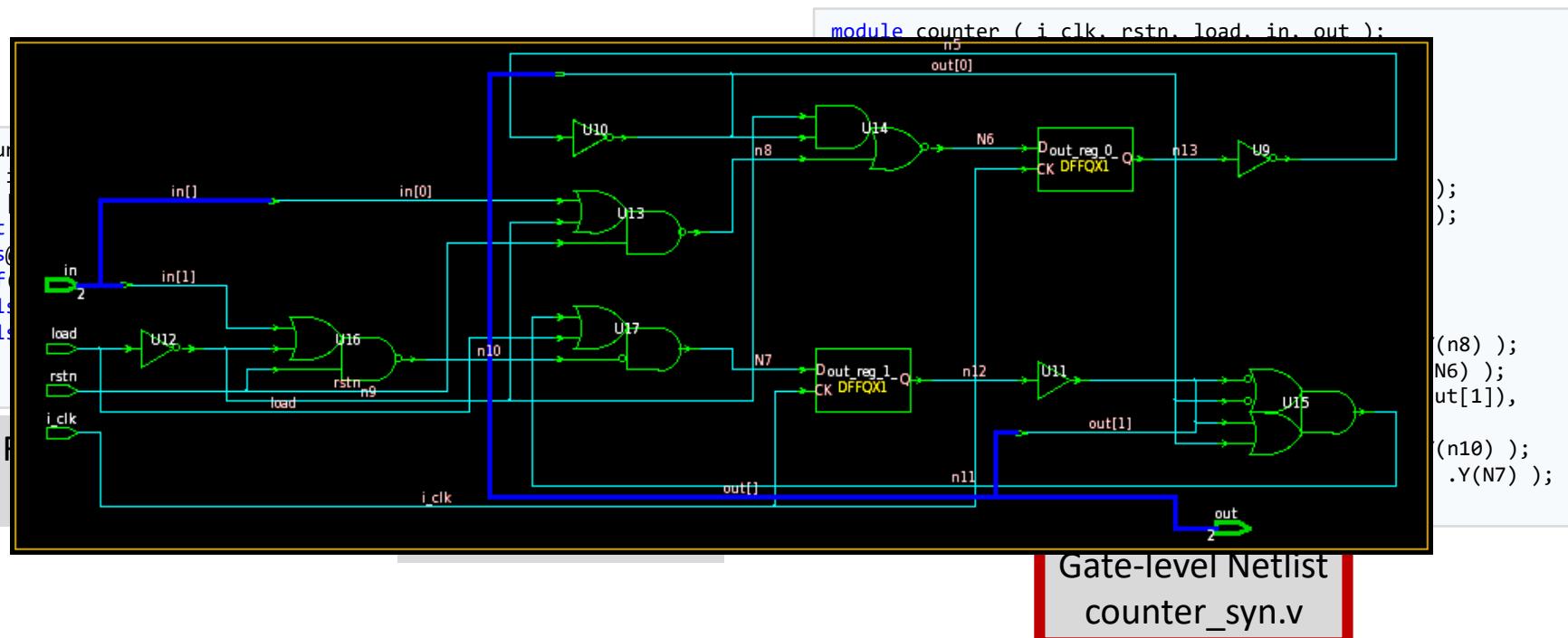
Gate-level Netlist
counter_syn.v

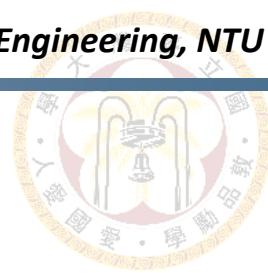


Logic Synthesis

■ Gate-level Netlist

- Describes the circuit with standard cells





Logic Synthesis

- Standard cell library defines the components for gate-level netlist
- Standard cell library provided by foundry (e.g., TSMC)
 - Standard cell list, e.g., AND, XOR, NAND, D flip-flop, etc.
 - Area, delay, power, functionality of each cell

```
module counter (
  input i_clk, rstn, load,
  input [1:0] in,
  output reg [1:0] out);
  always@(posedge i_clk) begin
    if(!rstn) out <= 2'b0;
    else if (load) out <= in;
    else out <= out+1;
  end
endmodule
```

RTL Design
counter.v

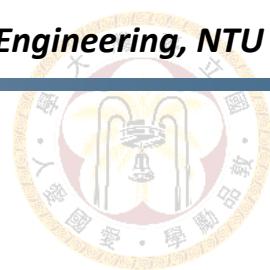
Synthesis Tool:
Design Compiler

Standard Cell Lib.
Design Constraints

```
module counter ( i_clk, rstn, load, in, out );
  input [1:0] in;
  output [1:0] out;
  input i_clk, rstn, load;
  wire n12, n13, N6, N7, n5, n8, n9, n10, n11;

  DFFQX1 out_reg_1_ ( .D(N7), .CK(i_clk), .Q(n12) );
  DFFQX1 out_reg_0_ ( .D(N6), .CK(i_clk), .Q(n13) );
  CLKINVX1 U9 ( .A(n13), .Y(n5) );
  INVX16 U10 ( .A(n5), .Y(out[0]) );
  BUFX16 U11 ( .A(n12), .Y(out[1]) );
  INVXL U12 ( .A(load), .Y(n9) );
  OAI21XL U13 ( .A0(in[0]), .A1(n9), .B0(rstn), .Y(n8) );
  AOI21XL U14 ( .A0(n9), .A1(out[0]), .B0(n8), .Y(N6) );
  AOI2BB2X1 U15 ( .B0(out[1]), .B1(out[0]), .A0N(out[1]),
    .A1N(out[0]), .Y(n11) );
  OAI21XL U16 ( .A0(in[1]), .A1(n9), .B0(rstn), .Y(n10) );
  AOI2BB1X1 U17 ( .A0N(n11), .A1N(load), .B0(n10), .Y(N7) );
endmodule
```

Gate-level Netlist
counter_syn.v



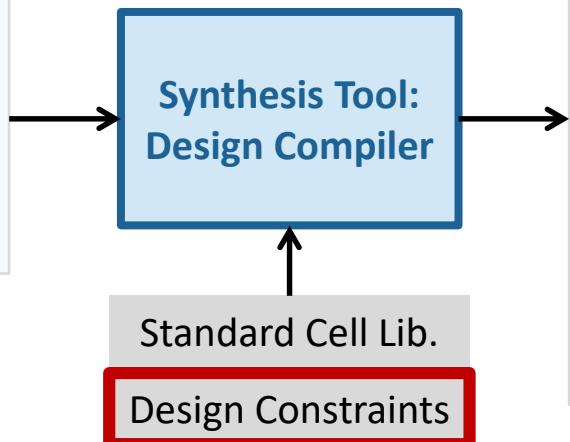
Logic Synthesis

■ Design constraints

- Conditions or requirements for the gate-level netlist
 - E.g., require the circuit to run at 100 MHz, minimize the area
- Iteratively optimization is performed based on constraints

```
module counter (
  input i_clk, rstn, load,
  input [1:0] in,
  output reg [1:0] out);
  always@(posedge i_clk) begin
    if(!rstn) out <= 2'b0;
    else if (load) out <= in;
    else out <= out+1;
  end
endmodule
```

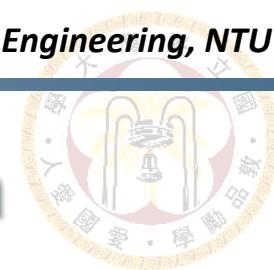
RTL Design
counter.v



```
module counter ( i_clk, rstn, load, in, out );
  input [1:0] in;
  output [1:0] out;
  input i_clk, rstn, load;
  wire n12, n13, N6, N7, n5, n8, n9, n10, n11;

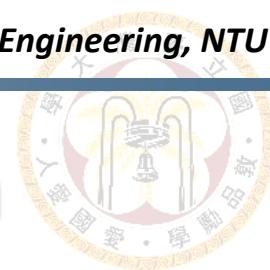
  DFFQX1 out_reg_1_ ( .D(N7), .CK(i_clk), .Q(n12) );
  DFFQX1 out_reg_0_ ( .D(N6), .CK(i_clk), .Q(n13) );
  CLKINVX1 U9 ( .A(n13), .Y(n5) );
  INVX16 U10 ( .A(n5), .Y(out[0]) );
  BUFX16 U11 ( .A(n12), .Y(out[1]) );
  INVXL U12 ( .A(load), .Y(n9) );
  OAI21XL U13 ( .A0(in[0]), .A1(n9), .B0(rstn), .Y(n8) );
  AOI21XL U14 ( .A0(n9), .A1(out[0]), .B0(n8), .Y(N6) );
  AOI2BB2X1 U15 ( .B0(out[1]), .B1(out[0]), .A0N(out[1]),
    .A1N(out[0]), .Y(n11) );
  OAI21XL U16 ( .A0(in[1]), .A1(n9), .B0(rstn), .Y(n10) );
  AOI2BB1X1 U17 ( .A0N(n11), .A1N(load), .B0(n10), .Y(N7) );
endmodule
```

Gate-level Netlist
counter_syn.v



1. Constraint-driven Optimization

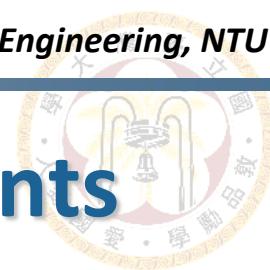
- The gate-level netlist generated in synthesis is meant to meet several goals defined by designer
 - Design rule constraints
 - E.g., capacitance limit/fanout/transition time limit for each wire
 - Timing requirements for each path
 - Power constraint
 - Area constraint
- Optimization in synthesis is **constraint-driven**
 - Not exhaustive search
 - The gate-level netlist is iteratively optimized for unmet goals



1. Constraint-driven Optimization

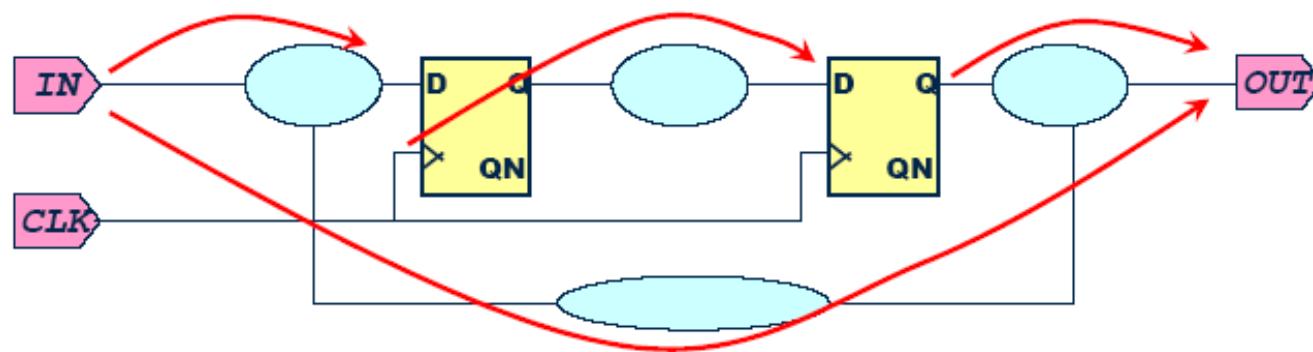
■ Optimization process example in Design Compiler

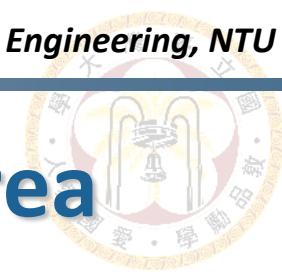
ELAPSED TIME	AREA	WORST NEG SLACK	TOTAL SETUP COST	DESIGN RULE COST	ENDPOINT	LEAKAGE POWER	MIN DELAY COST
0:00:09	24208.3	0.07	7.2	0.0		24438066.0000	0.00
0:00:09	24208.3	0.07	7.2	0.0		24438066.0000	0.00
Beginning Constant Register Removal							
Beginning Global Optimizations							
Numerical Synthesis (Phase 1)							
Numerical Synthesis (Phase 2)							
Global Optimization (Phase 1)							
Global Optimization (Phase 2)							
Global Optimization (Phase 3)							
Global Optimization (Phase 4)							
Beginning Isolate Ports							
Beginning Delay Optimization							
0:00:10	15865.6	0.51	48.3	37.6		15621728.0000	0.00
0:00:12	16744.9	0.13	13.0	19.3		16497935.0000	0.00
0:00:12	16744.9	0.13	13.0	19.3		16497935.0000	0.00
0:00:12	16733.0	0.14	13.4	0.0		16813510.0000	0.00
0:00:12	16733.0	0.14	13.4	0.0		16813510.0000	0.00
0:00:12	16733.0	0.14	13.4	0.0		16813510.0000	0.00
Beginning WLM Backend Optimization							
0:00:13	16673.6	0.14	13.9	0.0		16743739.0000	0.00
0:00:13	16673.6	0.14	13.9	0.0		16743739.0000	0.00
0:00:13	16673.6	0.14	13.9	0.0		16743739.0000	0.00
0:00:13	16783.9	0.14	13.6	0.0		16824478.0000	0.00
0:00:13	16783.9	0.14	13.6	0.0		16824478.0000	0.00
0:00:13	17700.5	0.12	10.9	0.0		17591000.0000	0.00
0:00:14	17700.5	0.12	10.9	0.0		17591000.0000	0.00
0:00:14	17748.0	0.12	10.5	0.0		17656992.0000	0.00
0:00:14	17748.0	0.12	10.5	0.0		17656992.0000	0.00
0:00:14	17748.0	0.12	10.5	0.0		17656992.0000	0.00
0:00:14	17748.0	0.12	10.5	0.0		17656992.0000	0.00
0:00:16	18335.3	0.08	6.1	6.6		18312380.0000	0.00
0:00:16	18335.3	0.08	6.1	6.6		18312380.0000	0.00



2. Timing Paths & Timing Requirements

- Using inputs, outputs and registers as endpoints, the combinational part of design can be divided into 4 type of paths
 - Input to register
 - Register to register
 - Register to output
 - Input to output
- In the synthesized netlist, all paths should meet timing requirements
 - E.g., in a gate-level netlist synthesized for 200MHz, delay on all reg-to-reg paths should $\leq 5\text{ns}$



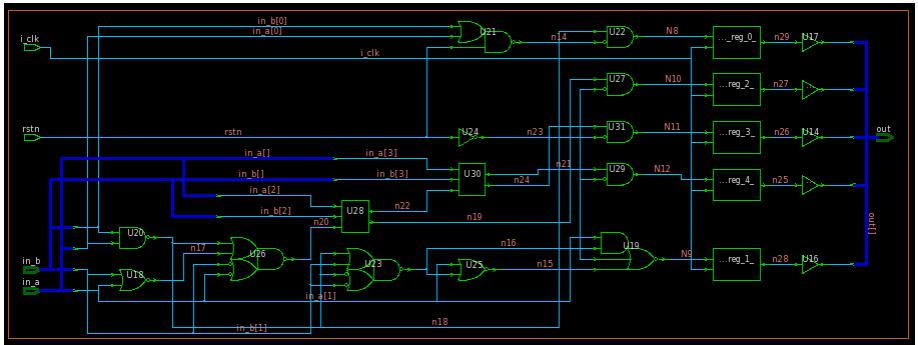


3. Trade-off between Timing and Area

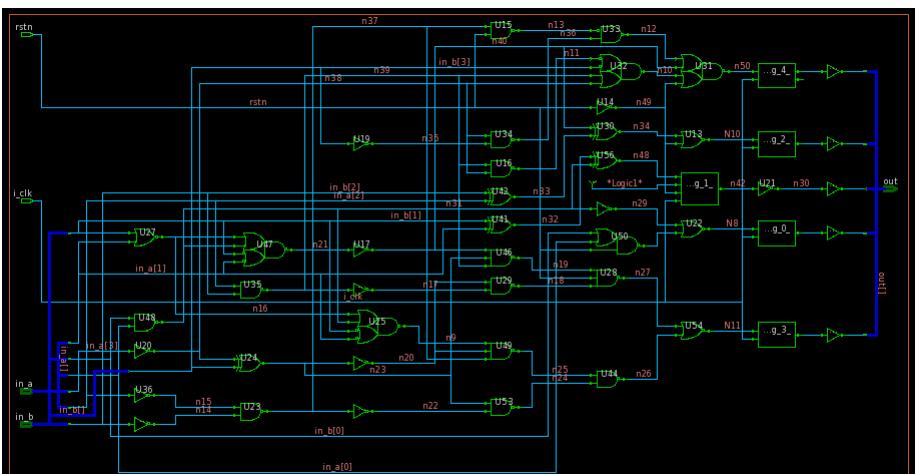
Clock Cycle = 10 ns

```
module adder (
    input i_clk, rstn,
    input [3:0] in_a,in_b,
    output reg [4:0] out);
    always@(posedge i_clk) begin
        if (!rstn) out <= 0;
        else out <= in_a+in_b;
    end
endmodule
```

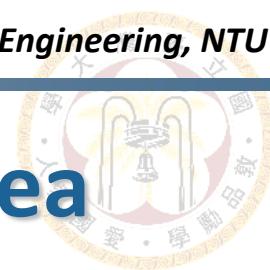
Clock Cycle = 5 ns



Cell area = 361 μm^2

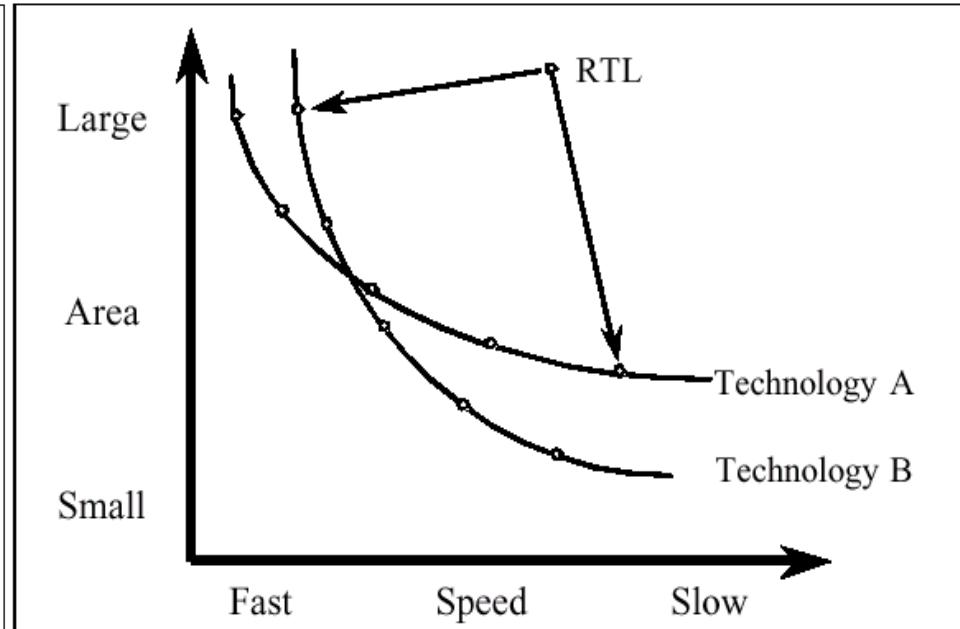
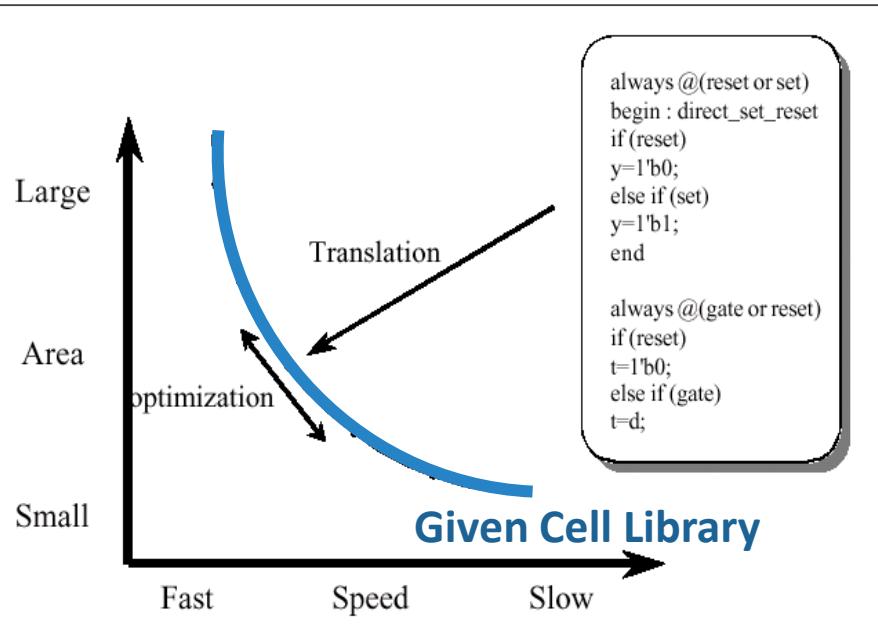


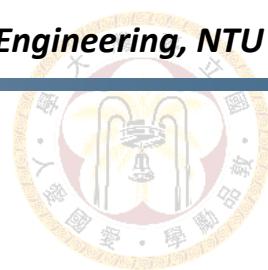
Cell area = 729 μm^2



3. Trade-off between Timing and Area

- Given the same library and the same source code, you can
 - Sacrifice area for higher speed
 - Sacrifice speed for lower area





Logic Synthesis

- A process to convert RTL into a technology-specific gate-level netlist optimized with a set of design constraints

```
module counter (
    input i_clk, rstn, load,
    input [1:0] in,
    output reg [1:0] out);
    always@(posedge i_clk) begin
        if(!rstn) out <= 2'b0;
        else if (load) out <= in;
        else out <= out+1;
    end
endmodule
```

RTL Design
counter.v

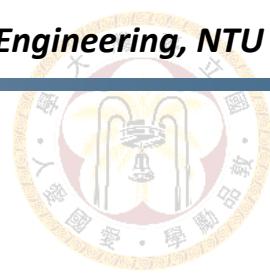
Synthesis Tool:
Design Compiler

Standard Cell Lib.
Design Constraints

```
module counter ( i_clk, rstn, load, in, out );
    input [1:0] in;
    output [1:0] out;
    input i_clk, rstn, load;
    wire n12, n13, N6, N7, n5, n8, n9, n10, n11;

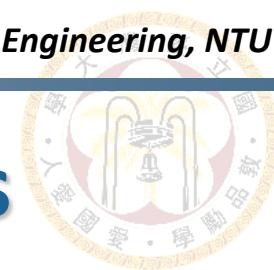
    DFFQX1 out_reg_1_ ( .D(N7), .CK(i_clk), .Q(n12) );
    DFFQX1 out_reg_0_ ( .D(N6), .CK(i_clk), .Q(n13) );
    CLKINVX1 U9 ( .A(n13), .Y(n5) );
    INVX16 U10 ( .A(n5), .Y(out[0]) );
    BUFX16 U11 ( .A(n12), .Y(out[1]) );
    INVXL U12 ( .A(load), .Y(n9) );
    OAI21XL U13 ( .A0(in[0]), .A1(n9), .B0(rstn), .Y(n8) );
    AOI21XL U14 ( .A0(n9), .A1(out[0]), .B0(n8), .Y(N6) );
    AOI2BB2X1 U15 ( .B0(out[1]), .B1(out[0]), .A0N(out[1]),
                      .A1N(out[0]), .Y(n11) );
    OAI21XL U16 ( .A0(in[1]), .A1(n9), .B0(rstn), .Y(n10) );
    AOI2BB1X1 U17 ( .A0N(n11), .A1N(load), .B0(n10), .Y(N7) );
endmodule
```

Gate-level Netlist
counter_syn.v



Outline

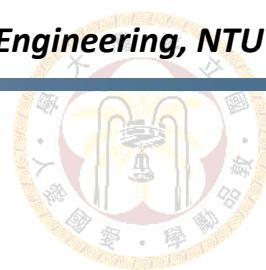
- Introduction
- **RTL Coding Related to Synthesis**
- Synopsys Environment
- Synthesis Design Flow
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- Files Demo



Unsupported Syntax for Synthesis

- These syntaxes are for simulation only and cannot be converted to gates

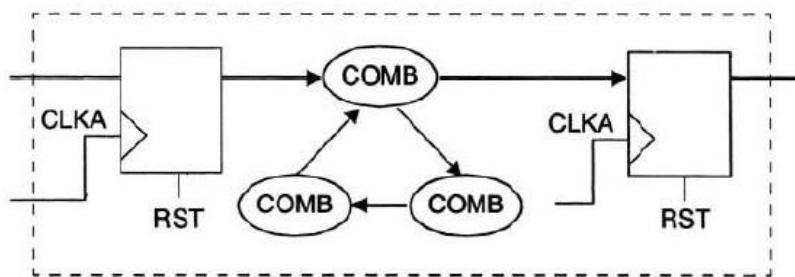
- **delay**
- **initial**
- **repeat**
- **wait**
- **fork ... join**
- **event**
- **deassign**
- **force**
- **release**
- **primitive**
- **time**
- triand, trior, tri1, tri0, trireg
- nmos, pmos, cmos, rnmos, rpmos, rcmos
- pullup, pulldown
- rtran, tranif0, tranif1, rtranif0, rtranif1
- **case identity (==)**
- **not identity (!==)**



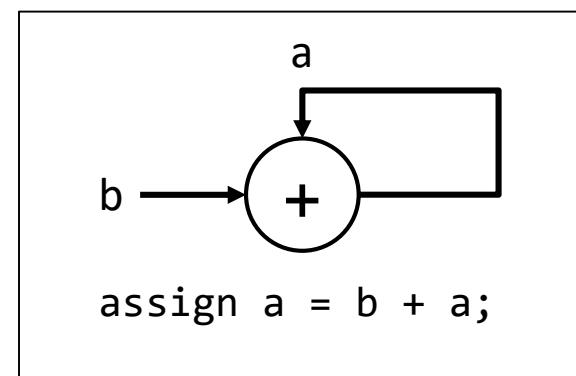
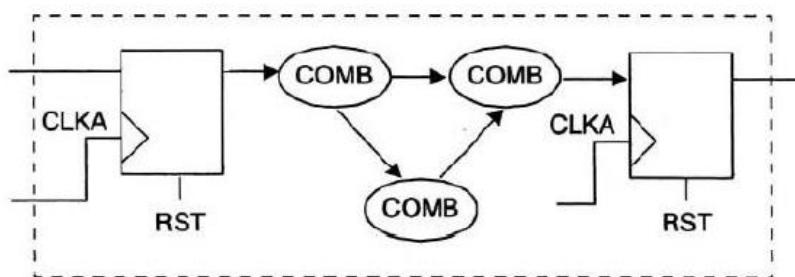
Avoid Combinational Loop

- An output of a combinational block feeds back to an input of the same block

Bad: Combinational processes are looped

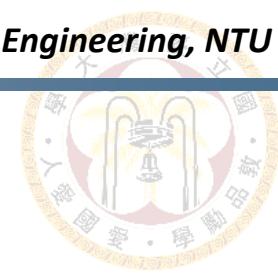


Good: Combinational processes are not looped



An error example

Static timing analysis (STA) cannot be applied



Avoid Combinational Loop

Check_timing

- Checks for possible timing problems in the current design
- Can detect combination loop, unconstrained path, etc.

```

1 Information: Checking out the license 'DesignWare'. (SEC-104)
2 Information: Updating design information... (UID-85)
3
4 Information: Checking generated_clocks...
5
6 Information: Checking loops...
7
8 Information: Checking no_input_delay...
9
10 Information: Checking unconstrained_endpoints...
11
12 Information: Checking pulse_clock_cell_type...
13
14 Information: Checking no_driving_cell...
15
16 Information: Checking partial_input_delay...
17 1
18

```

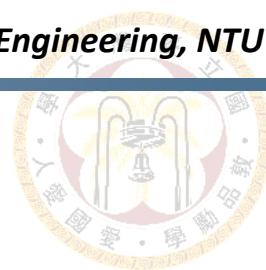
Example of check_timing
(No problems detected)

```

1 Information: Updating design information... (UID-85)
2
3 Information: Checking generated_clocks...
4
5 Information: Checking loops...
6 Warning: timing loops detected. (TIM-209)
7      #           loop breakpoint
8
9          cell_arc          lib cell
10 -----
11 C38/B      -> C38/Z      gtech/GTECH_AND2   #
12 C54/A      -> C54/Z      gtech/GTECH_OR2
13
14          cell_arc          lib cell
15 -----
16 C39/B      -> C39/Z      gtech/GTECH_AND2   #
17 C55/A      -> C55/Z      gtech/GTECH_OR2
18
19          cell_arc          lib cell
20 -----
21 C40/B      -> C40/Z      gtech/GTECH_AND2   #
22 C56/A      -> C56/Z      gtech/GTECH_OR2
23
24          cell_arc          lib cell
25 -----
26 C41/B      -> C41/Z      gtech/GTECH_AND2   #
27 C57/A      -> C57/Z      gtech/GTECH_OR2
28
29          cell_arc          lib cell
30 -----
31 C42/B      -> C42/Z      gtech/GTECH_AND2   #
32 C58/A      -> C58/Z      gtech/GTECH_OR2

```

Loops detected in check_timing



Supported Syntax for Synthesis

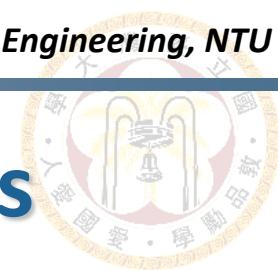
■ Operators

- Binary bit-wise (\sim , $\&$, $|$, \wedge , $\sim\wedge$)
- Unary reduction ($\&$, $\sim\&$, $|$, $\sim|$, \wedge , $\sim\wedge$)
- Logical (\sim , $\&\&$, $\|$)
- 2's complement arithmetic ($+$, $-$, $*$, $/$, $\%$)
- Relational ($>$, $<$, \geq , \leq)
- Equality ($\==$, $\!=$)
- Logical shift ($>>$, $<<$)
- Conditional ($?:$)

■ Continuous assignment (assign)

■ Always block

- Combinational always block (`always@(*)`)
- Register (`always@(posedge clk)`)
- if-else & case statements

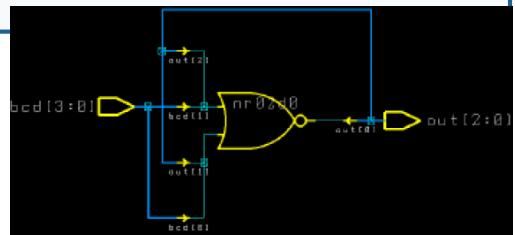


Special Syntax: Compiler Directives

■ synopsys full_case

- Do not specify default case/all cases
- Requirement: no other cases will appear
- Other branches will be considered as don't-care conditions

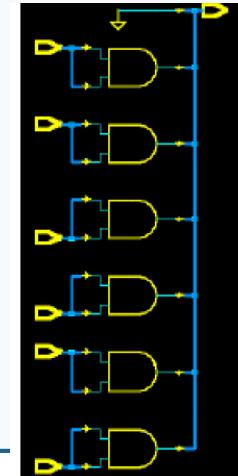
```
always@ (bcd) begin
    case (bcd) //synopsys full_case
        4'd0: out = 3'b001;
        4'd1: out = 3'b010;
        4'd2: out = 3'b100;
    endcase
end
```

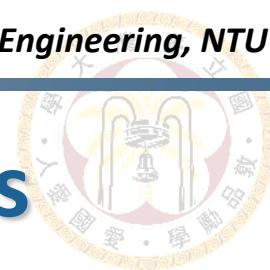


■ synopsys parallel_case

- Eliminate priority in case statements
- Requirement: only 1 case matched at a time

```
always@ (u or v or w or x or y or z) begin
    case (2'b11) //synopsys parallel_case
        u: out = 6'b000001;
        v: out = 6'b000010;
        w: out = 6'b000100;
        x: out = 6'b001000;
        y: out = 6'b010000;
        z: out = 6'b100000;
    default:
        out = 6'b000000;
    endcase
end
```





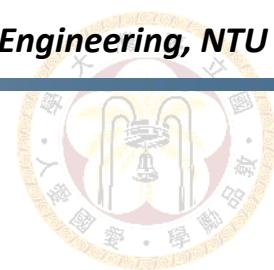
Special Syntax: Compiler Directives

■ Example

- synopsys full_case parallel_case for one-hot finite state machines (FSMs)

```
// Coding Style 1
case({sel3, sel2, sel1}) //synopsys full_case parallel_case
    3'b001: out = in1;
    3'b010: out = in2;
    3'b100: out = in3;
endcase
```

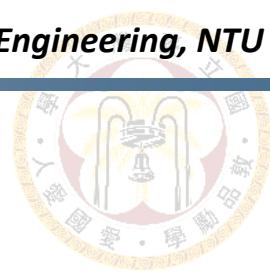
```
// Coding Style 2
case(1'b1) //synopsys full_case parallel_case
    sel1: out = in1;
    sel2: out = in2;
    sel3: out = in3;
endcase
```



RTL Coding Related to Synthesis

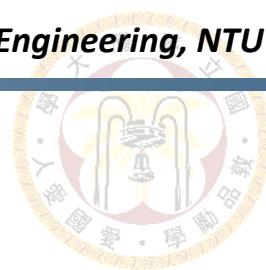
- Special-case needs constraint setting
 - Clock gating
 - Multi-cycle
 - False path
 - Asynchronous logic

- General guidelines for RTL coding
 - Separate combinational and sequential part
 - Separate control and VLSI-design strategy
 - Register at input/output



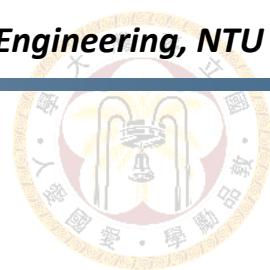
Outline

- Introduction
- RTL Coding Related to Synthesis
- **Synopsys Environment**
 - Tools Used in Logic Synthesis
 - Design Objects
 - DC-TCL: Introduction
- Synthesis Design Flow
- Gate-Level Simulation
- Files Demo



Tools We Will Use

Tool	Purpose
Design Compiler (DC)	Constraint driven logic optimizer
Design Vision	Graphical User Interface Version of DC
Presto HDL Compiler	Translate Verilog descriptions into GTECH
Design Ware	Provide building blocks & operators for synthesis
Design Time	Static Timing Analysis (STA) engine
Power Compiler	For power optimization, e.g., multi- V_t , clock gating



Design Compiler

Design Compiler Graphical
DC Ultra (TM)
DFTMAX (TM)
Power Compiler (TM)
DesignWare (R)
DC Expert (TM)
Design Vision (TM)
HDL Compiler (TM)
VHDL Compiler (TM)
DFT Compiler
Design Compiler(R)

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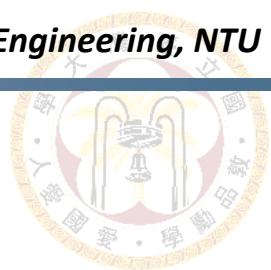
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Initializing...

Initializing gui preferences from file /home/raid7_2/user09/r09176/.synopsys_dc_g
dc_shell> █



Design Vision

DV Design Vision - TopLevel.1 (top)@cad30.ee.ntu.edu.tw

File Edit View Select Highlight List Hierarchy Design Attributes Schematic Timing Test Power AnalyzeRTL Window

Hier.1 x Schematic.15 x Schematic.14 x

Logical Hierarchy

Pins/Ports

Pin Name

- i_{clk}
- i_{rst_n}
- $i_{write[0]}$
- $i_{write_ready[0]}$
- $i_{op_code[0]}$
- $i_{write[0]}$
- $B[2]$
- $A[3]$
- i_{clk}
- i_{rst_n}
- $A[1]$
- $A[0]$
- $B[1]$
- $B[3]$
- $B[0]$
- $out_sig[2]$
- $i_{op_code[0]}$
- $out_sig[3]$
- $out_sig[1]$

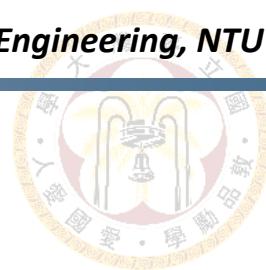
top

Unconnected ports (LINT-28)

Console Log History dc_shell>

Click objects or drag a box to select (Hold Ctrl to add, Shift to remove) Alt DoubleClick expands Fanin/Fanout | Design: top

A screenshot of the Design Vision software interface. The top menu includes File, Edit, View, Select, Highlight, List, Hierarchy, Design, Attributes, Schematic, Timing, Test, Power, AnalyzeRTL, and Window. The left sidebar shows a 'Hier.1' tree with a node 'top' selected. A 'Pins/Ports' panel lists various pins and ports. The main area contains three windows: 'Schematic.15' showing a block diagram with inputs like i_clk, i_rst_n, i_write[0], i_write_ready[0], i_op_code[0] and outputs o_write[0], o_write_ready[0], o_write[0], out_sig[4]; 'Schematic.14' showing a detailed logic circuit with multiple AND, OR, and NOT gates; and a 'Console' window at the bottom with tabs for Log, History, and dc_shell>. A status bar at the bottom provides instructions for selecting objects and expanding fanin/fanout, and displays the design name 'top'.



Launching Design Compiler

- Launching design compiler

```
dc_shell
```

- Launching graphical user interface

```
design_vision
```

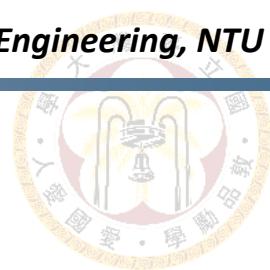
```
dc_shell -gui
```

```
dc_shell  
dc_shell> gui_start
```

- Running script

```
dc_shell -f script.tcl
```

```
dc_shell  
dc_shell> source script.tcl
```



Design Compiler Interaction

```

Design Compiler Graphical
    DC Ultra (TM)
    DFTMAX (TM)
Power Compiler (TM)
    DesignWare (R)
    DC Expert (TM)
Design Vision (TM)
HDL Compiler (TM)
VHDL Compiler (TM)
    DFT Compiler
Design Compiler(R)

Version R-2020.09-SP5 for linux64 - Apr 23, 2021

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https://solvnetplus.synopsys.com)
Initializing...
Initializing gui preferences from file /home/raid7_2/user09/r09176/.synopsys_dc_g
dc_shell> 
```

1 dc_shell

3 GUI

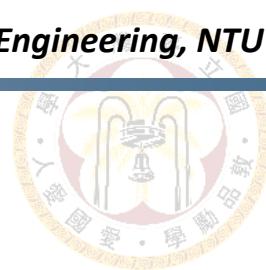
The screenshot shows the Design Vision graphical user interface. At the top, there's a menu bar with File, Edit, View, Select, Highlight, List, Hierarchy, Design, Attributes, and various tool icons. Below the menu is a toolbar with icons for opening files, saving, zooming, and other functions. The main area is divided into two panes: 'Logical Hierarchy' on the left and 'Cells (Hierarchical)' on the right. The 'Cells (Hierarchical)' pane has a table with columns for 'Cell Name' and 'Ref Nam'. At the bottom of the interface, there's a command line window with the following text:

```

x Initializing gui preferences from file /home/raid7_2/user09/r09176/.sy
dc_shell> gui_start
4.1
design_vision>
design_vision>
```

A red box highlights the command line window at the bottom of the interface.

2 Command line



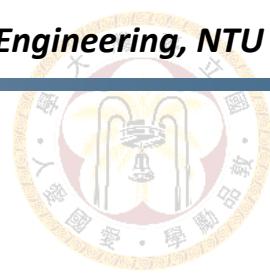
Design Compiler Interaction

- Each action in GUI is equivalent to a series of commands
 - But only a part of commands can be done by GUI actions

The screenshot shows the 'Design' menu open in the Design Compiler interface. The 'Operating Conditions...' option is highlighted with a purple rectangle. A large blue arrow points downwards from this menu towards a terminal window at the bottom.

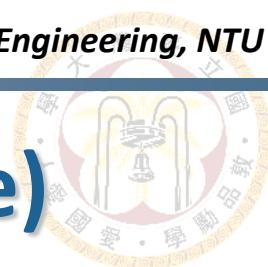
The 'Operating Conditions' dialog box is shown, titled 'Operating Conditions@cad30.ee.ntu.edu.tw'. It contains fields for 'Current design: top', 'Analysis condition' (with 'Single' selected), 'Maximum operating condition' (Library: slow, Condition: slow), and 'Minimum operating condition' (Library: slow, Condition: slow). Buttons for 'OK', 'Cancel', and 'Apply' are at the bottom right.

```
dc_shell> set_operating_conditions -library slow slow
Using operating conditions 'slow' found in library 'slow'.
dc_shell>
```

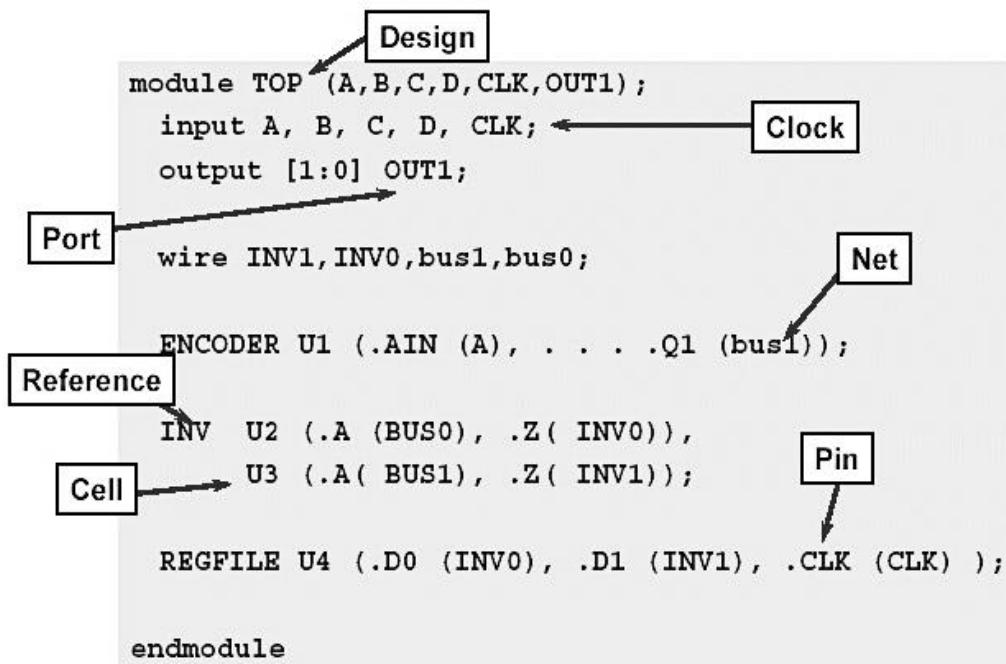


Outline

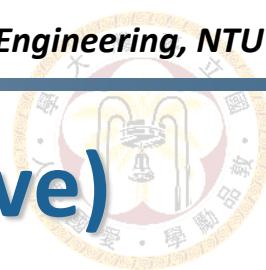
- Introduction
- RTL Coding Related to Synthesis
- **Synopsys Environment**
 - Tools Used in Logic Synthesis
 - Design Objects
 - DC-TCL: Introduction
- Synthesis Design Flow
- Gate-Level Simulation
- Files Demo



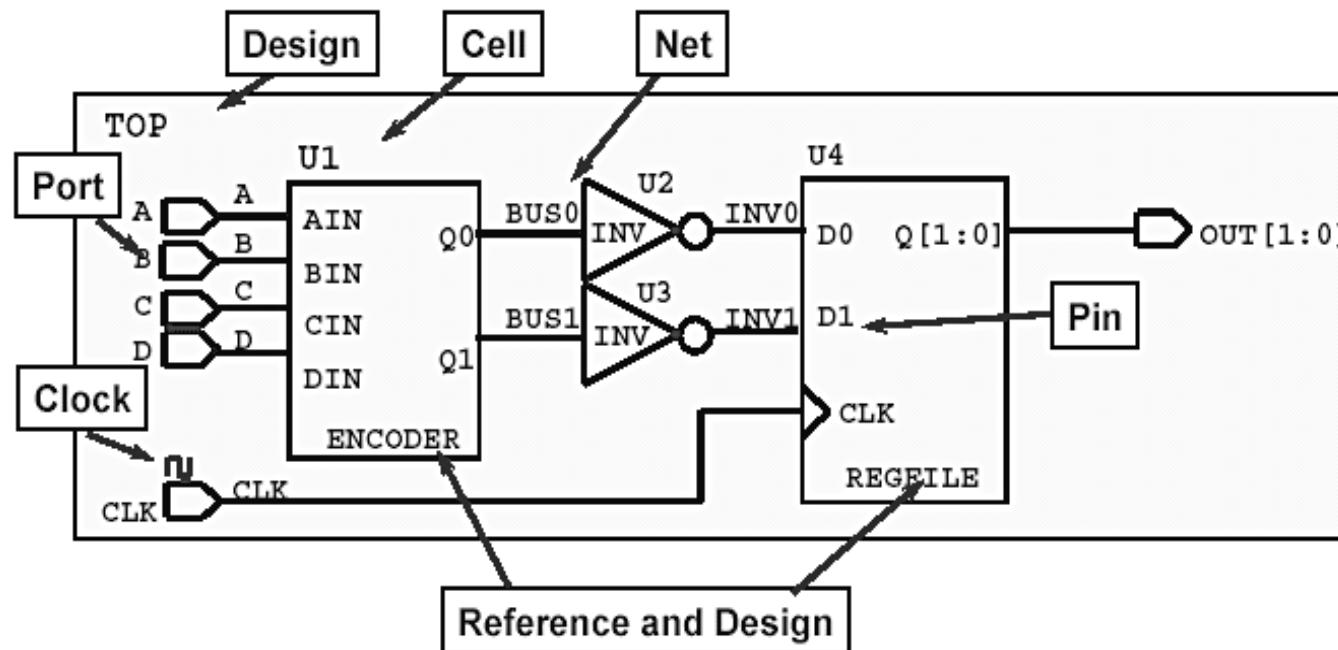
Design Objects (Verilog Perspective)



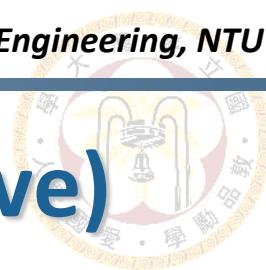
- Design: A circuit that performs one or more logical functions
- Cell: An instance of a design or library primitive within a design
- Reference: The name of the original design that a cell instance “points to”
- Port: The input or output of a design
- Pin: The input or output of a cell
- Net: The wire that connects ports to pins and/or pins to each other
- Clock: Waveform applied to a port or pin identified as a clock source



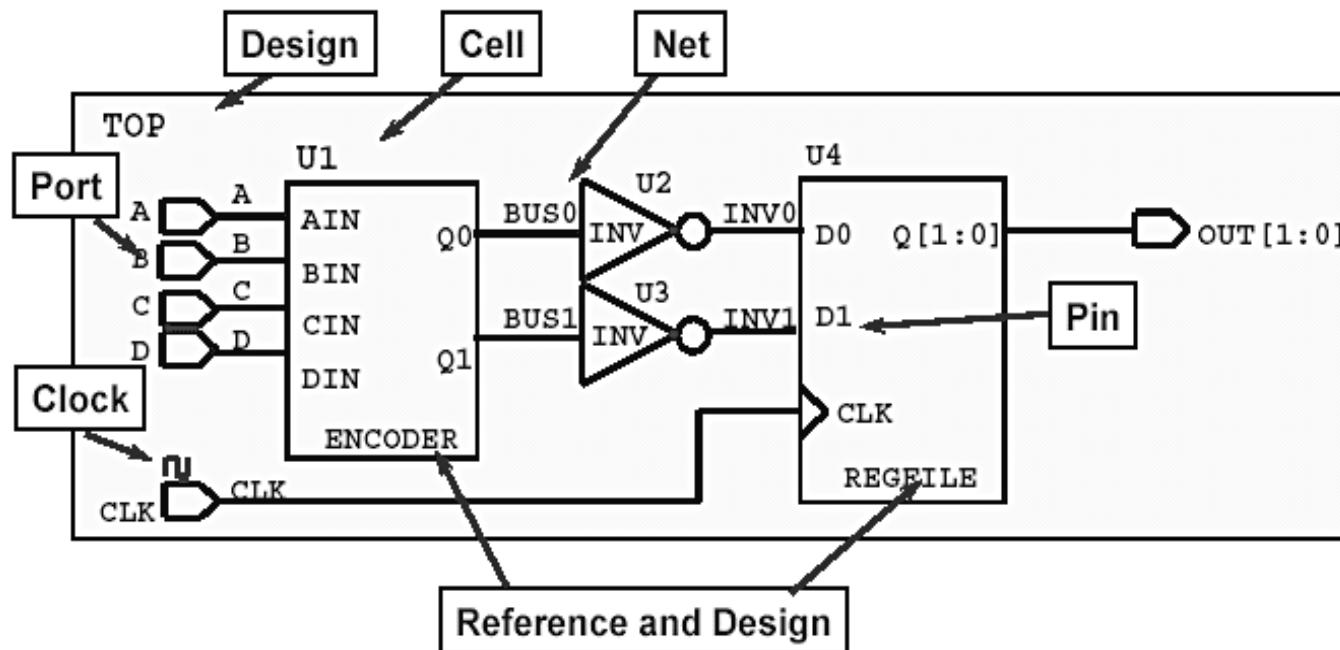
Design Objects (Schematic Perspective)



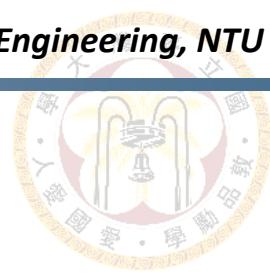
- Design: A circuit that performs one or more logical functions
- Cell: An instance of a design or library primitive within a design
- Reference: The name of the original design that a cell instance “points to”
- Port: The input or output of a design
- Pin: The input or output of a cell
- Net: The wire that connects ports to pins and/or pins to each other
- Clock: Waveform applied to a port or pin identified as a clock source



Design Objects (Schematic Perspective)

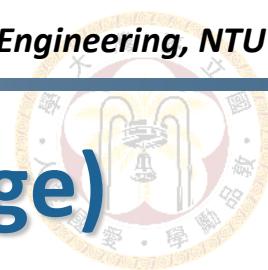


- Design: {TOP ENCODER REGFILE INV}
- Cell: {U1 U2 U3 U4}
- Reference: {ENCODER REGFILE INV}
- Port: {A B C D CLK OUT[1] OUT[0]}
- Pin: {U1/AIN U1/BIN U1/CIN U1/Q0 ...}
- Net: {A B C D CLK BUS0 BUS1 INV0 ...}
- Clock: {CLK}



Outline

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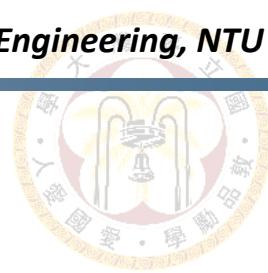
Basic of TCL (Tool Command Language)

- Frequently used syntaxes in control flow and operations
 - TCL script = sequence of commands
 - Used in .synopsys_setup.tcl / my_script.tcl / DUT_syn.sdc
- DC-TCL command (recommended*)

```
dc_shell -f script.tcl
```

```
dc_shell  
dc_shell> source script.tcl
```

- Some references
 - Official: www.tcl.tk/man/tcl8.5/tutorial/tcltutorial.html
 - Chinese: www.nhu.edu.tw/~cmwu/Lab/TCL.doc
 - English: jan.newmarch.name/ProgrammingUnix/tcl/tcl_tut.html



Basics of TCL in Design Compiler

- General syntax

```
command [options] arg_list
```

- Termination by newline or “;”

- Separation by “ \ ”

```
command \
[options] \
arg_list
```

- Comments by #

- Only valid in the beginning of a line
 - Error Example

```
read_verilog top.v #reading file
```

- Wildcard characters

- “*” any character(s), e.g. u*e = use or usage ...
 - “?” single character, e.g. u?e = use...

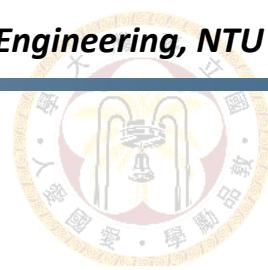
- Help: list all commands with given name

```
dc_shell> help *clock*
```

- Get help/manual about command

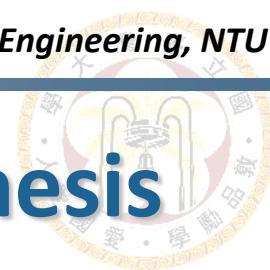
```
dc_shell> compile -help
```

```
dc_shell> man compile
```



TCL: Special Characters

Character	Meaning
\$	Used to access the value of a variable.
()	Used to group expressions.
[]	Denotes a nested command.
\	Used for escape quoting and as a line continuation character.
“ ”	Denotes weak quoting. Nested commands and variable substitutions still occur.
{ }	Denotes rigid quoting. There are no substitutions.
;	Ends a command.
#	Begins a comment.



Common Syntax of TCL used for Synthesis

- set
- Syntax: \$variable_name
- Variable name is letters, digits, underscores

Command	Result
set b 66	66
set a b	b
set a \$b	66

Example

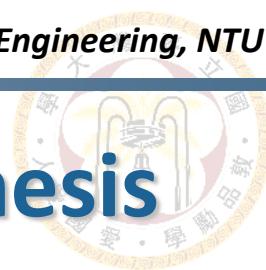
```
dc_shell> set DESIGN "top"
dc_shell> current_design [get_designs ${DESIGN}]
Current design is 'top'.
dc_shell> check_design > "./${DESIGN}_check_design.txt"
```



top_check_design.txt

1

2022-



Common Syntax of TCL used for Synthesis

- Search the current design and return a list of given object types

- **get_**

- get_cells, get_designs, get_libs, get_lib_cells
 - get_nets
 - get_pins, get_ports
 - get_clocks

Example

```
set_max_capacitance 0.1 [get_ports *]
```

```
set_ideal_network [get_ports *clk*]
```

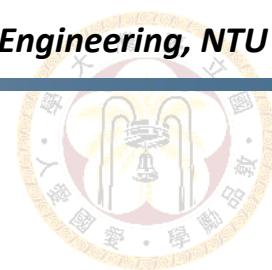
- **all_**

- all_instance
 - all_fanin, all_fanout, all_connected
 - all_inputs, all_outputs
 - all_registers

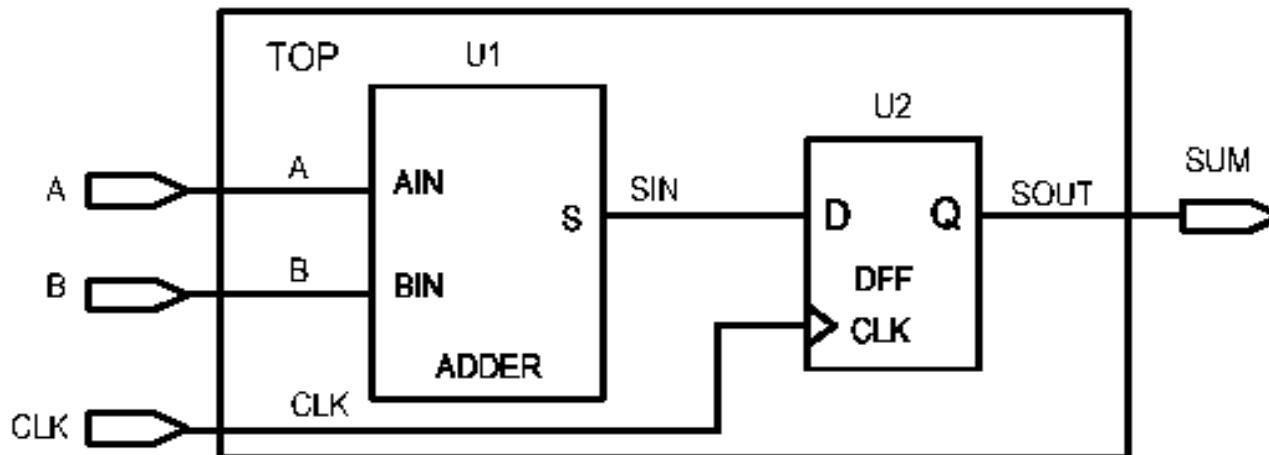
Example

```
set_load 0.05 [all_outputs]
```

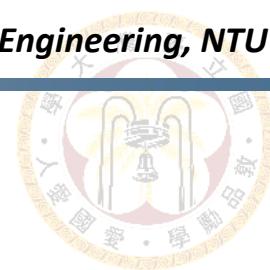
```
set_drive 0.05 [all_inputs]
```



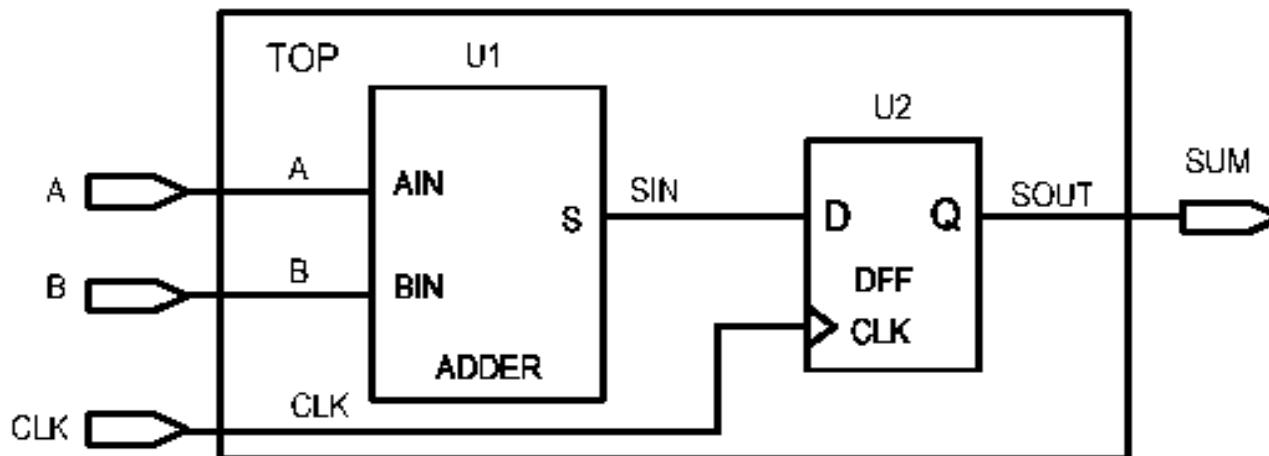
get_ & Design Objects Exercise



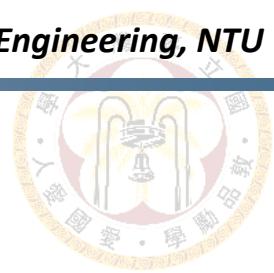
- Find a list of all the ports in the design? (`get_ports`)
- Find a list of all the cells that have the letter “U” in their name?
(`get_cells *U*`)
- Find a list of all the nets ending with “CLK”? (`get_nets *CLK`)
- Find a list of all the “Q” pins in the design? (`get_pins */Q`)
- Find a list of all the references? (`get_references`) Pins must appear w/ cell



get_ & Design Objects Exercise

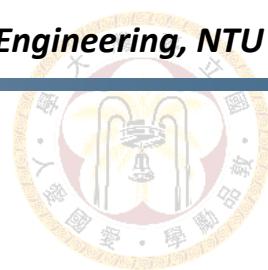


- Find a list of all the ports in the design? (**{A B CLK SUM}**)
- Find a list of all the cells that have the letter “U” in their name?
(**{U1 U2}**)
- Find a list of all the nets ending with “CLK”? (**{CLK}**)
- Find a list of all the “Q” pins in the design? (**{U2/Q}**)
- Find a list of all the references? (**{ADDER DFF}**)



Outline

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- Synopsys Environment
- **Synthesis Design Flow**
- Gate-Level Simulation
- Files Demo



What is Logic Synthesis?

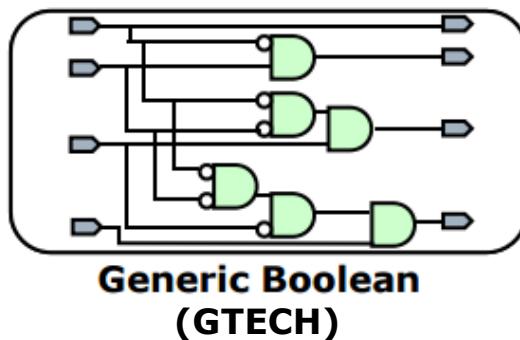
Synthesis = translation + optimization + mapping

```
if(high_bits == 2'b10)begin  
    residue = state_table[i];  
end  
else begin  
    residue = 16'h0000;  
end
```

HDL Source
(RTL)

Translate (HDL Compiler)

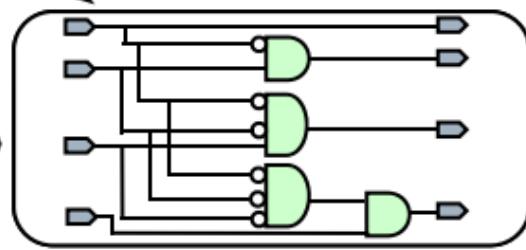
No Timing Info.



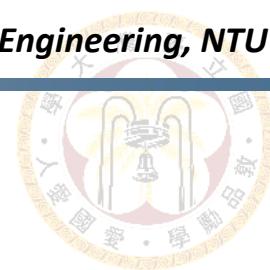
Generic Boolean
(GTECH)

Optimize + Mapping
(Design Compiler)

Timing Info.
Constraints



Target Technology

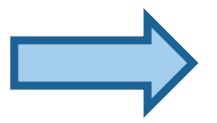


Translation

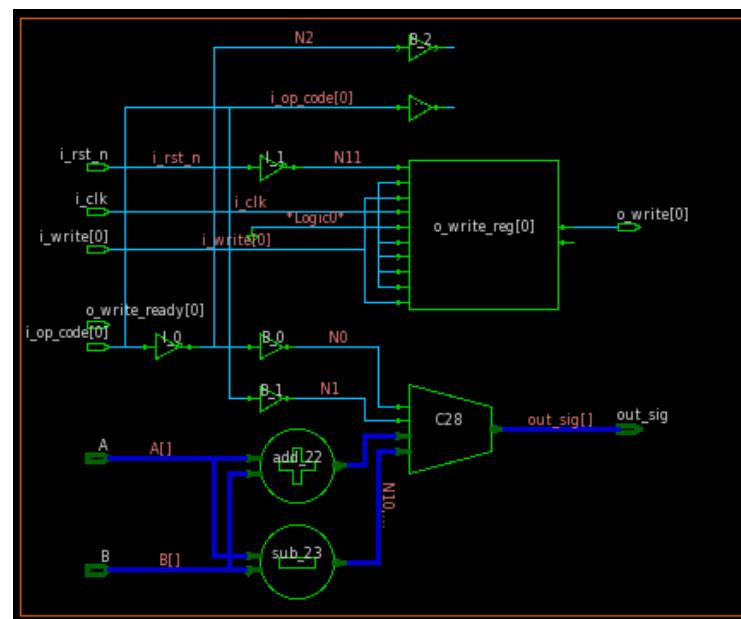
- HDL Compiler translates Verilog HDL descriptions into **GTECH**
- GTECH (generic tech.): a built-in intermediate format in Design Compiler
 - **Technology-independent**
 - **No timing information**
 - **+,-,*,/ operators not unfolded** to gate level

```
module alu (
  ...
  assign y = a + b;
  assign o = s? y:z;
  ...
endmodule
```

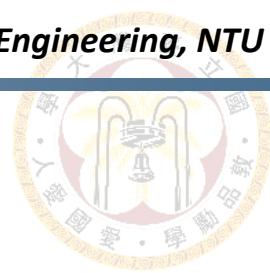
RTL



Translate

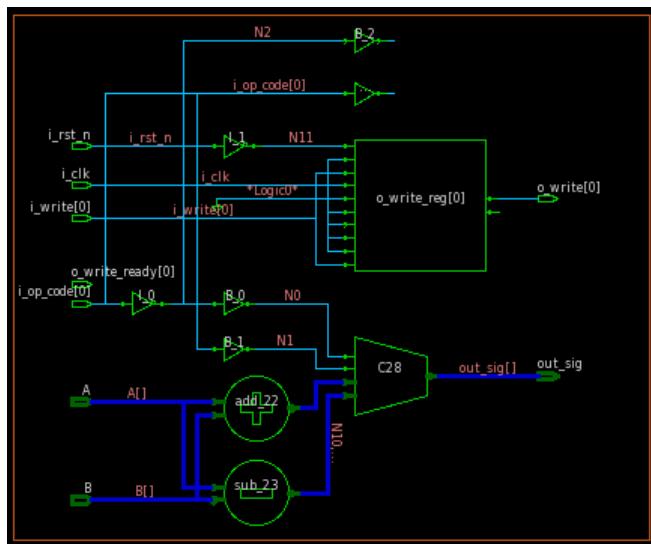


GTECH

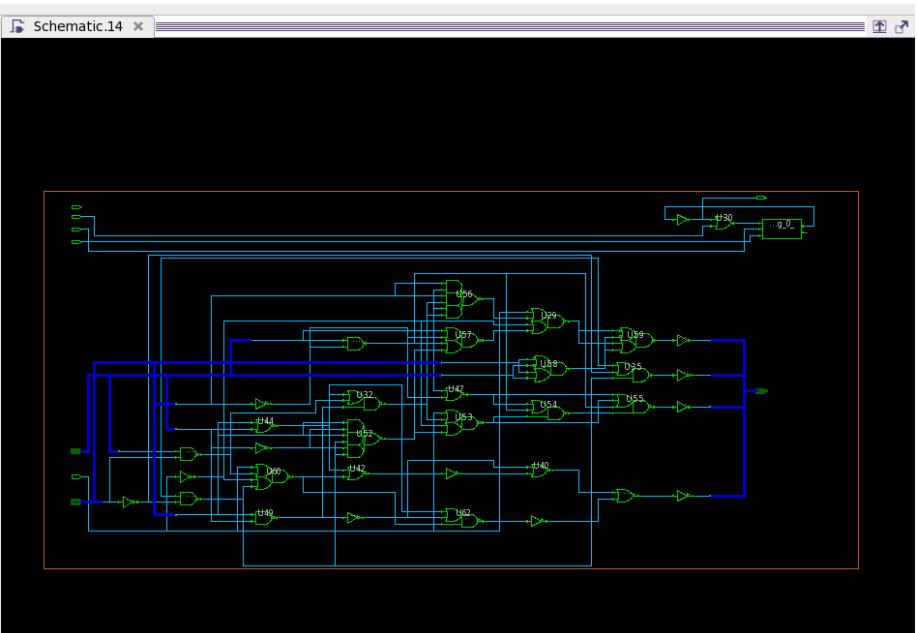


Optimization + Mapping

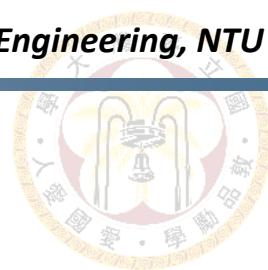
- Design Compiler maps GTECH to **gate-level netlist**
 - Using cells from user-specified technology library (e.g., 0.18um TSMC)
 - Iteratively optimized with area/timing constraints



GTECH

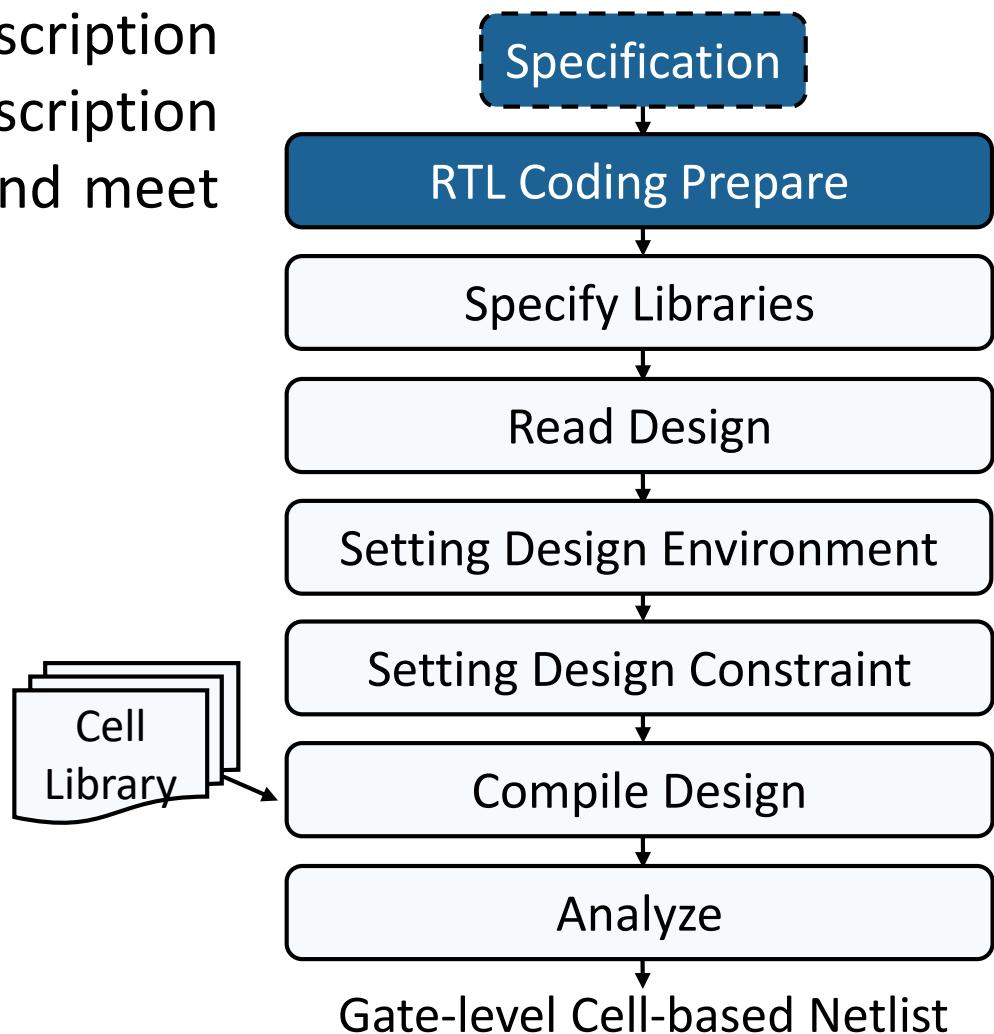


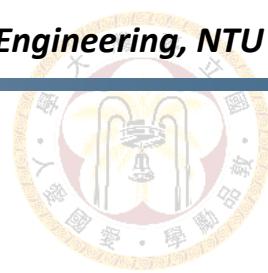
Gate-level Netlist



Synthesis Design Flow

- Develop the HDL design description and simulate the design description to verify that it is correct and meet the specification.





Synthesis Design Flow

Specify libraries in `.synopsys_dc.setup`

Example files:

Technology library files:

`fast.db` `slow.db`

`typical.db`

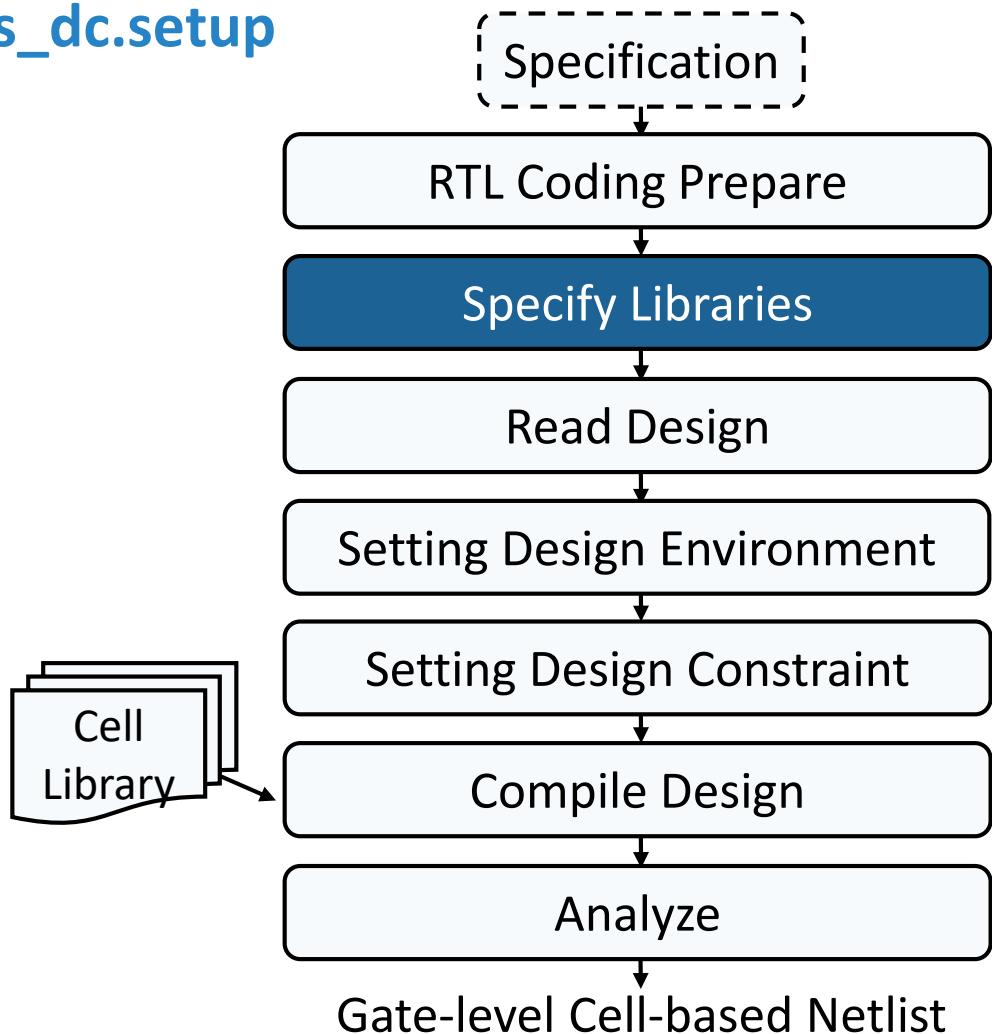
DesignWare library file:

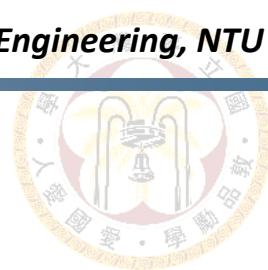
`dw_foundation.sldb`

Other macro file:

`sram.db`

```
set link_library  
set target_library  
set symbol_library  
set synthetic_library
```





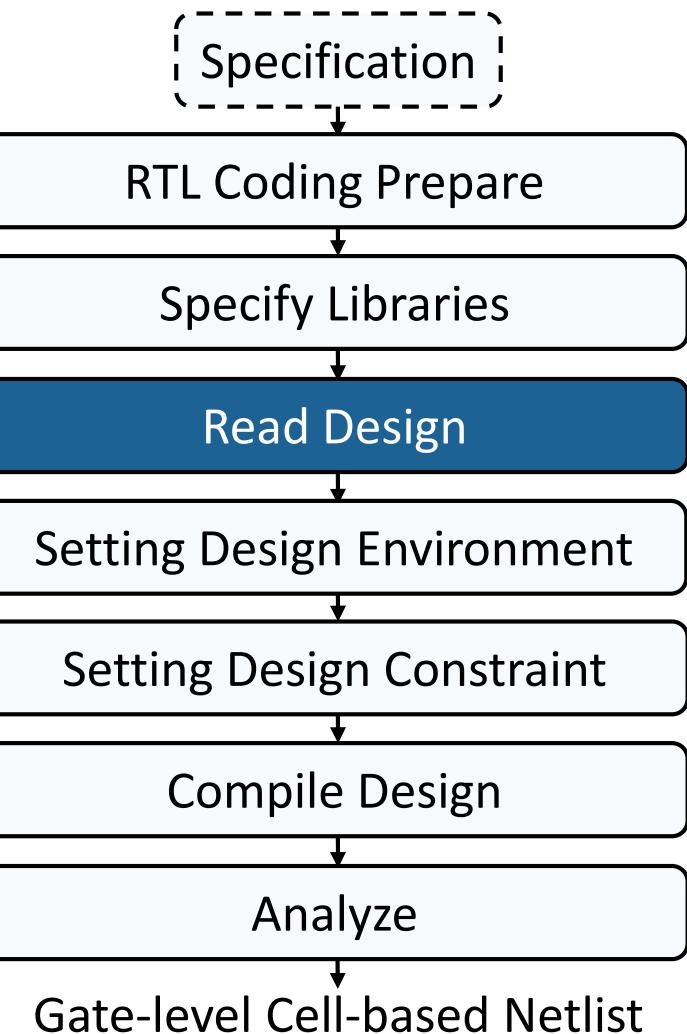
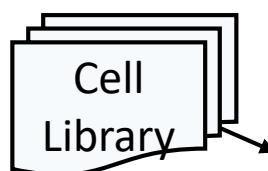
Synthesis Design Flow

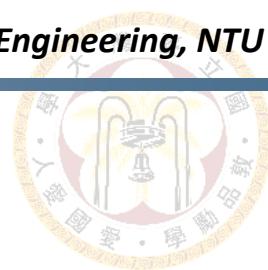
- Read the HDL design description
- Check synthesizability
- Perform Presto compilation

analyze
elaborate

or

read_file

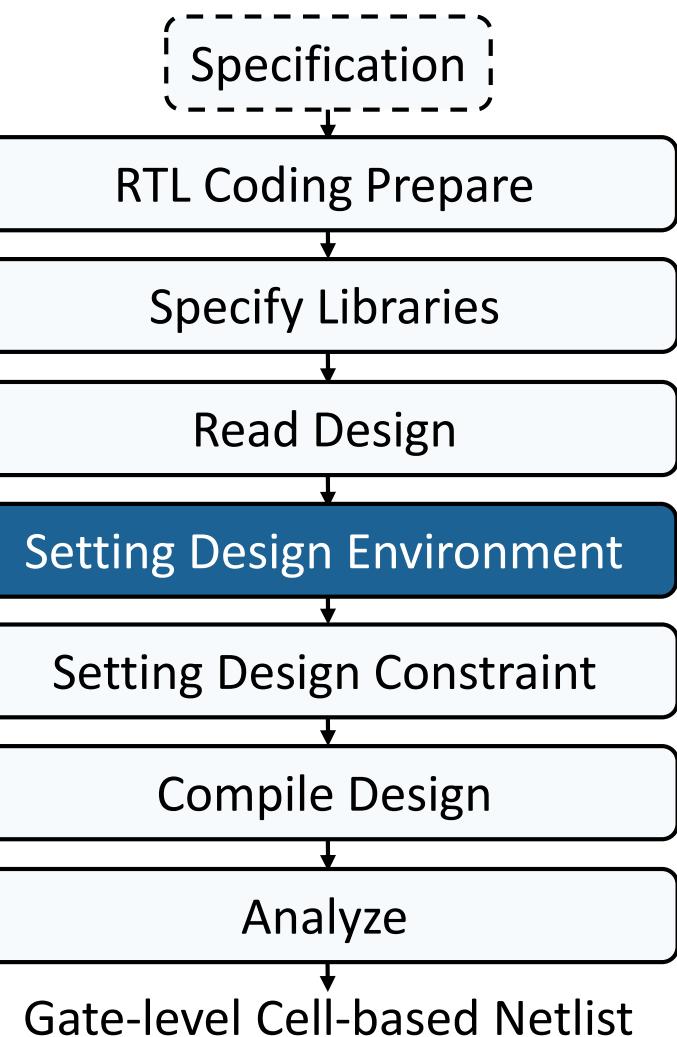
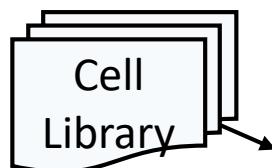


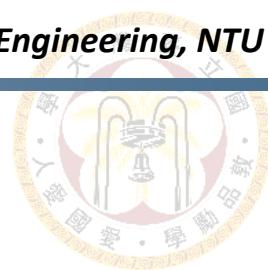


Synthesis Design Flow

- Set parameters for delay calculation
 - Operating condition
 - RC information of wires & I/O
 - I/O delay

```
set_operating_conditions  
set_wire_load_model  
set_drive  
set_load  
set_input_delay  
set_output_delay
```

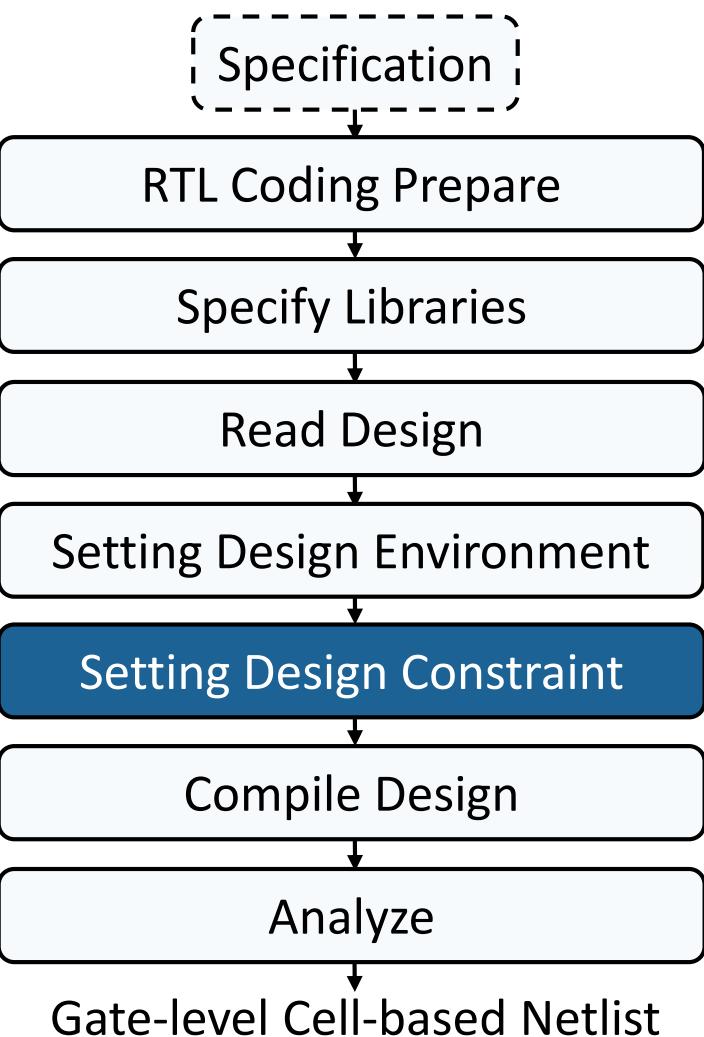
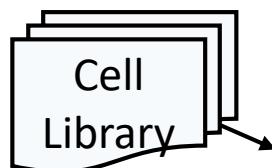


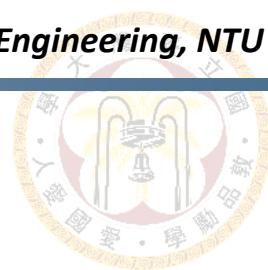


Synthesis Design Flow

- Set constraints for synthesis
 - Design rule constraints
 - Clock constraints
 - Special circuits
 - Optimization objective

```
# Design Rule Constraints  
set_max_transition  
set_max_fanout  
set_max_capacitance
```

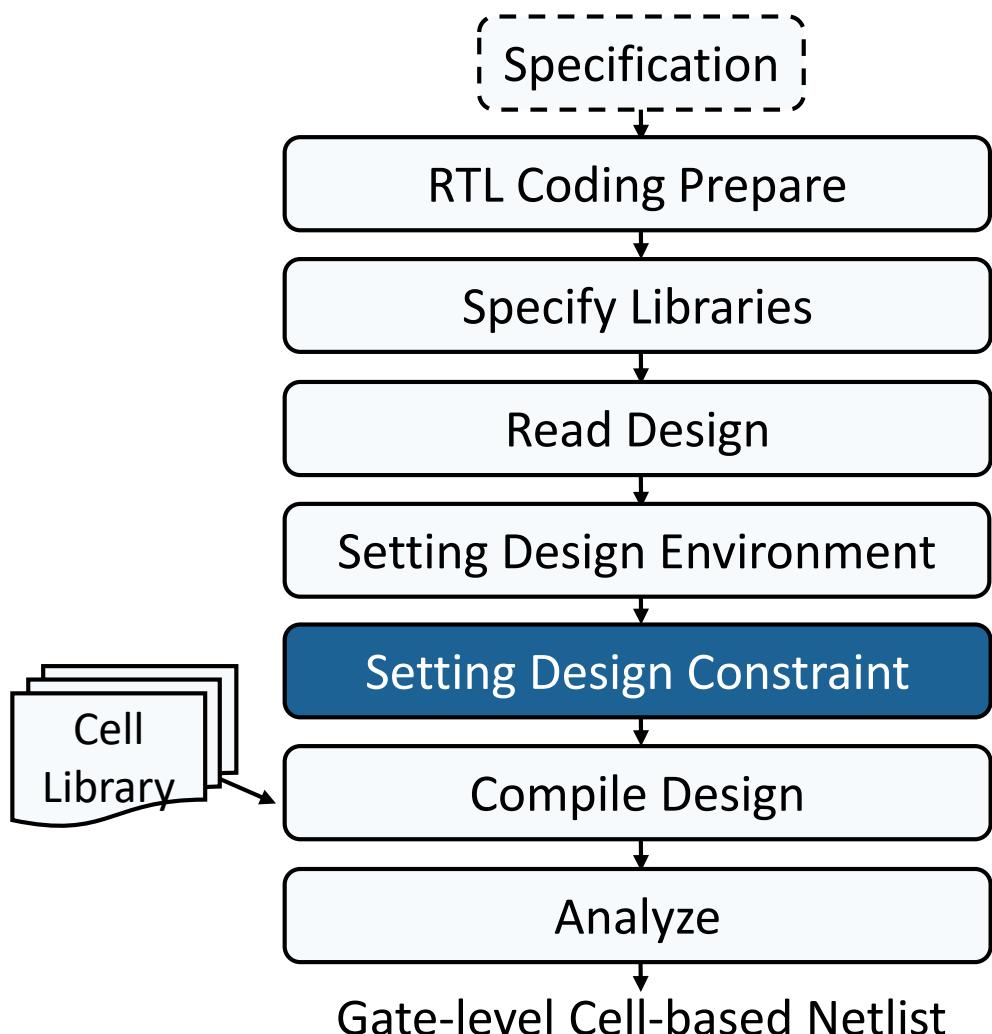


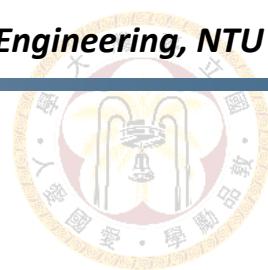


Synthesis Design Flow

- Set constraints for synthesis
 - Design rule constraints
 - Clock constraints
 - Special circuits
 - Optimization objective

```
# Clock Constraints
create_clock
set_fix_hold
set_dont_touch_network
set_ideal_clock
set_clock_latency
set_clock_uncertainty
set_input_transition
set_clock_transition
```

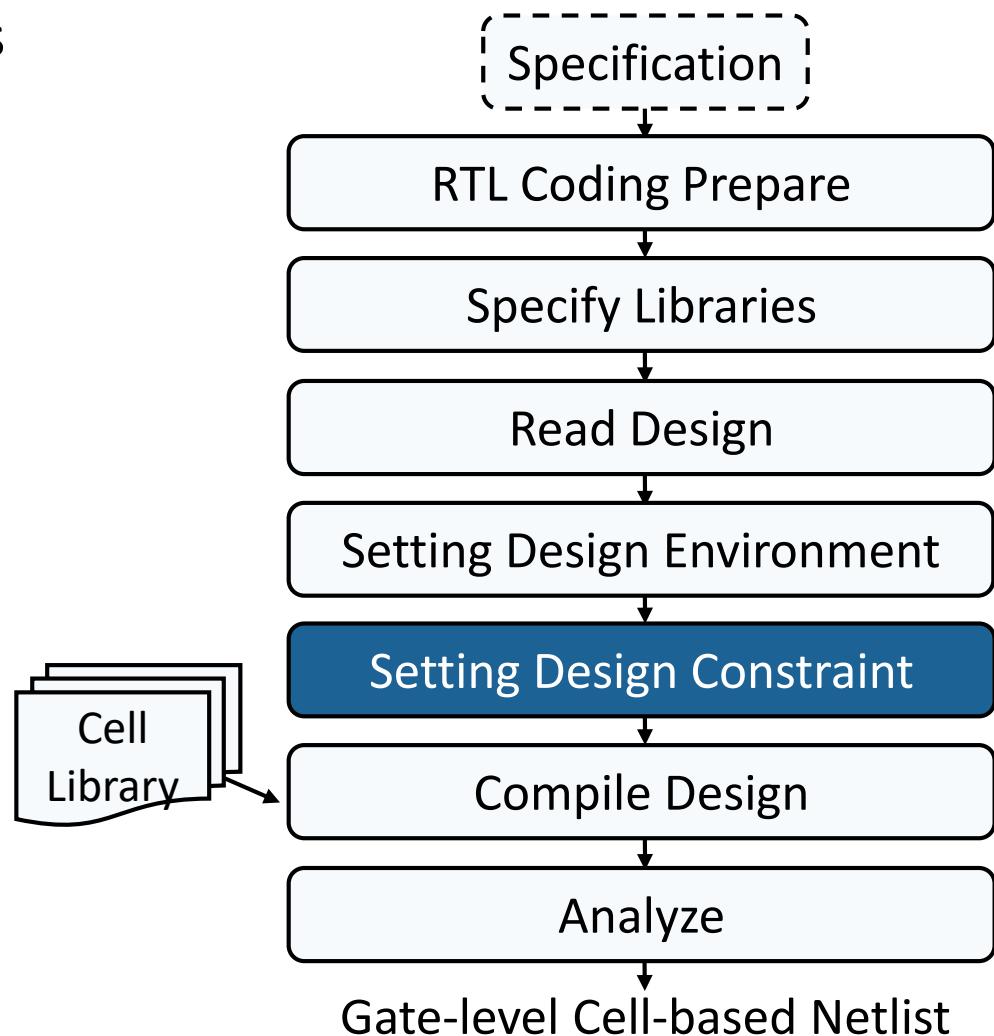


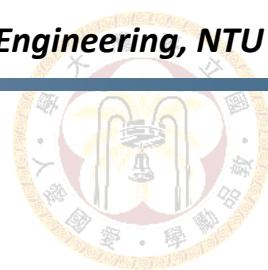


Synthesis Design Flow

- Set constraints for synthesis
 - Design rule constraints
 - Clock constraints
 - Special circuits
 - Optimization objective

```
# Special Circuits  
set_false_path  
replace_clock_gates  
  
# Optimization Objective  
set_max_area
```





Synthesis Design Flow

- Optimization & mapping to gate-level netlist

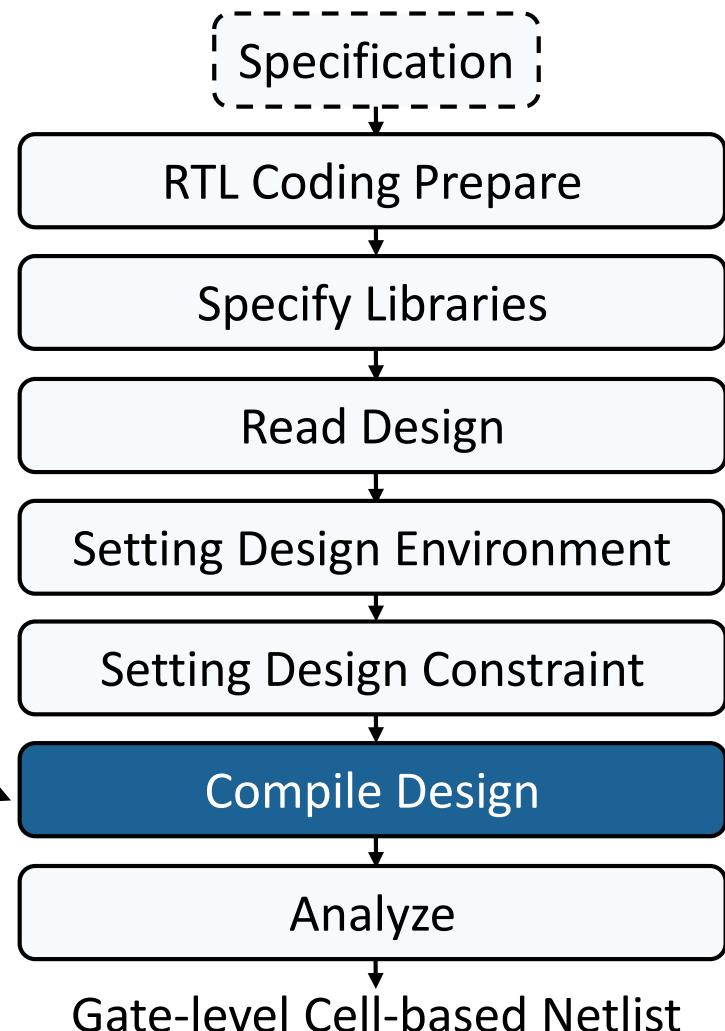
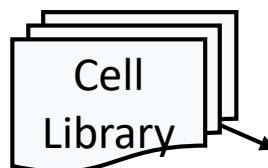
`compile`

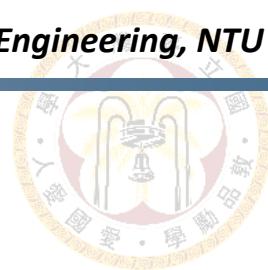
or

`compile -inc`

or

`compile_ultra`

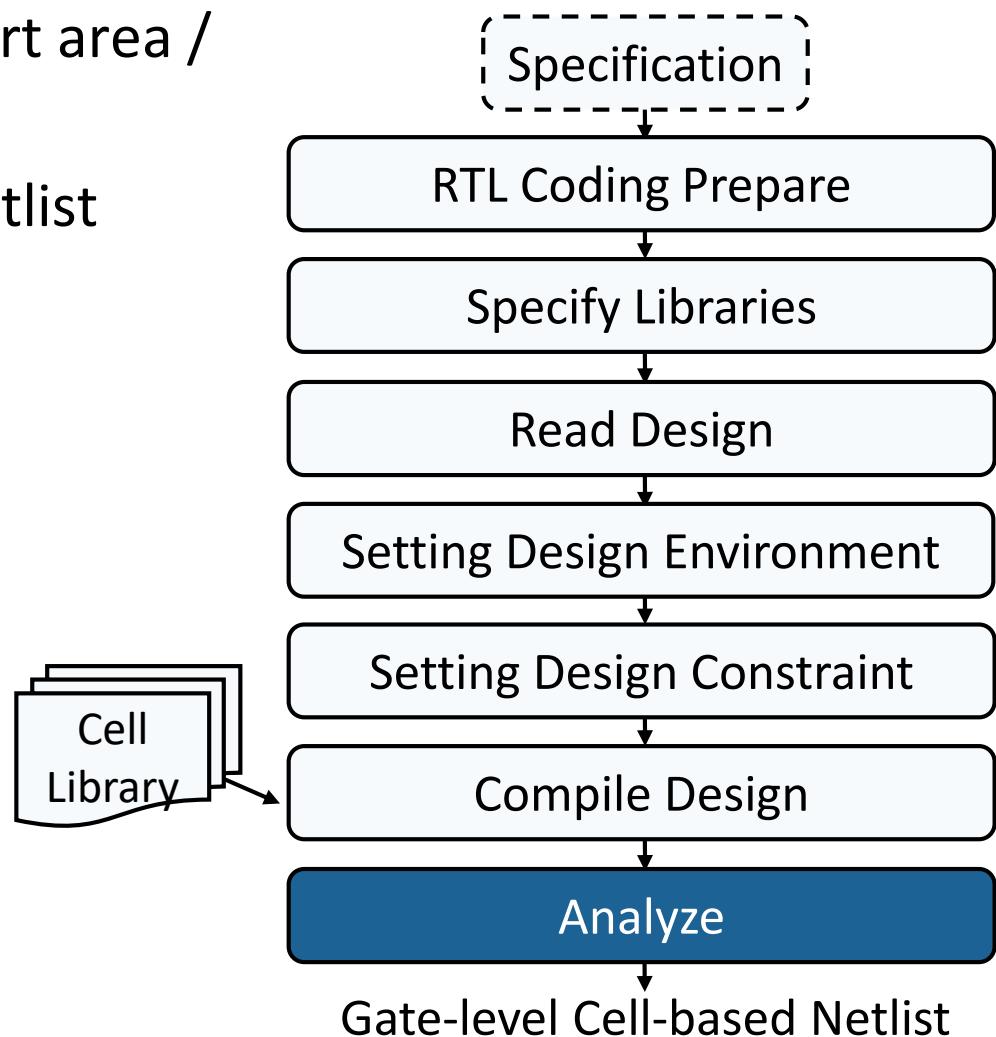


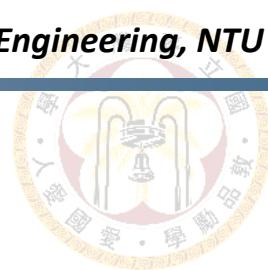


Synthesis Design Flow

- Check design and then report area / constraints / timing issue
- Output files of gate-level netlist

```
check_design  
report_area  
report_constraint  
report_timing  
  
write_sdc  
write_sdf  
write -format verilog
```





Synthesis Design Flow

Specify libraries in `.synopsys_dc.setup`

Example files:

Technology library files:

`fast.db` `slow.db`

`typical.db`

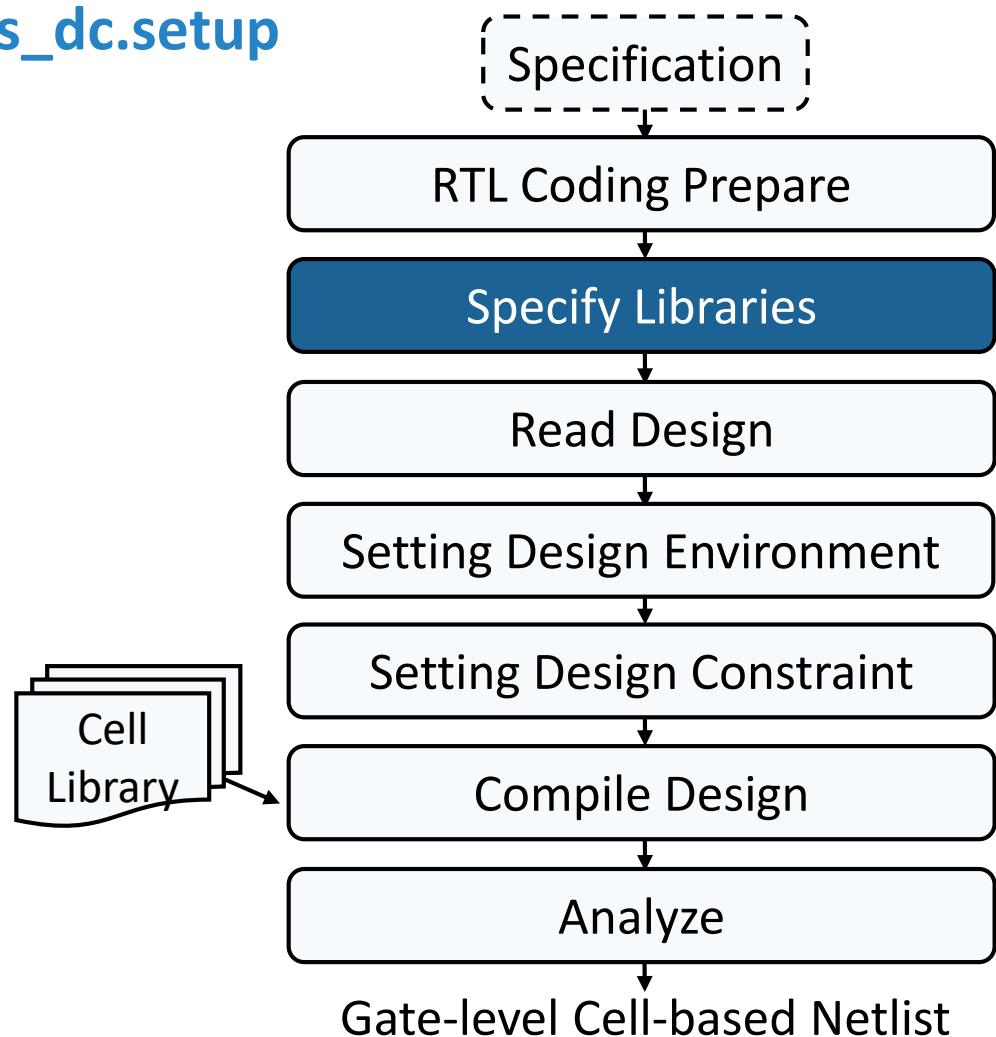
DesignWare library file:

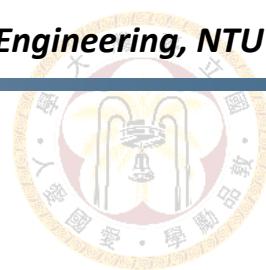
`dw_foundation.sldb`

Other macro file:

`sram.db`

```
set link_library  
set target_library  
set symbol_library  
set synthetic_library
```





Technology Library

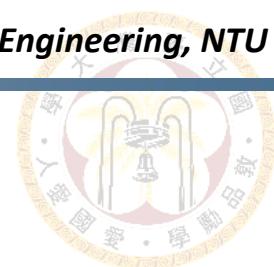
- Technology library includes information of standard cells
 - Operating conditions
 - Process, voltage, temperature
 - Wire load model
 - Standard cell descriptions
 - Functionality, pin info.
 - Timing, area, power info.
 - Etc.

Same set of cells,
different PVT conditions

fast.db

typical.db

slow.db



Technology Library

- Standard cell descriptions
 - Combinational cell & sequential cell list of the technology
 - Detailed **area, power, timing, function** info. of each cell

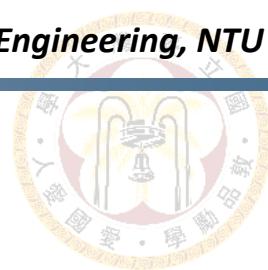
- Provides basic elements to form gate-level netlist

```

cell (NAND2BX1) {
  cell_footprint : nand2b;
  area : 6.789600;
  pin(AN) {
    direction : input;
    capacitance : 0.001359;
  }
  pin(B) {
    direction : input;
    capacitance : 0.002767;
  }
  pin(Y) {
    direction : output;
    capacitance : 0.0;
    function : "(!(!AN B))";
    internal_power() {
      related_pin : "AN";
      rise_power(energy_template_7x7) {
        index_1 ("0.042, 0.066, 0.112, 0.206, 0.392, 0.764, 1.5");
        index_2 ("0.00079, 0.002054, 0.00474, 0.010112, 0.020856, 0.042186, 0.08532");
        values ( \
          "0.003768, 0.003806, 0.003858, 0.003891, 0.003848, 0.003657, 0.003192", \
          "0.003744, 0.003780, 0.003827, 0.003858, 0.003820, 0.003634, 0.003170", \
          "0.003750, 0.003777, 0.003815, 0.003845, 0.003812, 0.003634, 0.003179", \
          "0.003795, 0.003808, 0.003829, 0.003848, 0.003819, 0.003654, 0.003213", \
          "0.003976, 0.003976, 0.003975, 0.003967, 0.003926, 0.003768, 0.003340", \
          "0.004549, 0.004535, 0.004513, 0.004410, 0.004341, 0.004171, 0.003750", \
          "0.005815, 0.005774, 0.005726, 0.005691, 0.005496, 0.005223, 0.004791");
      }
      fall_power(energy_template_7x7) {
        index_1 ("0.042, 0.066, 0.112, 0.206, 0.392, 0.764, 1.5");
        index_2 ("0.00079, 0.002054, 0.00474, 0.010112, 0.020856, 0.042186, 0.08532");
        values ( \
          "0.005118, 0.005214, 0.005344, 0.005457, 0.005528, 0.005567, 0.005591", \
          "0.005100, 0.005197, 0.005326, 0.005439, 0.005511, 0.005551, 0.005576", \
          "0.005113, 0.005210, 0.005342, 0.005459, 0.005535, 0.005578, 0.005606", \
          "0.005164, 0.005254, 0.005380, 0.005493, 0.005572, 0.005620, 0.005652", \
          "0.005377, 0.005454, 0.005565, 0.005669, 0.005743, 0.005795, 0.005832", \
          "0.006123, 0.006079, 0.006074, 0.006168, 0.006224, 0.006269, 0.006305", \
          "0.007591, 0.007527, 0.007456, 0.007403, 0.007346, 0.007374, 0.007400");
      }
    }
    timing() {
      related_pin : "AN";
      timing_sense : positive_unate;
      cell_rise(delay_template_7x7) {
        index_1 ("0.042, 0.066, 0.112, 0.206, 0.392, 0.764, 1.5");
        index_2 ("0.00079, 0.002054, 0.00474, 0.010112, 0.020856, 0.042186, 0.08532");
        values ( \
          "0.103606, 0.115100, 0.137951, 0.181525, 0.266700, 0.434270, 0.772003", \
        )
      }
    }
}

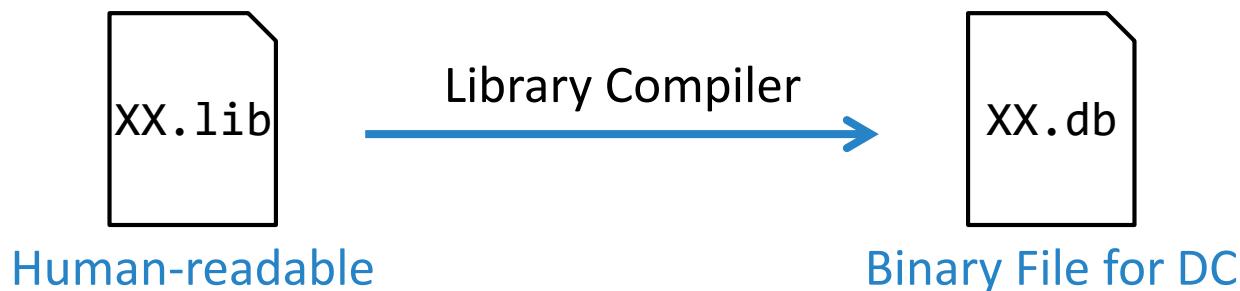
```

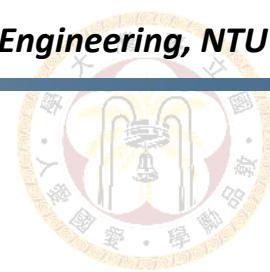
slow.lib



Library Compiler

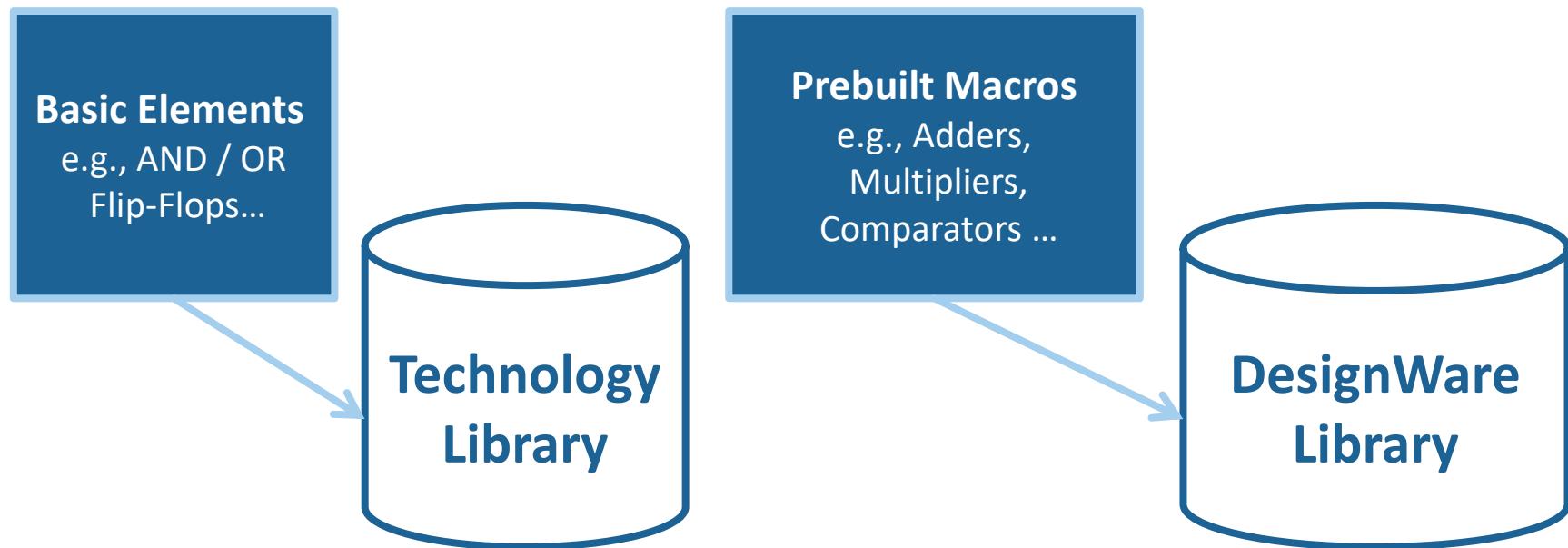
- Library compiler (`lc_shell`) can generate .db file from .lib file
 - .lib contains information about cells
 - .db files are binary files for DC

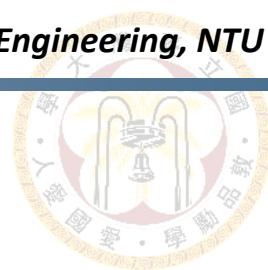




DesignWare Library

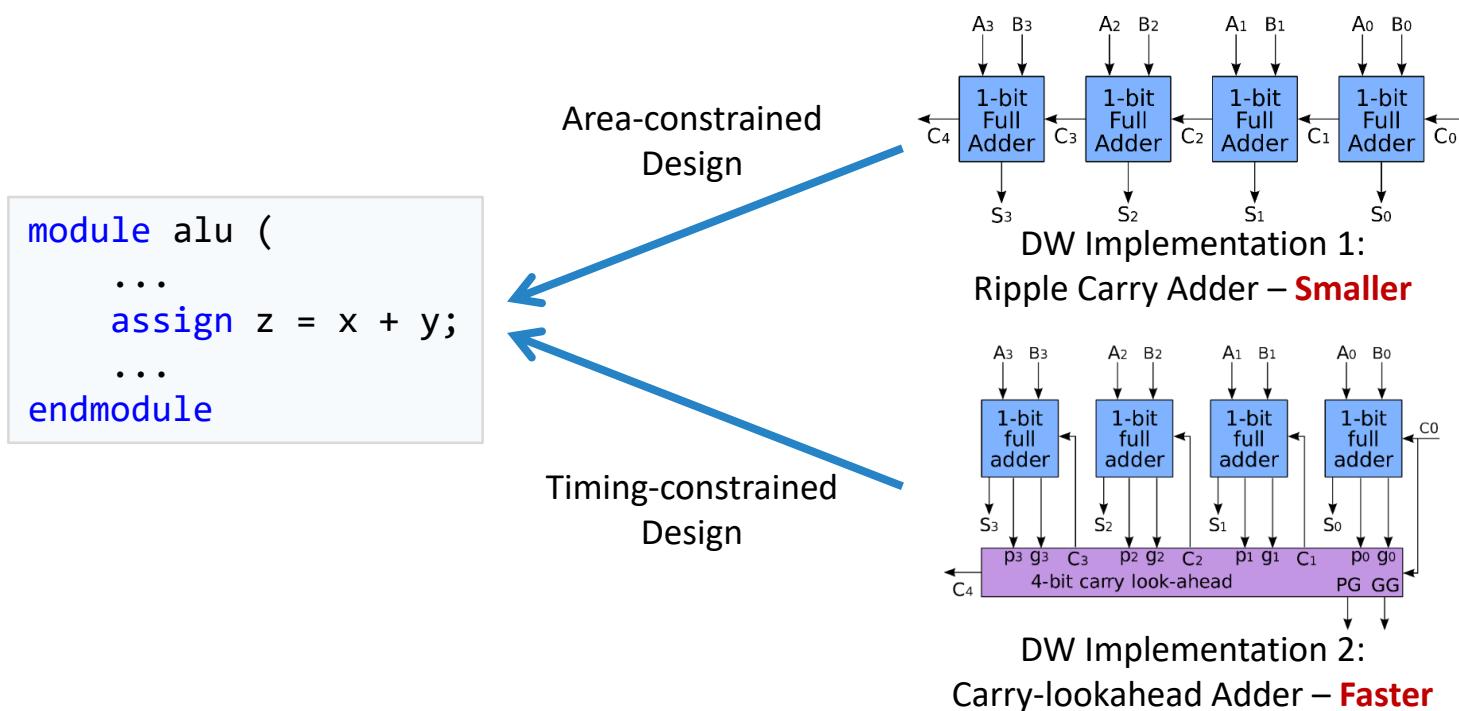
- A **technology-independent** soft macros
- These macros can be synthesized into gates from target library
 - Usage 1: Multiple implementation for +,*,>,etc. operators
 - Usage 2: User directly instantiated building blocks

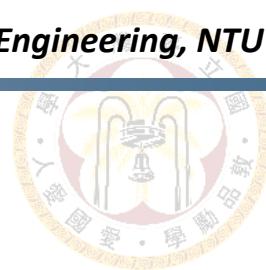




DesignWare Library

- Multiple architectures for each operators like $+$, $-$, $*$, $/$, $<$, etc.
 - In DC, these operators are mapped to DW library
 - DC selects appropriate implementation for your constraints
- Still can be optimized in compilation process





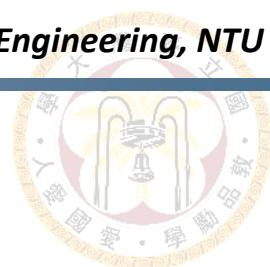
DesignWare Building Blocks

- Besides basic operators, various building blocks are provided
 - E.g., float arithmetic, DSP, coding

Path: /usr/cad/synopsys/synthesis/cur/dw/doc/manuals/dwbb_userguide.pdf
Website (Latest Ver.): <https://www.synopsys.com/dw/buildingblock.php>

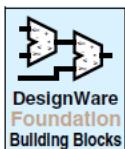
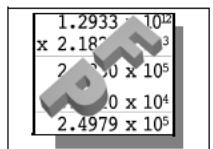
Table 2-1 List of DesignWare Building Block IP

Component	Inference?	Description
Application Specific: Control Logic		
DW_arb_2t	No	Two-Tier Arbiter with Dynamic/Fair-Among-Equal Scheme
DW_arb_dp	No	Arbiter with Dynamic Priority Scheme
DW_arb_fcfs	No	Arbiter with First-Come-First-Served Priority Scheme
DW_arb_rr	No	Arbiter with Round Robin Priority Scheme
DW_arb_sp	No	Arbiter with Static Priority Scheme
Datapath: Arithmetic Components		
DW01_absval	Function	Absolute Value
DW01_add	Operator	Adder
DW01_addsub	Operator	Adder-Subtractor
DW_addsub_dx	No	Duplex Adder/Subtractor with Saturation and Rounding



DesignWare Building Blocks

Path: /usr/cad/synopsys/synthesis/cur/doc/dw_bb/datasheets/dw_fp_mult.pdf



DW_fp_mult

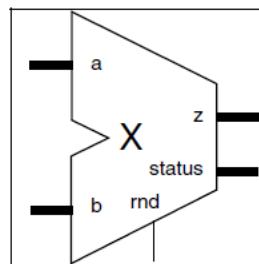
Floating-Point Multiplier

Version, STAR, and myDesignWare Subscriptions: [IP Directory](#)

Features and Benefits

- The precision format is parameterizable for either IEEE single, double precision, or a user-defined custom format
- Hardware for denormal numbers of IEEE 754 standard is selectively provided.
- Configurable to be fully compliant with the IEEE Std 754-1985 standard
- Configurable for NaN representation compatible with the IEEE Std 754-2008 standard (controlled by the *ieee_compliance* parameter)
- DesignWare datapath generator is employed for better timing and area

Revision History



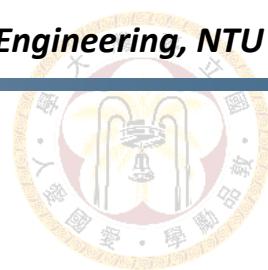
Description

DW_fp_mult is a floating-point multiplier that multiplies two floating-point values, *a* and *b*, to produce a floating-point product, *z*.

Component pins are described in [Table 1-1](#) and configuration parameters are described in [Table 1-2](#).

Table 1-1 Pin Description

Pin Name	Width	Direction	Function
<i>a</i>	<i>exp_width + sig_width + 1</i> bits	Input	Multiplier
<i>b</i>	<i>exp_width + sig_width + 1</i> bits	Input	Multiplicand
<i>rnd</i>	3 bits	Input	Round mode: supports all rounding modes described in the



DesignWare Building Blocks

■ Example: instantiation in Verilog

Path: /usr/cad/synopsys/synthesis/cur/dw/examples/DW_fp_mult_inst.v

Website: https://www.synopsys.com/dw/doc.php/doc/dwf/examples/DW_fp_mult_inst.v

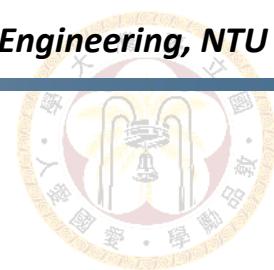
```
module DW_fp_mult_inst( inst_a, inst_b, inst_rnd, z_inst, status_inst );

parameter sig_width = 23;
parameter exp_width = 8;
parameter ieee_compliance = 1;

input [sig_width+exp_width : 0] inst_a;
input [sig_width+exp_width : 0] inst_b;
input [2 : 0] inst_rnd;
output [sig_width+exp_width : 0] z_inst;
output [7 : 0] status_inst;

// Instance of DW_fp_mult
DW_fp_mult #(sig_width, exp_width, ieee_compliance)
    U1 ( .a(inst_a), .b(inst_b), .rnd(inst_rnd), .z(z_inst), .status(status_inst) );

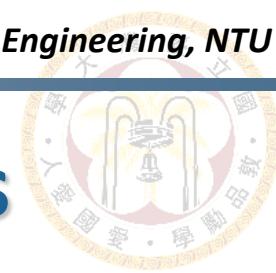
endmodule
```



DesignWare Building Blocks

- Note: if DW building blocks are used in your design, remember to include DW behavior model in RTL simulation

```
ncverilog test_top.v top.v -y /usr/cad/synopsys/synthesis/cur/dw/sim_ver  
+libext+.v +define+RTL +access+r +notimingchecks
```

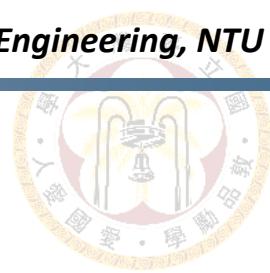


Including .db File for Hard Macros

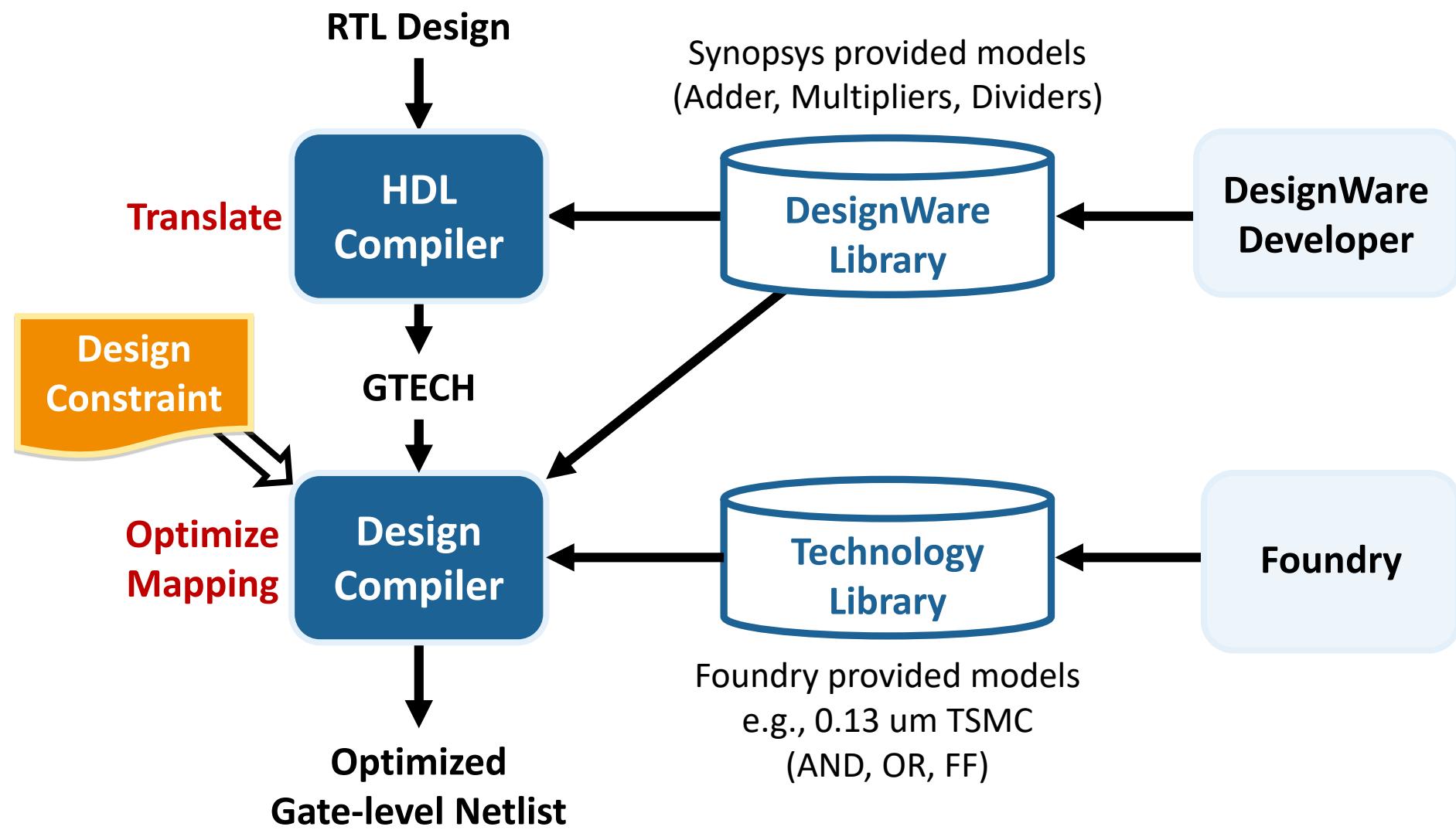
- Hard macros (e.g., SRAM, IO pad, other external IPs)
 - Black box for design compiler, cannot be optimized
 - Note: soft macros (e.g., building blocks in DW library) can still be optimized in compilation

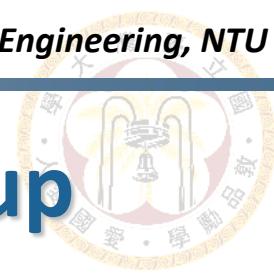
```
library(sram_256x8) {  
    delay_model      : table_lookup;  
    revision        : 1.1;  
    date            : "2013-03-29 08:26:06Z";  
    comment         : "Confidential Information of Artisan Components, Inc. Use sub  
ject to Artisan Components license. Copyright (c) 2013 Artisan Components, Inc.";  
    time_unit        : "1ns";  
    voltage_unit     : "1V";  
    current_unit     : "1mA";  
    leakage_power_unit : "1mW";  
    nom_process      : 1;  
    nom_temperature   : 125.000;  
    nom_voltage       : 1.080;  
    capacitive_load_unit : (1,pf);  
    pulling_resistance_unit : "1kohm";
```

sram_256x8_slow_syn.lib



Libraries in Logic Synthesis

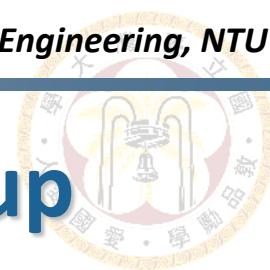




DC Library Setup: `.synopsys_dc.setup`

- `.synopsys_dc.setup` is automatically sourced when launching DC
 - Remember to put it in the directory where you launch DC

- The following variables are set
 - search_path
 - link_library
 - target_library
 - symbol_library
 - synthetic_library
 - Others



DC Library Setup: .synopsys_dc.setup

■ Search path

- Lists all the related directories of design and libraries

```
set search_path {CAD_path/CBDK013_TSMC_Artisan/CIC/SynopsysDC/db \
/home/raid7_2/course/cvsd/CBDK_IC_Contest/CIC/SynopsysDC/lib \
/home/raid7_2/course/cvsd/CBDK_IC_Contest/CIC/SynopsysDC/db \
$search_path }
```

■ Link library

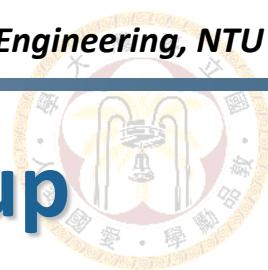
- Used to solve references, set operating conditions & wire load models, etc.
- Usually set to technology libraries, macros & DW library

```
set link_library "typical.db slow.db fast.db dw.foundation.sldb"
```

■ Target library

- Provide timing, area, power info. for optimization
- Usually set to technology libraries, macros

```
set target_library "typical.db slow.db fast.db"
```



DC Library Setup: .synopsys_dc.setup

■ Symbol library

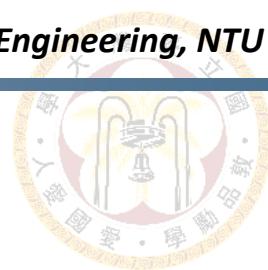
- Defines symbols of schematic view for Design Vision

```
set symbol_library "generic.sdb"
```

■ Synthetic library

- Defines built-in operators in Synopsys

```
set synthetic_library "dw_foundation.sldb"
```



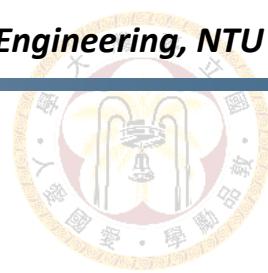
.synopsys_dc.setup Examples

Library setup example

```
set search_path {CAD_path/CBDK013_TSMC_Artisan/CIC/SynopsysDC/db \
                 /home/raid7_2/course/cvsd/CBDK_IC_Contest/CIC/SynopsysDC/lib \
                 /home/raid7_2/course/cvsd/CBDK_IC_Contest/CIC/SynopsysDC/db \
                 $search_path }
set link_library      "typical.db slow.db fast.db dw.foundation.sldb"
set target_library    "typical.db slow.db fast.db"
set symbol_library    "generic.sdb"
set synthetic_library "dw.foundation.sldb"
```

Library setup example (with SRAM)

```
set search_path {CAD_path/CBDK013_TSMC_Artisan/CIC/SynopsysDC/db \
                 /home/raid7_2/course/cvsd/CBDK_IC_Contest/CIC/SynopsysDC/lib \
                 /home/raid7_2/course/cvsd/CBDK_IC_Contest/CIC/SynopsysDC/db \
                 $search_path }
set link_library      "typical.db slow.db fast.db sram_256x8_slow_syn.db sram_256x8_typical_syn.db \
                         sram_256x8_fast_syn.db dw.foundation.sldb"
set target_library    "typical.db slow.db fast.db sram_256x8_slow_syn.db sram_256x8_typical_syn.db \
                         sram_256x8_fast_syn.db"
set symbol_library    "generic.sdb"
set synthetic_library "dw.foundation.sldb"
```



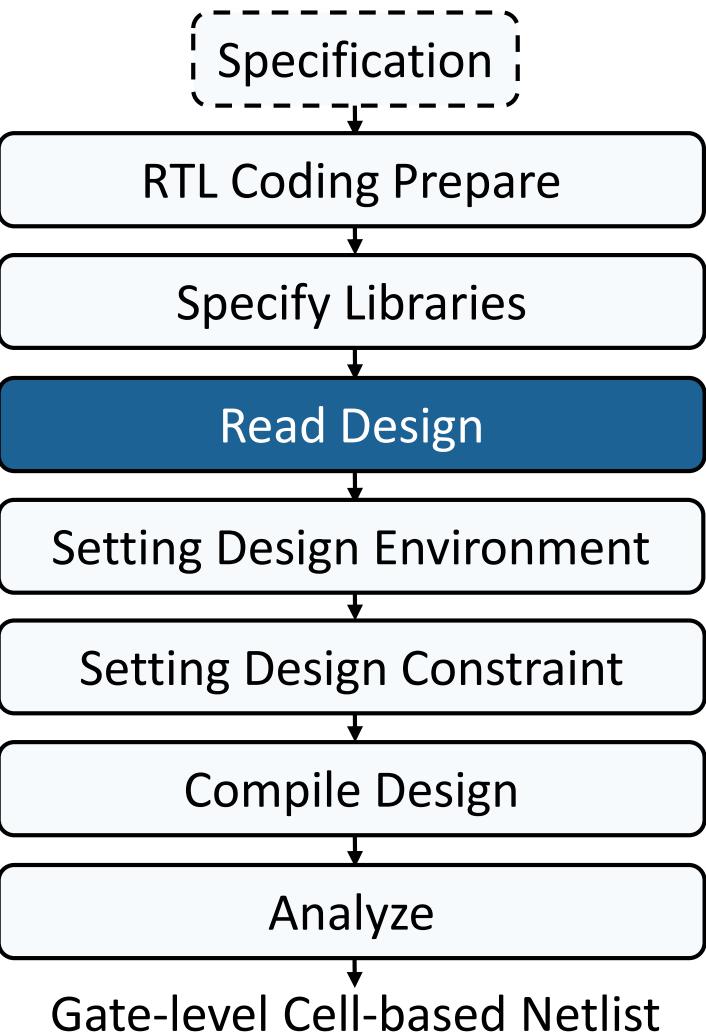
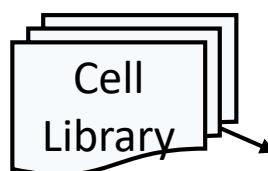
Synthesis Design Flow

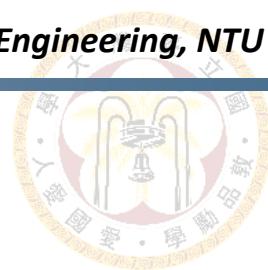
- Read the HDL design description
- Check synthesizability
- Perform Presto compilation

① analyze
elaborate

or

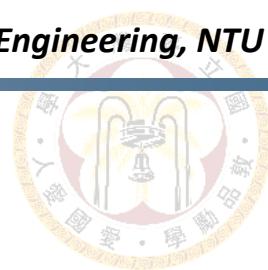
② read_file





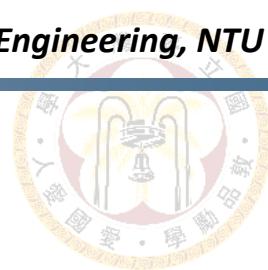
Synthesize Using Design Vision

- File/Read or File/Analyze + File/Elaborate
- Attributes – set up Design Environment & Goals
(record in script sdc files)
- Analysis/Report – check if set up is OK
- Analysis/Check Design
- Tools/Design Optimization
- Analysis/Report
- File/Save



Reading Design

- Read netlists or design descriptions into Design Compiler
- Support different formats:
 - Verilog(.v) / VHDL(.vhdl) / System Verilog(.sv)
 - Berkeley Espresso format(.pla)
 - Synopsys internal formats(.db, .dc)
- Method1
 - Analyze + Elaborate
- Method2
 - Read_file



Analyze + Elaborate

■ Analyze

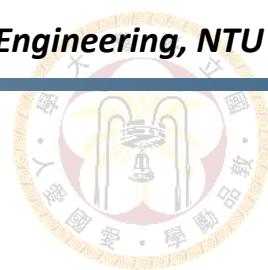
- Check VHDL & Verilog for syntax and synthesizability
- Create intermediate .syn .mr .pvl files

■ Elaborate

- Translate intermediate objects into technology-independent design (**GTECH**)
- Load parameters in HDL source files
- Resolve design references

■ *File / Analyze + File / Elaborate*

```
analyze -format verilog {top.v fifo.v}  
elaborate top
```



Read_file

- Read files with selected format
 - e.g., RTL design, gate-level netlist, .ddc, .db files
- Reading RTL: performs steps similar to analyze + elaborate
 - Does not create intermediate objects
 - Does not work with parameterized designs
- *File/Read*

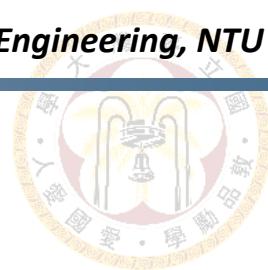
```
read_file -format verilog -rtl {top.v fifo.v}
```

```
read_verilog -rtl {top.v fifo.v}
```

Example of other usages:

```
read_file -format verilog -netlist $Gate_Level_file
```

```
read_file -format ddc $DDC_file
```

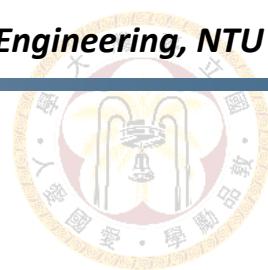


Reading Parameterized Design

- Read_file does not load parameters into designs
- Use analyze + elaborate for parameterized design

```
module top
...
fifo #(
    .DEPTH(8),
    .LENGTH(8)
)u_fifo_0(
    ...
);
fifo #(
    .DEPTH(4),
    .LENGTH(2)
)u_fifo_1(
    ...
);
...
endmodule
```

```
module fifo #(
    parameter DEPTH = 8,
    parameter LENGTH = 8
)(
    input          i_clk,
    input          i_rst_n,
    input          i_write,
    output         o_write_ready,
    input [LENGTH-1:0]i_wdata,
    output         o_read_valid,
    input          i_read,
    output [LENGTH-1:0]o_rdata
);
...
endmodule
```



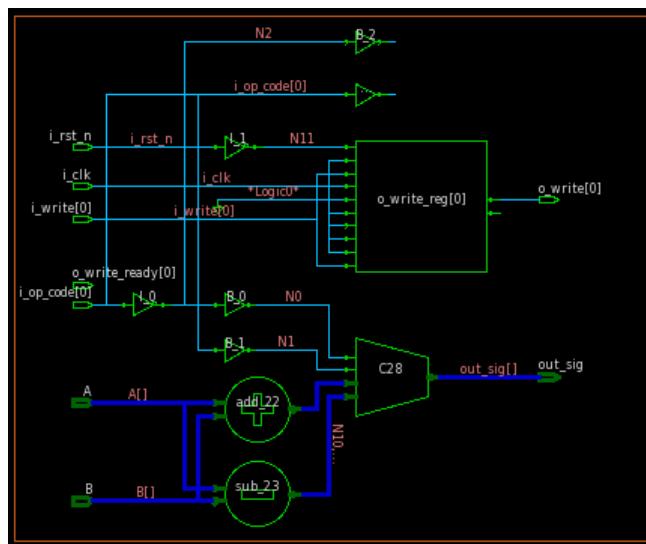
Presto Compilation

- HDL Compiler (Presto Verilog) is automatically invoked in `read_file` or `elaborate`
 - GTECH netlist
 - No timing information
 - **Link library** & built-in **GTECH library** used
 - Flip-flops and `+, =, *, ...` operators not unfolded to gate-level

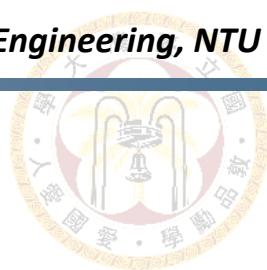
```
module alu (
    ...
    assign y = a + b;
    assign o = s? y:z;
    ...
);
```

RTL

Translate



GTECH



Check Latches

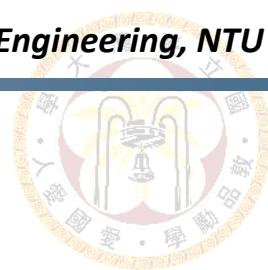
- Flip-flops and latches are listed in Presto Compilation
 - If there are latches, check your RTL design
(usually incomplete if-else or case statements)

```
Inferred memory devices in process
in routine fifo line 55 in file
  '/home/raid7_2/user09/r09176/CVSD/exp6_sram/fifo.v'.
=====
| Register Name | Type      | Width | Bus | MB | AR | AS | SR | SS | ST |
=====
|   wpos_r_reg  | Flip-flop |  4   | Y  | N  | Y  | N  | N  | N  | N  |
| buffer_r_reg  | Flip-flop | 64  | Y  | N  | Y  | N  | N  | N  | N  |
|   rpos_r_reg  | Flip-flop |  4   | Y  | N  | Y  | N  | N  | N  | N  |
=====

Statistics for MUX_OPs
=====
| block name/line | Inputs | Outputs | # sel inputs |
=====
|   fifo/34       |    8   |     8    |        3        |
=====

Presto compilation completed successfully.
Current design is now '/home/raid7_2/user09/r09176/CVSD/exp6_sram/fifo.db:fifo'
Loaded 2 designs.
Current design is 'fifo'.
```

Check latches using design compiler



Set Current Design

- Only one design can be set as current design for optimization

```
set DESIGN "top"  
current_design $DESIGN
```

After read_file

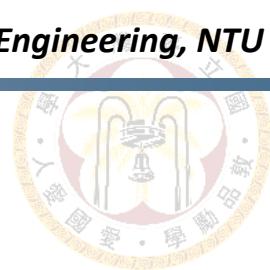
```
|      r10/35 | 0 | 0 | 0 | 0 |  
=====
```

Presto compilation completed successfully.
Current design is now '/home/raid7_2/user09/r09176/CVSD/exp5_link/fifo.db:fifo'
Loaded 2 designs.
Current design is 'fifo'.
t10 top



Set Current Design

```
dc shell> current_design [get_designs $DESIGN]  
Current design is 'top'.  
{top}  
dc_shell>
```

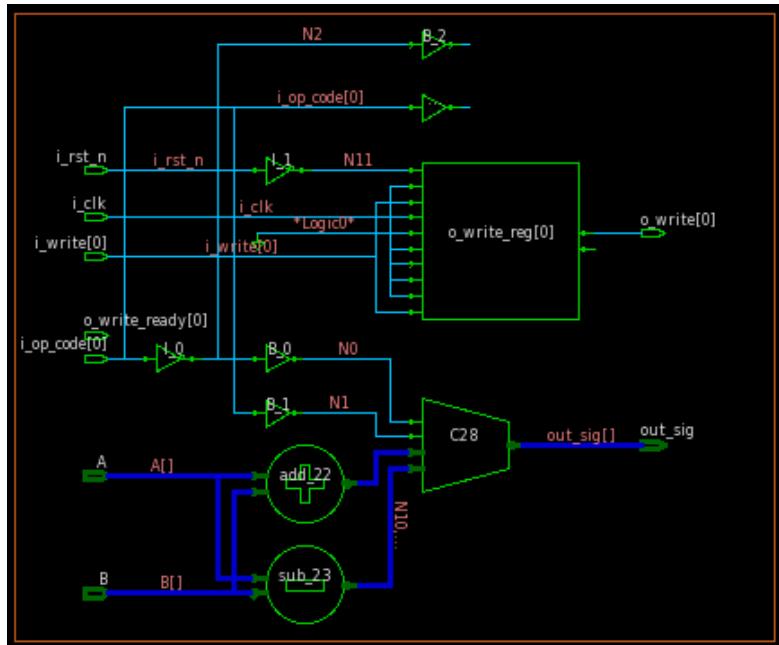


Output GTECH Netlist (Optional)

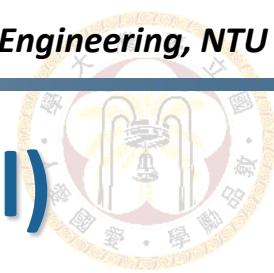
```

1 ///////////////////////////////////////////////////////////////////
2 // Created by: Synopsys Design Compiler(R)
3 // Version   : R-2020.09-SP5
4 // Date      : Mon Feb 20 13:23:08 2023
5 ///////////////////////////////////////////////////////////////////
6
7
8 module top ( i_clk, i_rst_n, i_write, o_write_ready, A, B, i_op_code, out_sig,
9       o_write );
10    input [0:0] i_write;
11    output [0:0] o_write_ready;
12    input [3:0] A;
13    input [3:0] B;
14    input [0:0] i_op_code;
15    output [3:0] out_sig;
16    output [0:0] o_write;
17    input i_clk, i_rst_n;
18    wire   N0, N1, N2, N3, N4, N5, N6, N7, N8, N9, N10, N11;
19
20  /**SEQGEN** \o_write_reg[0] (.clear(N11), .preset(1'b0), .next_state(
21    i_write[0]), .clocked_on(i_clk), .data_in(1'b0), .enable(1'b0), .Q(
22    o_write[0]), .synch_clear(1'b0), .synch_preset(1'b0), .synch_toggle(
23    1'b0), .synch_enable(i_write[0]) );
24  SUB_UNS_OP sub_19 (.A(A), .B(B), .Z({N10, N9, N8, N7}) );
25  ADD_UNS_OP add_18 (.A(A), .B(B), .Z({N6, N5, N4, N3}) );
26  SELECT_OP C28 (.DATA1({N6, N5, N4, N3}), .DATA2({N10, N9, N8, N7}),
27    .CONTROL1(N0), .CONTROL2(N1), .Z(out_sig) );
28  GTECH_BUF B_0 (.A(N2), .Z(N0) );
29  GTECH_BUF B_1 (.A(i_op_code[0]), .Z(N1) );
30  GTECH_NOT I_0 (.A(i_op_code[0]), .Z(N2) );
31  GTECH_BUF B_2 (.A(N2) );
32  GTECH_BUF B_3 (.A(i_op_code[0]) );
33  GTECH_NOT I_1 (.A(i_rst_n), .Z(N11) );
34 endmodule

```



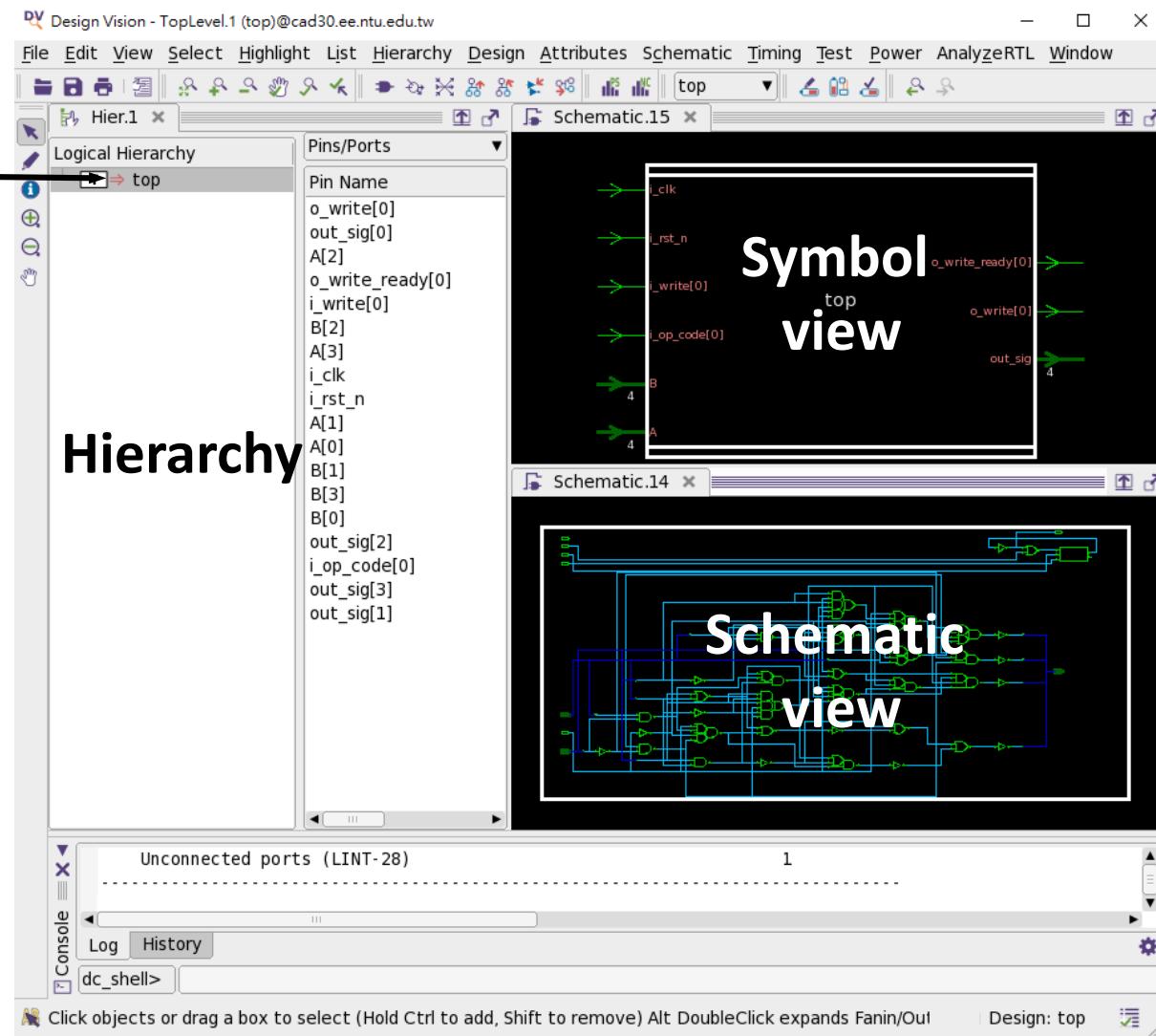
write -format verilog -hierarchy -output TOP_GTECH.v

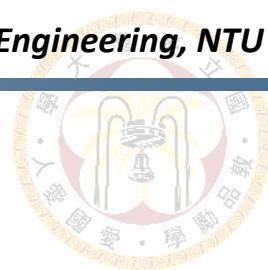


Symbol / Schematic View (Optional)

Current
Design

Hierarchy



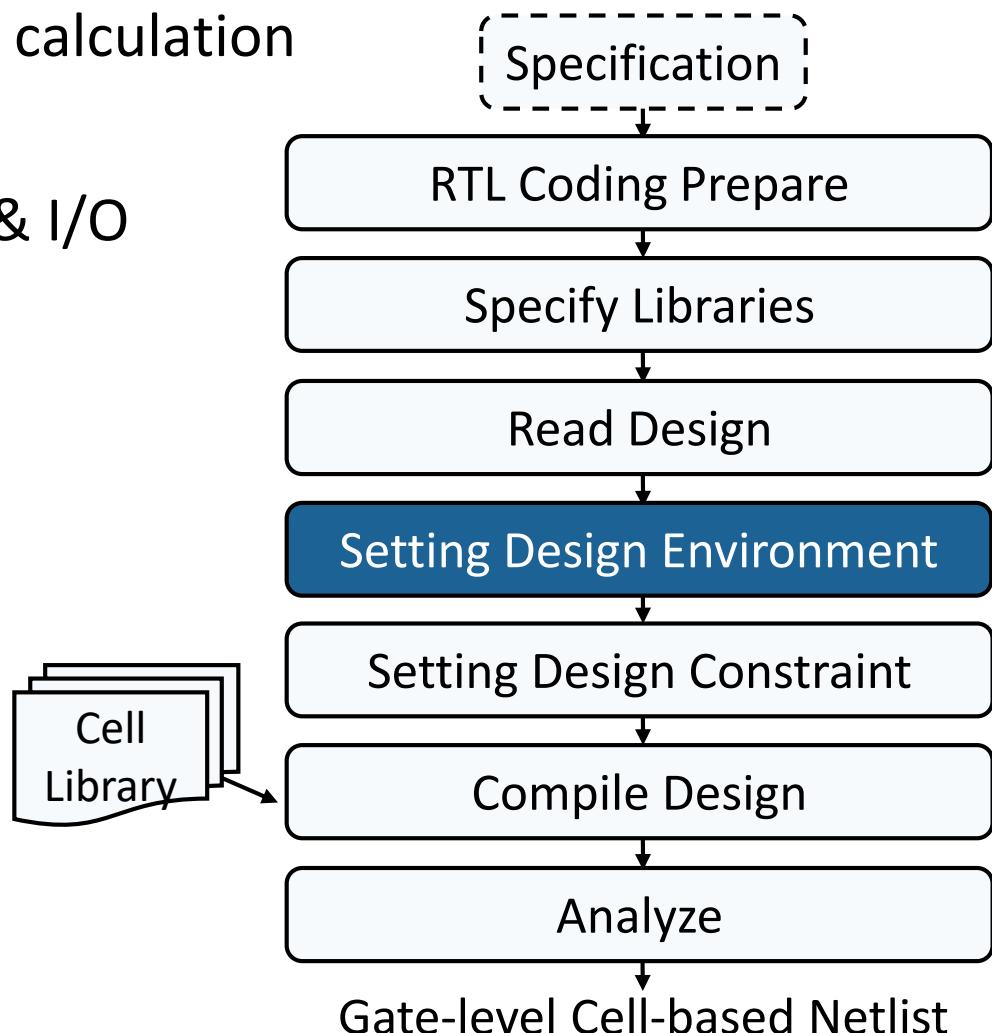


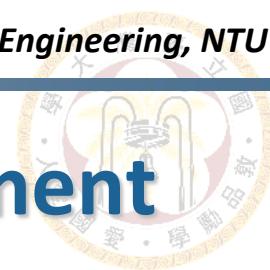
Synthesis Design Flow

■ Set parameters for RC delay calculation

- Operating condition
- RC information of wires & I/O
- I/O delay

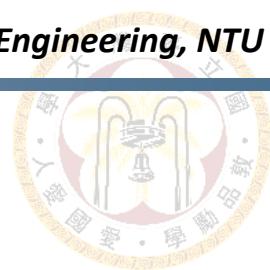
```
1 set_input_delay  
2 set_output_delay  
3 set_drive  
4 set_load  
5 set_operating_conditions  
6 set_wire_load_model
```



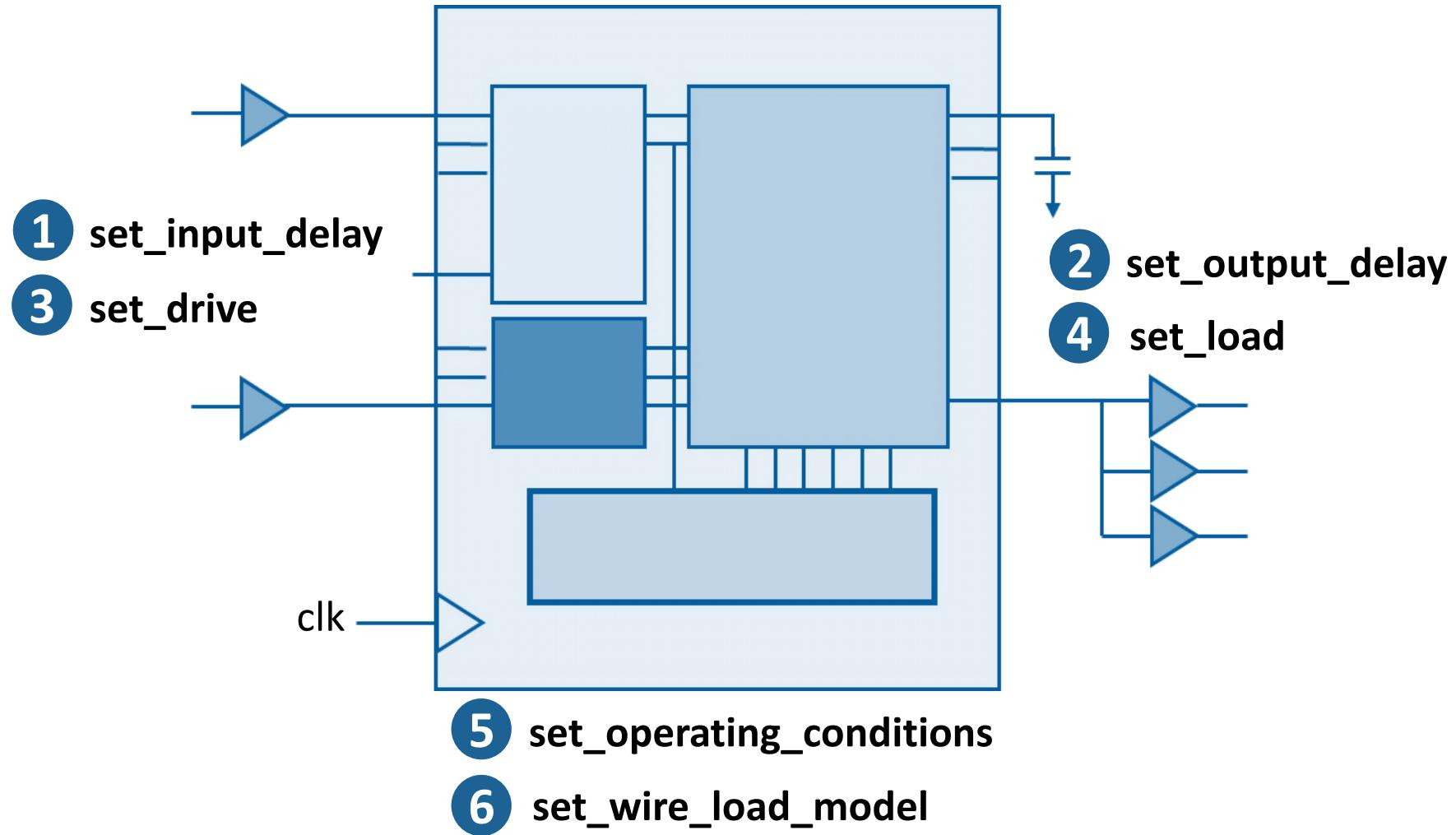


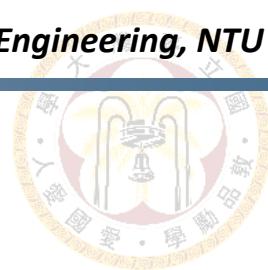
Why Describes the Real World Environment

- 1. Operating condition
 - The operating condition affects the components selected from technology library and the timing through your design
- 2. Environment parameters
 - The real world environment you define describes the conditions that the circuit will operate within
- The defaults are not realistic conditions
 - Input drive is not infinite
 - Capacitive loading is usually not zero
 - Consider **process, voltage, and temperature (PVT)** variation



Describing Design Environment





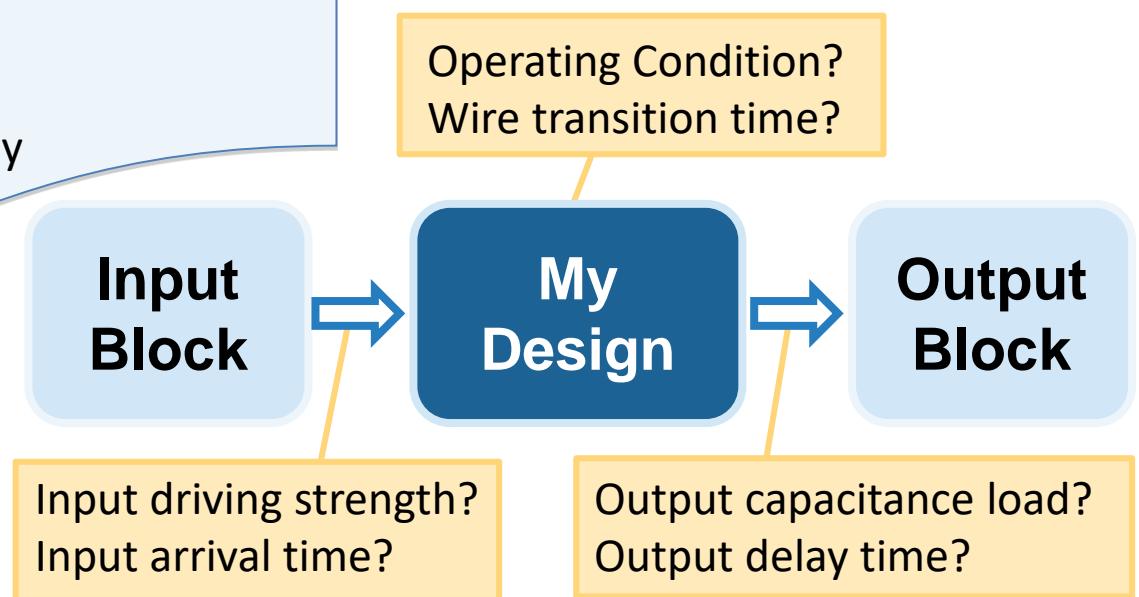
Describing Design Environment

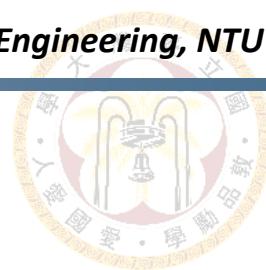
For STA, every node should be known:

- **RC value**
 - Inside DUT: Tech lib
 1. standard cell/external-IP
 2. wire load model
 - Outside DUT:
 1. set_drive / set_driving_cell
 2. set_load
- **I/O delay**
 - set_input_delay
 - set_output_delay

STA: static timing analysis

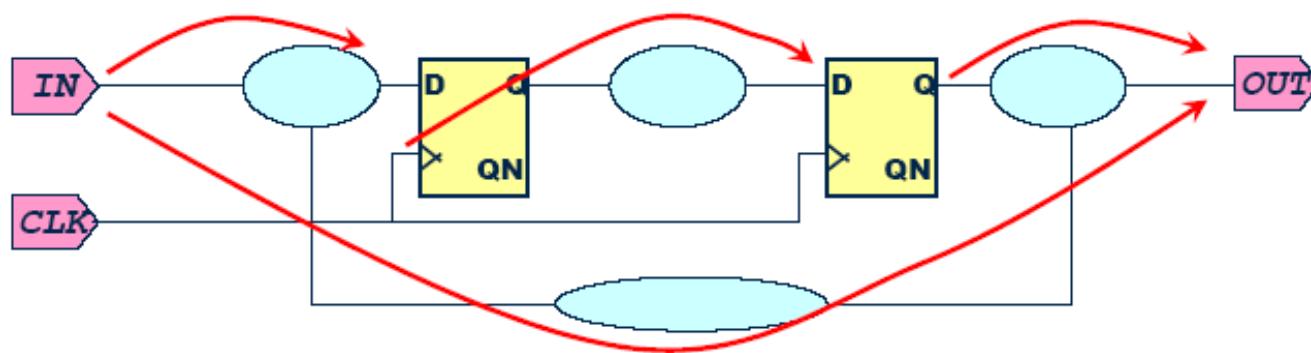
DUT: device under test

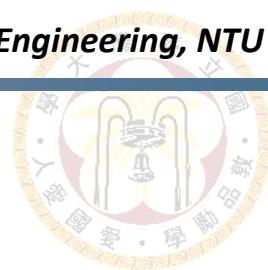




Recall: Timing Paths

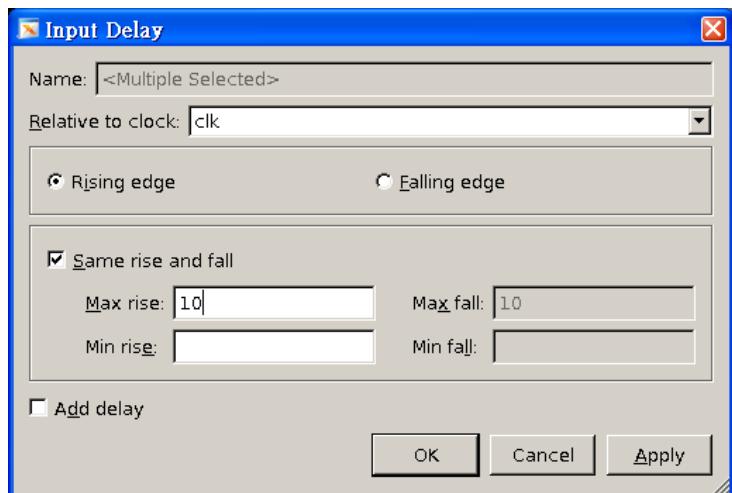
- Using inputs, outputs and registers as endpoints, the combinational part of design can be divided into 4 type of paths
 - Input to register
 - Register to register
 - Register to output
 - Input to output
- In the synthesized netlist, all paths should meet timing requirements
 - E.g., in a gate-level netlist synthesized for 200MHz, delay on all reg-to-reg paths should $\leq 5\text{ns}$



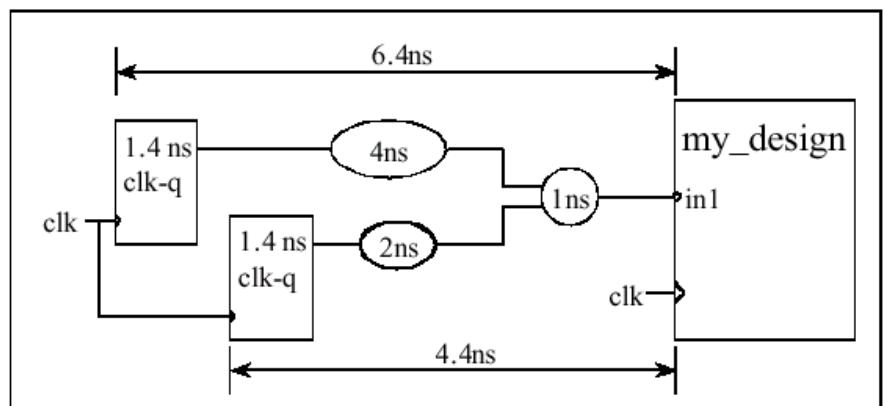


1. Setting Input Delay

- Input delay: input arrival time related to clock
- *Attributes / Operating Environment / Input Delay*

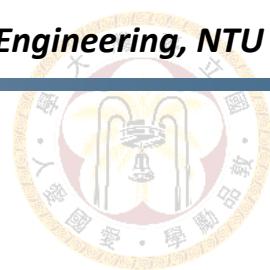


◆ Example



```
set_input_delay -clock clk -max 6.4 [get_ports in1]
set_input_delay -clock clk -min 4.4 [get_ports in1]
```

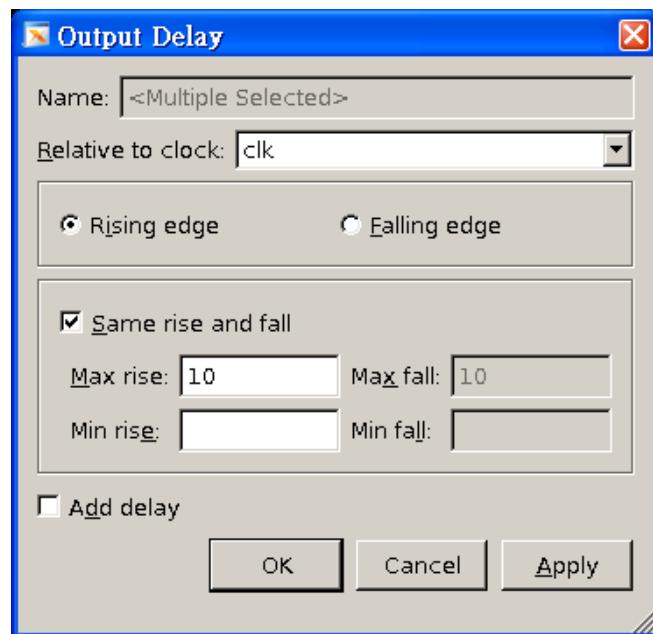
```
set_input_delay 2.6 -clock clk \
[remove_from_collection [all_inputs] [get_ports clk]]
```



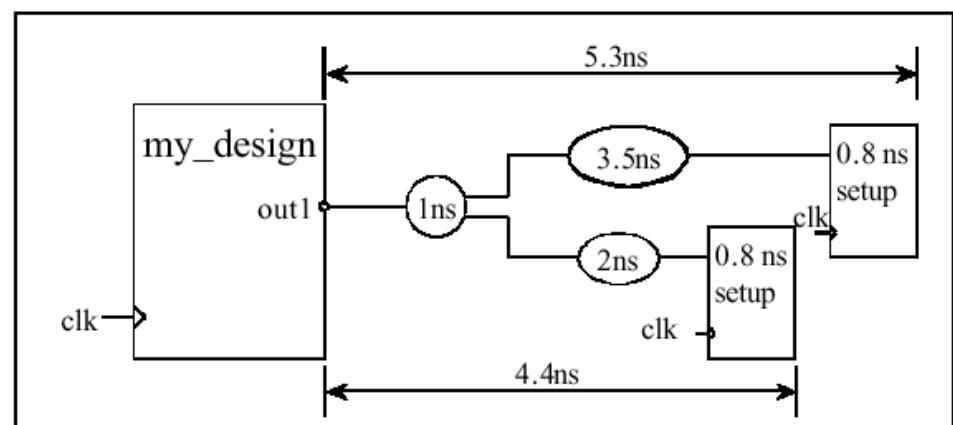
2. Setting Output Delay

- Output require time related to next clock

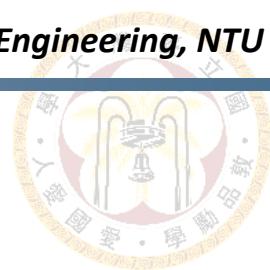
- **Attributes / Operating Environment / Output Delay**



- ◆ Example

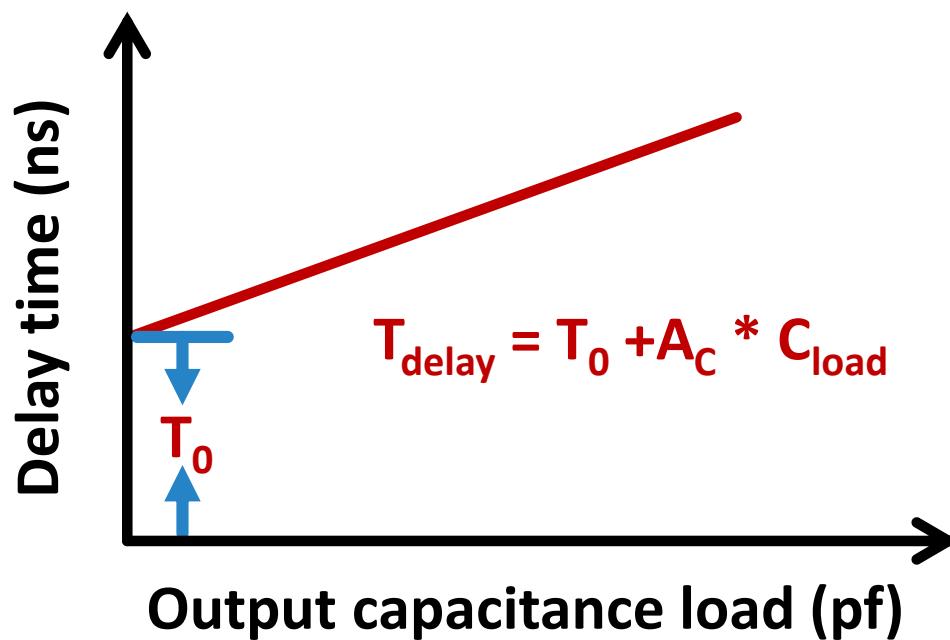


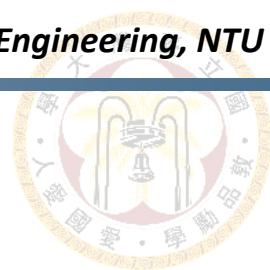
```
set_output_delay -clock clk -max 5.3 [get_ports out1]
```



Input Drive Impedance

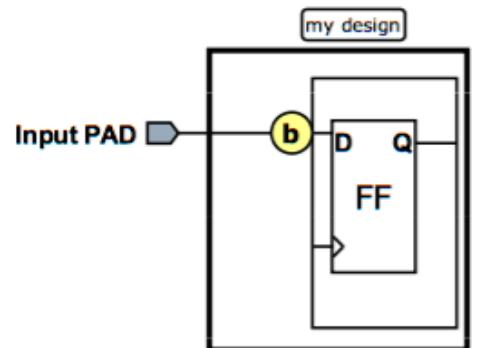
- $T_{\text{delay}} = T_0 + A_c * C_{\text{load}}$
 - T_0 : cell pin to pin intrinsic delay
 - A_c : drive impedance (ns/pf)
 - C_{load} : output capacitance load (pf)



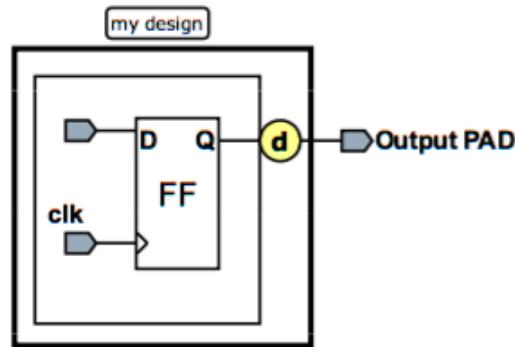


Drive Strength & Load for Pads

■ Input Drive Strength for Pads



■ Output Load for Pads



3V CMOS Input Only Pads

PC3D01, PC3D11, PC3D21, and PC3D31

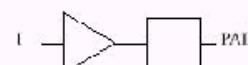
Performance Equations

PC3D01		RISE	FALL
ICD	PAD => CIN	$0.3877 + 0.0378 \cdot C_{ld}$	$0.2596 + 0.0503 + 0.1978 \cdot C_{ld}$
PC3D11		RISE	FALL
ICD	PAD => CIN	$0.3761 + 0.0792 + 0.2265 \cdot C_{ld}$	$0.3787 + 0.0553 + 0.1980 \cdot C_{ld}$
PC3D21		RISE	FALL
ICD	PAD => CIN	$0.7915 + 0.0574 + 0.2578 \cdot C_{ld}$	$0.6064 + 0.0595 + 0.2762 \cdot C_{ld}$
PC3D31		RISE	FALL
ICD	PAD => CIN	$0.6528 + 0.0289 + 0.2206 \cdot C_{ld}$	$0.5911 + 0.0253 + 0.1976 \cdot C_{ld}$

3V CMOS Output Pads

PC3O01 through PC3O05

PC3O01 through PC3O05 cells are CMOS output pads with AC drive capabilities ranging from 1x to 5x.



Function Table

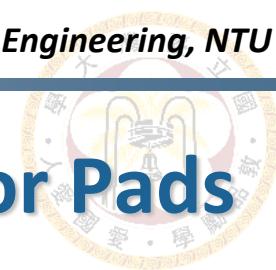
INPUT	OUTPUT
I	PAD
L	L
H	F

Cell Description

Macro Name:	PC3O01	PC3O02	PC3O03	PC3O04	PC3O05
Drive Capability	1x	2x	3x	4x	5x
Width (mils)	3.4	3.4	3.4	3.4	3.4
Power (μW/MHz)	198.55	198.59	158.75	198.61	197.58

Pin Description

name	Capacitance (pF)					Description
	PC3O01	PC3O02	PC3O03	PC3O04	PC3O05	
I	0.096	0.096	0.095	0.132	0.133	Input
PAD	8.577	8.577	8.577	8.576	8.473	Output



3 & 4. Input Drive Strength & Output Load for Pads

- Defined in technology library
- Consider for IO Pads (Synthesis w/IO)
- Setting Input Driving Strength

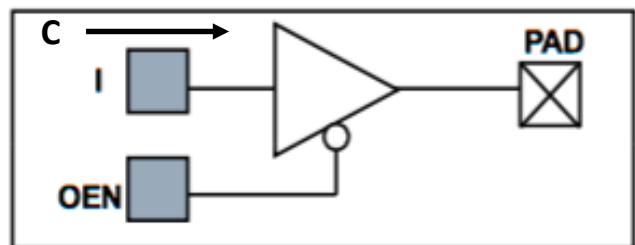
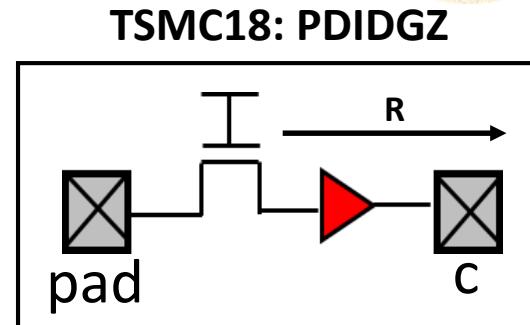
```
set_drive 0.05 [all_inputs]
```

```
set_driving_cell -library tpz973gvwc -lib_cell PDIDGZ -pin {C} [all_inputs]
```

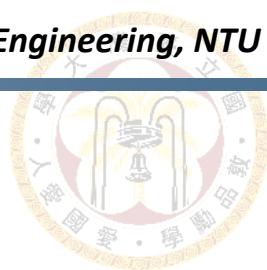
- Setting Output Load

```
set_load [load_of "tpz973gvwc/PDT16DGZ/I"] [all_outputs]
```

- Remember to add ***.db file for IO Pad*** into link_library in .synopsys_setup



TSMC18: PDT16DGZ



Port Report

```
report_port -verbose
```

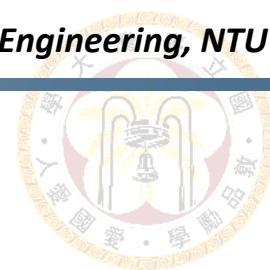
- or in the option menu set verbose

```
*****
Report : port
Design : counter
Version: W-2004.12-SP1
Date   : Fri May  6 12:52:28 2005
*****



          Pin      Wire      Max      Max      Connection
          Port     Load     Load    Trans    Cap    Class    Attrs
Port      Dir
-----+-----+-----+-----+-----+-----+-----+
counter[3]  out    0.0180  0.0000  --    --    --
counter[1]  out    0.0180  0.0000  --    --    --
reset      in     0.0000  0.0000  --    --    --
counter[2]  out    0.0180  0.0000  --    --    --
clk        in     0.0000  0.0000  --    --    --
counter[0]  out    0.0180  0.0000  --    --    --

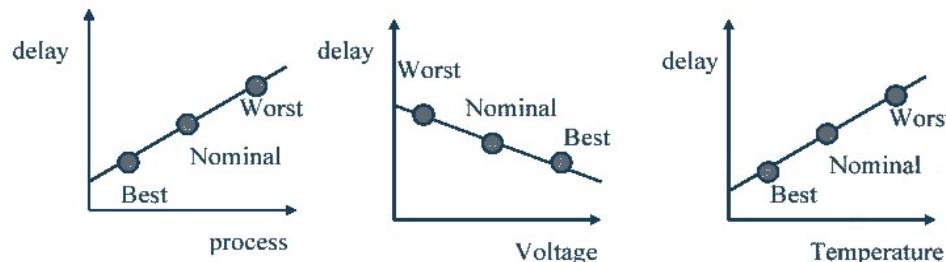
***** End Of Report *****
```



5. Setting Operating Condition

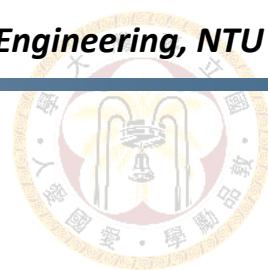
- Operating condition model scales components delay, directs the optimizer to simulate variations in **process**, **voltage**, and **temperature**.

Name	Process	Temp	Volt	Interconnection Model
WCCOM	1.32	100.00	2.7	worst_case_tree
BCCOM	0.73	0.00	3.6	best_case_tree
NCCOM	1.00	25.00	3.3	balance_tree



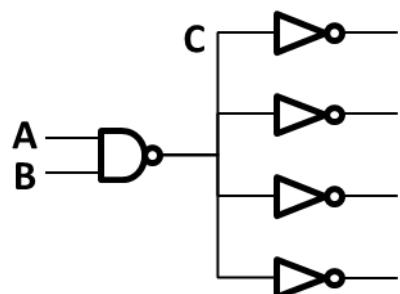
- General operating conditions in technology process
 - Best case (fast) / Typical case / **Worst case (slow)**
- **Attributes / Operating Environment / Operating Condition**

```
set_operating_conditions -max_library slow -max slow -min_library fast -min fast
```



Wire Load Model (WLM)

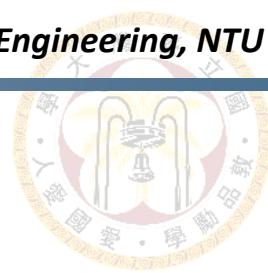
- Fanout of a wire/pin
 - The **number of load gates** connected to the output of the driving gate
- WLM contains information about
 - A lookup table to estimate wire length by its fanout
 - Extrapolation for fanouts not in list
 - Area/capacitance/resistance coefficients
- Note: WLM only provide a rough estimation, area/delay of wire will be more accurate in automatic place and route (APR) stage



WLM	
Fanout	Length
1	4.1
2	5.3
3	6.4
4	7.4

Part of gate-level netlist

Fanout of C = 4
 ↓
 Estimated length = 7.4
 ↓
 Estimated Area = 7.4*0.7
 Estimated Cap. = 7.4*1e-4
 Estimated Resist. = 7.4*8e-8



WLM Example for tsmc13_wl10

■ Example: calculating R, C and net area of a net with fanout = 3

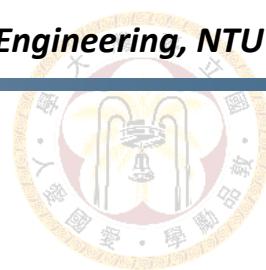
- Length = **66.667** \times 3
- $C_{\text{wire}} = (\text{fanout}=3) \times \text{capacitance coefficient}$
 - (length= **66.667** \times 3) \times (**1.5e-4**) = 0.03 pf
- $R_{\text{wire}} = (\text{fanout}=3) \times \text{resistance coefficient}$
 - (length= **66.667** \times 3) \times (**8.5e-8**) = 0.017 ohm
- Net area = (fanout=3) x area coefficient
 - (length= **66.667** \times 3) \times (**0.7**) = 140 um²

slow.lib header

```
/* unit attributes */
time_unit: "1ns";
voltage_unit: "1V";
current_unit: "1mA";
pulling_resistance_unit: "1kohm";
leakage_power_unit: "1pw";
Capacitive_load_unit(1.0, pf);
```

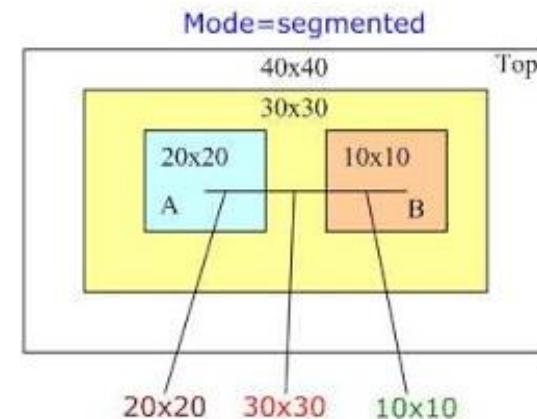
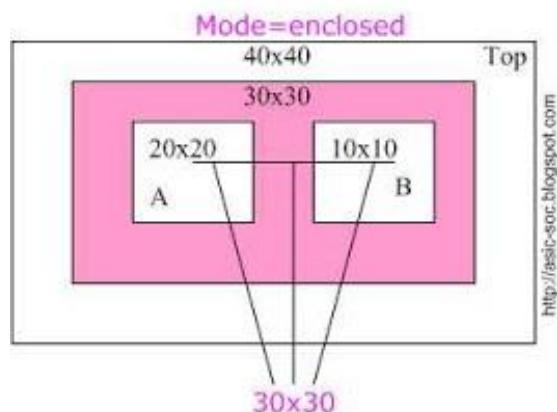
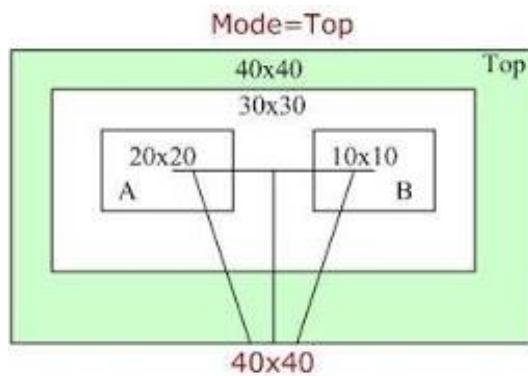
slow.lib

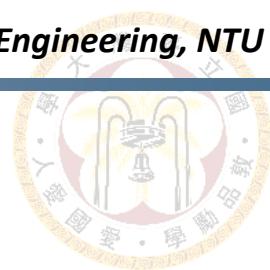
```
/* wire-loads */
wire_load("tsmc13_wl10"){
    resistance : 8.5e-8;
    capacitance: 1.5e-4;
    area       : 0.7;
    slope       : 66.667;
    fanout_length (1, 66.667);
}
```



Wire Load Modes

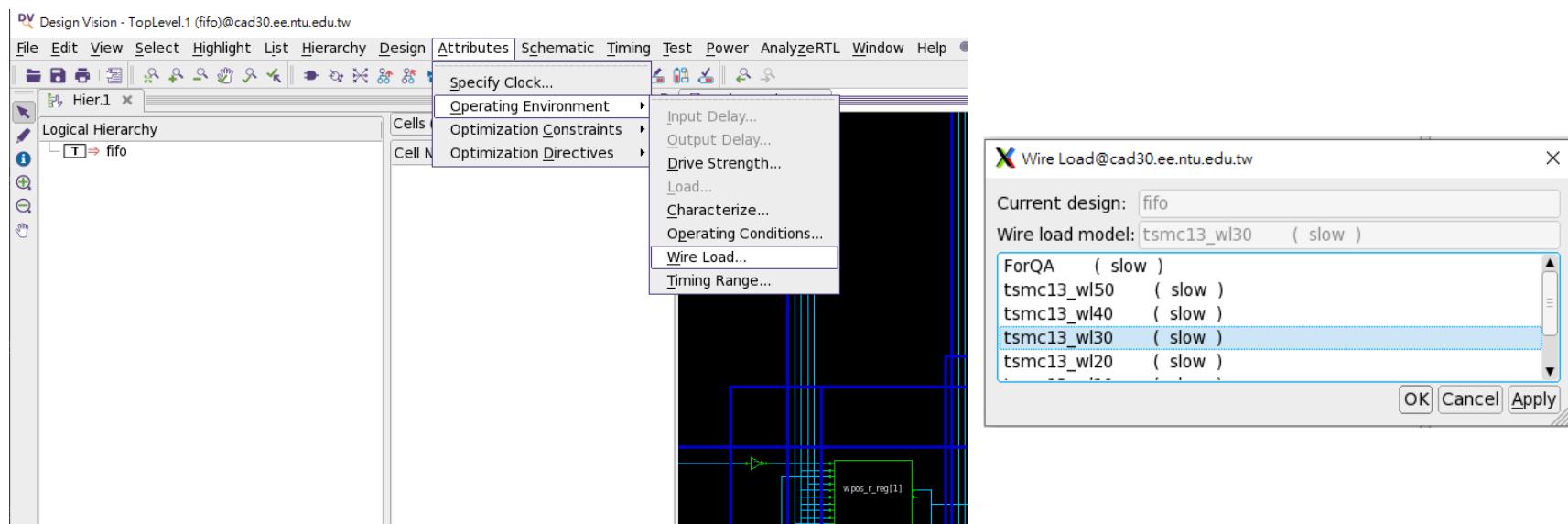
- 3 hierarchical wire load modes
 - Top
 - Applying the wire load models specified for the top level of the design to all nets, the most rough estimation
 - Enclosed
 - Using the wire load model which inherits from its upper-level design
 - Segmented
 - Nets crossing hierarchical boundaries are divided into segments



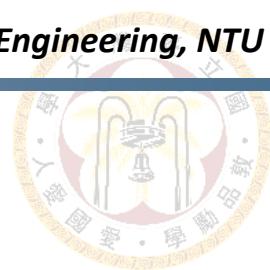


6. Setting Wire Load Model

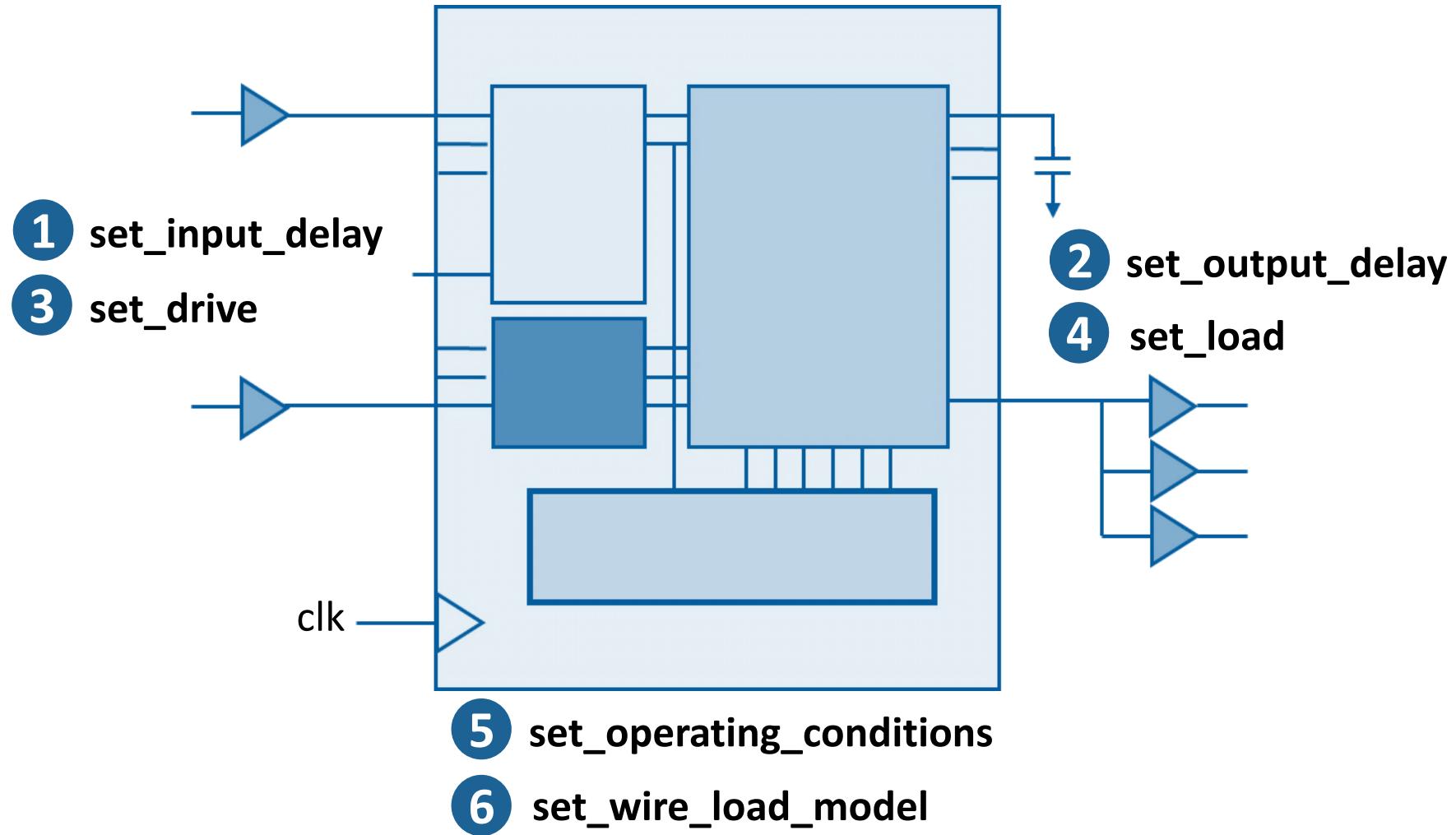
■ Attributes/Operating Environment/Wire Load

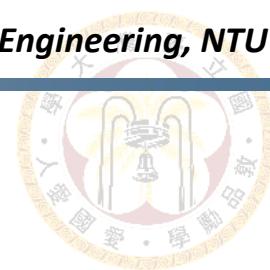


```
set_wire_load_model -name tsmc13_wl10 -library slow  
set_wire_load_mode top
```



Describing Design Environment





Appendix: Gate-Level Simulation

- Prepare the following files for gate-level simulation

File	Example Filename
Testbench	testbench.v
Gate-level netlist	chip_syn.v
SDF file	chip_syn.sdf
Cell model	tsmc13_neg.v

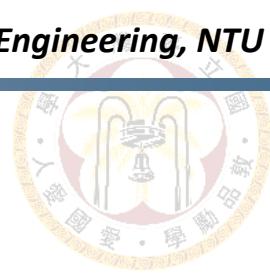
- Modify your testbench file to **include timing delay from SDF file**

```
$sdf_annotate ("chip_syn.sdf", top_module_instance_name);
```

- Gate level simulation with timing information:

```
ncverilog testbench.v chip_syn.v -v tsmc13_neg.v +access+r
```

```
vcs -full64 -debug_access -R +v2k +neg_tchk testbench.v  
chip_syn.v tsmc13_neg.v
```



Including SDF File

- Without SDF file, simulator uses delay information from cell model (e.g., tsmc13_neg.v), which must be wrong
- The simulation can still be performed, but lots of **timing violations** may occur even if there's no negative slack in synthesis

ncverilog

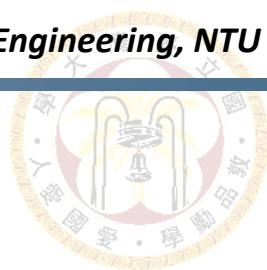
```
Warning! Timing violation
$setuphold<hold>(> posedge CK && (flag == 1):6170 NS, posedge D:6170 NS, 1.000 : 1 NS, 0.500 : 500 PS );
File: ./tsmc13_neg.v, line = 18416
Scope: test.u_RFILE.yt_reg_4_
Time: 6170 NS

Warning! Timing violation
$setuphold<hold>(> posedge CK && (flag == 1):6170 NS, posedge D:6170 NS, 1.000 : 1 NS, 0.500 : 500 PS );
File: ./tsmc13_neg.v, line = 18416
Scope: test.u_RFILE.yt_reg_3_
Time: 6170 NS

Warning! Timing violation
$setuphold<hold>(> posedge CK && (flag == 1):6170 NS, posedge D:6170 NS, 1.000 : 1 NS, 0.500 : 500 PS );
File: ./tsmc13_neg.v, line = 18416
Scope: test.u_RFILE.yt_reg_2_
Time: 6170 NS

Warning! Timing violation
$setuphold<hold>(> posedge CK && (flag == 1):6170 NS, posedge D:6170 NS, 1.000 : 1 NS, 0.500 : 500 PS );
File: ./tsmc13_neg.v, line = 18416
Scope: test.u_RFILE.yt_reg_0_
Time: 6170 NS

Warning! Timing violation
```



Including SDF File

- Without SDF file, simulator uses delay information from cell model (e.g., tsmc13_neg.v), which must be wrong
- The simulation can still be performed, but lots of **timing violations** may occur even if there's no negative slack in synthesis

VCS

```
"/home/raid7_2/course/cvsd/CBDK_IC_Contest_v2.5/Verilog/tsmc13_neg.v", 18348: Timing violation in test_alu.my_alu.alu_out_reg_7_
$setuphold( posedge CK && (flag == 1'b1):2600820000, negedge D:2600820000, limits: (1000,500) );

"/home/raid7_2/course/cvsd/CBDK_IC_Contest_v2.5/Verilog/tsmc13_neg.v", 18347: Timing violation in test_alu.my_alu.alu_out_reg_7_
$setuphold( posedge CK && (flag == 1'b1):2600900000, posedge D:2600900000, limits: (1000,500) );

"/home/raid7_2/course/cvsd/CBDK_IC_Contest_v2.5/Verilog/tsmc13_neg.v", 18347: Timing violation in test_alu.my_alu.alu_out_reg_5_
$setuphold( posedge CK && (flag == 1'b1):2601540000, posedge D:2601540000, limits: (1000,500) );

"/home/raid7_2/course/cvsd/CBDK_IC_Contest_v2.5/Verilog/tsmc13_neg.v", 18348: Timing violation in test_alu.my_alu.alu_out_reg_5_
$setuphold( posedge CK && (flag == 1'b1):2601560000, negedge D:2601560000, limits: (1000,500) );

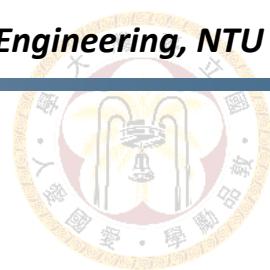
"/home/raid7_2/course/cvsd/CBDK_IC_Contest_v2.5/Verilog/tsmc13_neg.v", 18348: Timing violation in test_alu.my_alu.alu_out_reg_5_
$setuphold( posedge CK && (flag == 1'b1):2602180000, negedge D:2602180000, limits: (1000,500) );

"/home/raid7_2/course/cvsd/CBDK_IC_Contest_v2.5/Verilog/tsmc13_neg.v", 18347: Timing violation in test_alu.my_alu.alu_out_reg_5_
$setuphold( posedge CK && (flag == 1'b1):2602200000, posedge D:2602200000, limits: (1000,500) );

"/home/raid7_2/course/cvsd/CBDK_IC_Contest_v2.5/Verilog/tsmc13_neg.v", 18347: Timing violation in test_alu.my_alu.alu_out_reg_5_
$setuphold( posedge CK && (flag == 1'b1):2602820000, posedge D:2602820000, limits: (1000,500) );

"/home/raid7_2/course/cvsd/CBDK_IC_Contest_v2.5/Verilog/tsmc13_neg.v", 18348: Timing violation in test_alu.my_alu.alu_out_reg_5_
$setuphold( posedge CK && (flag == 1'b1):2602840000, negedge D:2602840000, limits: (1000,500) );

"/home/raid7_2/course/cvsd/CBDK_IC_Contest_v2.5/Verilog/tsmc13_neg.v", 18347: Timing violation in test_alu.my_alu.alu_out_reg_7_
$setuphold( posedge CK && (flag == 1'b1):2602280000, posedge D:2602280000, limits: (1000,500) );
```

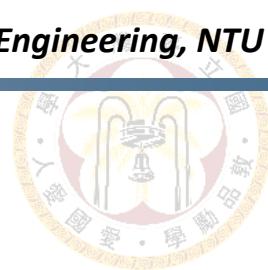


Including SDF File

- With SDF file properly included, timing paths are denoted and can be checked in gate-level simulation

ncverilog

```
Annotation completed with 0 Errors and 76 Warnings
SDF statistics: No. of Pathdelays = 1629 Annotated = 100.00% -- No. of Tchecks = 1386 Annotated = 93.94%
      Total      Annotated      Percentage
Path Delays        1629        1629          100.00
      $width        630         630          100.00
      $setuphold    756         672          88.89
Building instance overlay tables: ..... Done
Generating native compiled code:
  worklib.fifo_DEPTH8_LENGTH8_0:v <0x044be911>
    streams: 1, words: 1122
  worklib.fifo_DEPTH8_LENGTH8_1:v <0x2e6dc566>
    streams: 1, words: 1122
  worklib.top:v <0x38b989e1>
    streams: 1, words: 546
Building instance specific data structures.
Loading native compiled code: ..... Done
Design hierarchy summary:
      Instances   Unique
Modules:           517     84
UDPs:             238      2
Primitives:       1549     8
Timing outputs:   679     16
Registers:        256     23
Scalar wires:     1829     -
Expanded wires:   38       3
Always blocks:   2         2
Initial blocks:  5         5
Pseudo assignments: 8       8
Timing checks:   2142    407
Interconnect:    1329     -
Delayed tcheck signals: 714    204
Simulation timescale: 1ps
Writing initial simulation snapshot: worklib.test:v
Loading snapshot worklib.test:v ..... Done
*Verdi* Loading libsscore_ius152.so
ncsim> source /usr/cad/cadence/INCISIV/cur/tools/inca/files/ncsimrc
ncsim> run
```



Including SDF File

- With SDF file properly included, timing paths are denoted and can be checked in gate-level simulation

VCS

```
*** $sdf_annotation() version 1.2R
*** SDF file: "Lab2_alu_s.sdf"
*** Annotation scope: test_alu.my_alu
*** No MTM selection argument specified
*** No SCALE FACTORS argument specified
*** No SCALE TYPE argument specified
*** MTM selection defaulted to "TOOL_CONTROL":
      (+typdelays compiled, TYPICAL delays selected)
*** SCALE FACTORS defaulted to "1.0:1.0:1.0":
*** SCALE TYPE defaulted to: "FROM_MTM"
*** Turnoff delay: "FROM_FILE"
*** Approximation (mipd) policy: "MAXIMUM"

*** SDF annotation begin: Mon Mar 27 12:27:09 2023

SDF Info: +pulse_r/100, +pulse_e/100 in effect

      Total errors: 0
      Total warnings: 0
*** SDF annotation completed: Mon Mar 27 12:27:09 2023
```